CREATING AND EVALUATING A NEW CLICKER METHODOLOGY

DISSERTATION

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ABSTRACT

“Clickers”, an in-class polling system, has been used by many instructors to add active learning and formative assessment to previously passive traditional lectures. While considerable research has been conducted on clicker increasing student interaction in class, less research has been reported on the effectiveness of using clicker to help students understand concepts. This thesis reported a systemic project by the OSU Physics Education group to develop and test a new clicker methodology.

Clickers question sequences based on a constructivist model of learning were used to improve classroom dynamics and student learning. They also helped students and lecturers understand in real time whether a concept had been assimilated or more effort was required.

Chapter 1 provided an introduction to the clicker project. Chapter 2 summarized widely-accepted teaching principles that have arisen from a long history of research and practice in psychology, cognitive science and physics education. The OSU clicker methodology described in this thesis originated partly from our years of teaching experience, but mostly was based on these teaching principles.
Chapter 3 provided an overview of the history of clicker technology and different types of clickers. Also, OSU’s use of clickers was summarized together with a list of common problems and corresponding solutions. These technical details may be useful for those who want to use clickers.

Chapter 4 discussed examples of the type and use of question sequences based on the new clicker methodology. In several years of research, we developed a base of clicker materials for calculus-based introductory physics courses at OSU.

As discussed in chapter 5, a year-long controlled quantitative study was conducted to determine whether using clickers helps students learn, how using clickers helps students learn and whether students perceive that clicker has a positive effect on their own learning process. The strategy for this test was based on comparing clicker lecture sections using the new methodology to lecture sections with a similar population of students taught without clickers in a traditional manner. The results of this test were summarized in chapter 5.

Chapter 6 contains a brief summary of research results and conclusions, together with an overview of future efforts in the OSU clicker project.
Dedicated to my mother
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CHAPTER 1

INTRODUCTION

Physics Education Research (PER), which has already made a strong impact on the ways that many instructors teach physics, has been growing rapidly in the past two decades. The major goal of PER is to understand and create strategies to overcome the difficulties that students often encounter in learning physics.

“Clickers” is one name for in-class polling systems used by students to answer multiple-choice questions in lecture classrooms. The Ohio State University Clicker Project is an attempt to design and implement new instructional strategies. This thesis is based on an initial project result consisting of the creating and assessing a new clicker methodology. Student perceptions of using clickers also were assessed in several end-of-quarter surveys.

1.1 Motivations for this research

Most traditional introductory physics courses rely on “transmission-of-information” lectures and “cookbook” laboratory exercises—techniques that are neither highly active in class nor effective in fostering conceptual understanding or scientific reasoning [2004
Handelsman. Various methods have been developed to increase class dynamics and students’ understanding. Laws, Thornton and Sokoloff [1999 Law] developed RealTime Physics, which is an activity-based, computer-assisted, guided-inquiry curricula. They found student learning is improved when students were kept actively involved in the learning process by using activity-based guided-inquiry curricular materials. McConnell [2003 McConnell] showed that students, when given instant feedback, perform better on the exam than students from traditional lecture sections. Dykstra outlined a strategy in which students are exposed to phenomena that induce a conflict with previous conceptions, and then participate in a “town meeting” discussion to resolve perceived discrepancies [1992 Dykstra]. Steinberg & Sabella found that learning is strongly tied to and sustained by the contexts [1999 Sabella].

1.1.1 Teaching principles derived from previous PER research

Four basic teaching principles arose from these and other previous PER work:

1. Active learning is more effective than passive learning.

2. Formative assessment has a powerful impact on student learning.

3. Cognitive conflict can be used to stimulate conceptual change.

4. Learning is context dependent.
1.1.2 Motivations for using clickers

Using clickers can add active learning and formative assessment to previously passive traditional lectures. Draper and Brown showed that using clickers could improve classroom dynamics through a two-year, institution-wide project [2004 Draper]. This paper also showed that clickers can give feedback to learners about whether they understand the material presented. Woods [2004 Woods] found that clickers can be used as a tool to increase active engagement in the classroom.

1.1.3 Precursor of this research

Eric Mazur’s program “Peer Instruction” (PI) [2001 Mazur] modifies the traditional lecture format to include questions designed to engage students and uncover difficulties with the material. He also included active learning, formative assessment and cognitive conflict in his PI program. The Ohio State University (OSU) clicker project extends the PI methodology to include use of question sequences, rather than just single questions.

1.1.4 Motivations for using question sequences

There are many reasons for us to use question sequences. Among them, the most important reason is the context dependence of learning. Question sequences are also better assessment tools than a single question. Furthermore, question sequences can help check whether cognitive conflict fosters conceptual change.

Because context dependence in student responses is common, a single question usually fails to help students make context-dependent connections. Each of our clicker
question sequences has three to four questions, each with a context that looks different to students, while the underlying concept looks equivalent to experts. By recognizing and applying a new concept in different contexts and conditions, students can obtain a better level of understanding.

Question sequences also serve as a better assessment tool than a single question. By using question sequences, instructors can have a better understanding of where the students’ difficulties are, and thus can provide corresponding feedback. Question sequences can also provide specific feedback to students themselves. A common difficulty when students learn physics is that they cannot identify their mistakes. Question sequences can help students find specific difficulties.

Finally, question sequences can create cognitive conflict with less anxiety. In many “easy-hard-hard” question sequences, we used the first question to set up the cognitive conflict in the second question. Many students who select the right choice using an incorrect interpretation in the first question will choose wrong answers in the second question. We then use the third question to assess whether the cognitive conflict in the second question has helped students’ conceptual change. Though not formally tested, we believe that this methodology gives students more confidence and less anxiety.

1.2 Overview of thesis project

At the Ohio State University (OSU), a new clicker methodology based on using a sequence of questions, each displaying the same concept set in a different context has been created. The methodology is based on the four widely accepted teaching principles
described above. This thesis will review question-sequence material used in our clicker project, and then report results from a controlled quantitative study in which the question-sequence methodology was used during three consecutive quarters of the electricity-and-magnetism (E&M) sections of calculus-based introductory physics courses at OSU.

1.2.1 Goal of this research

The main goal of this research is to provide evidence to answer the following questions:

1. How should researchers develop question sequences to address the context dependence of learning?

2. Do students using clickers with the new question methodology perform better on conceptual test and common exam questions than students not using clickers?

3. Do students perform differently within different population subsets such as gender, and high achieving versus low achieving students?

4. Do students perceive that using clickers is a valuable learning experience and feel that clicker question sequences help them learn?

1.2.2 Overview of thesis content

The introduction in this chapter is followed in chapter 2 by a literature review that is connected to the new clicker methodology. For each of the four previously-described teaching principles, a brief overview of early work will be followed by a discussion of
later theories and practice developed in the field of PER. Finally, Mazur’s use of clicker in “Peer Instruction” has been included as a precursor to OSU’s project.

Chapter 3 reviews new PER technologies. It will begin with an introduction of two of the commonly used new technologies in teaching physics: computer simulation and web-based instruction. These topics will be followed by an overview of the history of clicker technology and a discussion of different types of clickers. Finally, OSU’s use of clickers is summarized together with a list of common problems and corresponding solutions.

Chapter 4 presents examples of question sequences. Detailed examples for two types of question sequences will be presented. Each sequence will start with a specific misconception followed by a discussion of question design and student polling results. Examples will focus on Electricity and Magnetism (E&M), though a few will be provided for Mechanics and Waves and Modern Physics. The focus is on E&M because:

1. The controlled quantitative study of the question-sequence methodology took place during three quarters of the E&M sections of calculus-based introductory physics courses.

2. The E&M question sequences are both more complete and better studied.

All question sequences and corresponding results will be presented in appendix 1.

Chapter 5 consists of analysis of the year-long study. The main method of this test is comparing clicker lecture section to a lecture section with a similar population of
students taught without clickers in a traditional manner. The findings of the year-long controlled quantitative study can be summarized as: 1) Students in the clicker section score better than students from non-clicker section on the CSEM post test. 2) Students in the clicker section also score better on common exam multiple choice questions. 3) The upper half students benefit both from the “easy-hard-hard” sequence and the “Rapid-Fire” sequence. On the other hand, the lower half students seem to benefit mostly from the “Rapid-Fire” sequence. 4) Gender specific CSEM results showed that using clickers reduces the gap between male and female students’ performances on tests. 5) Attitude surveys show that students like using clickers and think using clickers helps them understand the questions better.

Chapter 6 contains a brief summary of research results and conclusions, together with an overview of future efforts in the OSU clicker project.

We hope that this thesis will be beneficial to instructors who want to use clickers in their lectures and PER researchers who are interested in clicker question methodology.
References:


1999 M. Sabella “Using the context of physics problem solving to evaluate the coherence of student knowledge”. Ph.D. dissertation, University of Maryland

2001 C. Crouch and E. Mazur “Peer Instruction: Ten years of experience and results” 977 Am. J. Phys., Vol. 69, No. 9


CHAPTER 2

THEORETICAL FRAMEWORK OF OSU CLICKER METHODOLOGY

“Clickers” is the name for in-class polling systems used by students to answer multiple-choice questions in an increasing number of lecture classrooms. As reliable and inexpensive clicker systems have become commercially available, the present challenge is to create questions that are optimal for improving students’ understanding of physics. As with other teaching innovations, the strategy for designing clicker questions described in this thesis partly originated from our years of teaching experience. More importantly, the strategy is also based on four widely-accepted teaching principles that have arisen from a long history of research and practice in psychology, cognitive science and physics education. These four teaching principles can be summarized in the following statements:

1. Active learning is more useful than passive learning.

2. Formative assessment has a powerful impact on student learning.

3. Cognitive conflict can be used to stimulate conceptual change.
4. Learning is context dependent.

The purpose of this chapter is to describe the history of research and practice as related to the above principles, and connect it to the strategy for designing questions that form the basis for this thesis. For each of the above principles, a brief overview of early work will be followed by a discussion of later theories and practice developed in the field of Physics Education Research (PER). Finally, Mazur’s use of clickers in “Peer Instruction” has been included as a precursor to the Ohio State clicker project.

2.1 Active learning is more useful than passive learning.

2.1.1 Early Work

Psychologists began emphasizing active learning at the beginning of the twentieth century. Vygotsky [1930 Vygotsky] and Piaget [1969 Piaget] stated that one goal of instruction is to make the students transition from being other-regulated to becoming self-regulated. One of the important ways for the students to be self-regulated learners is actually to get involved and do things by themselves.

2.1.2 PER Work

In Physics Education Research (PER), researchers also realized that active learning is important. Redish [1994 Redish] found that “active learning works better than passive learning. People learn better by doing than by watching something being done.” Gamson [1987 Gamson] suggested that learning is not a spectator sport.
“Students do not learn much just by sitting in class listening to teachers, memorizing pre-packaged assignments, and spitting out answers. They must talk about what they are learning, write about it, relate it to past experiences, and apply it to their daily lives. They must make what they learn part of themselves.”

Bonwell [1996 Bonwell] summarized some of the major characteristics associated with active learning strategies in the context of the college classroom:

1. Students are involved in more than passive listening

2. Students are engaged in activities (e.g., reading, discussing, and writing)

3. There is greater emphasis placed on the exploration of attitudes and values

4. Student motivation is increased (especially for adult learners)

In summary, active learning involves students in doing things and thinking about the things they are doing. A similar theory of students doing and thinking about things is constructivism pedagogy. Constructivism is a set of assumptions about the nature of human learning that emphasizes an “active” approach. Constructivism values developmentally appropriate teacher-supported learning that is initiated and directed by the student [2002 DeVries]. This approach stands in contrast to learning by transmission, where the instructors try to transfer their own knowledge directly to students. Constructivism as a description of human cognition is often associated with pedagogic approaches that promote learning by doing [1996 Dalgarno].
### 2.1.3 Instructional Examples

Many traditional introductory physics courses rely on “transmission-of-information” lectures and “cookbook” laboratory exercises — techniques that are neither highly active in class nor effective in fostering conceptual understanding or scientific reasoning [2004 Handelsman]. Several researchers have shown that supplementing or replacing lectures with active learning strategies and engaging students in discovery and the scientific process improve learning and knowledge retention. This general approach is known as “active engagement” [1991 McDermott] [1997 Redish]. Both lectures and recitations involving interactive engagement place a more explicit focus on problem-solving techniques and conceptual understanding than do most traditional classes simply by the nature of the engagement. Students are continually asked to answer conceptual and quantitative questions and to talk about their answers with others. Students are forced to practice in the area where they are most deficient – their conceptual knowledge base – and develop meta-cognitive skills in trying to explain and understand the explanations of their group members.

One example of implementing active engagement in lectures is RealTime Physics, developed by Laws, Thornton and Sokoloff [1999 Laws], which is an activity-based, computer-assisted, guided-inquiry curricula. Laws, Thornton and Sokoloff found students’ learning is improved when they:
- use peer instruction and collaborative work

- keep students actively involved by using activity-based guided-inquiry curricular materials

Laws et al. found that after traditional instruction, only 30% of a sample of over 1200 students in calculus-based physics course understand fundamental acceleration concepts. At universities where the complete sets of RealTime Physics Mechanics laboratories have been implemented, 93% of students understand these concepts. Less than 15% of students held a Newtonian point of view after traditional instruction in dynamics, while 90% did so after RealTime Physics laboratories.

### 2.1.4 Influences on OSU Clicker Project

Clickers, in-class polling systems used by students to answer multiple-choice questions during lectures, have become increasingly popular. Draper and Brown showed that using clickers could improve classroom dynamics through a two-year, institution-wide project [2004 Draper]. They identified three important features of clickers:

1. Getting feedback to learners about whether they understand the material presented.

2. Getting most students to think about the question and decide on an answer.

3. Anonymity is often important in achieving these benefits.
Wood [2004 Wood] also found that clickers can be used as a tool to increase active engagement. A dramatically increasing number of instructors have started using clickers as a way to increase students’ engagement in class.

The primary goal for Ohio State clicker use is also implementing active learning and enhancing active engagement in lectures. As discussed in chapter 1, traditional lectures are not effective in fostering conceptual understanding or scientific reasoning [2004 Handelsman]. However, they are cost effective, since many active learning methods such as Studio Physics and Workshop Physics require higher teaching loads or more manpower. For example, Beichner [2005 Beichner] stated that Studio Physics and Workshop Physics are “difficult to implement at large research universities because of class size limitations”. Introducing clickers in lectures is a cost effective way to make students become more involved in lectures [2004 Draper]. As indicated both by frequent animated student discussions and student surveys (which will be shown in chapter 5), our clickers used with question sets based on a constructivist model of learning to improve classroom dynamics.

2.2 Formative assessment has a powerful impact on student learning.

2.2.1 Early Work

Vygotsky proposed that reaching the Zone of Proximal Development (ZPD), “the distance between the actual developmental level as determined by independent
problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with a more capable peer", is the key stage during human intellectual development [1930 Vygotsky]. The gap between the students’ current level and their desired level should not be huge; or the students will become lost. He proposed scaffolded instruction which involves an instructor guiding the learner to build a bridge between their current and desired levels. According to Vygotsky, scaffolded instruction consists of dividing the gap between a students’ current and desired level into several small steps. During each step, instructors give students instant feedback. This can be viewed as an early attempt at formative assessment.

2.2.2 Recent Work

Formative assessment is the diagnostic use of assessment to provide feedback to teachers and students over during instruction. It stands in contrast to summative assessment, which generally takes place after a period of instruction and requires making a judgment about the learning that has occurred (e.g., by grading or scoring a test or paper). Summative assessment is not designed to provide the immediate, contextualized feedback useful for helping teachers and students during the learning process. If the primary purpose of assessment is to support high-quality learning, then formative assessment should be understood as the most important assessment practice.
The evidence shows that high-quality formative assessment does have a powerful impact on student learning. Formative assessment is particularly effective for students who have not done well in school, thus narrowing the gap between low and high achievers while raising overall achievement. Black and Wiliam [1998 Black] conducted an extensive research review of 250 journal articles and book chapters winnowed to determine whether formative assessment raises academic standards in the classroom. They concluded that efforts to strengthen formative assessment produce significant learning gains as measured by comparing the average improvements in the test scores of the students involved in the innovation with the range of scores found for typical groups of students on the same tests [1998 Black]. The ratio of the former divided by the latter is known as the effect size. Typical effect sizes of the formative assessment experiments were between 0.4 and 0.7.

\[
\text{Effect Size} = \frac{M_{\text{treatment}} - M_{\text{control}}}{\sigma}
\]

\(M_{\text{treatment}}\) is the mean of the treatment group, \(M_{\text{control}}\) is the mean of the control group, \(\sigma\) is the standard deviation of the students’ score.

Many of these studies arrive at another important conclusion: that improved formative assessment helps low achievers more than other students, and so reduces the range of achievement while raising overall achievement. A notable recent example is a study devoted entirely to low-achieving students and students with learning disabilities, which shows that frequent assessment feedback helps both groups
enhance their learning [1986 Fuchs].

Feedback plays an important role in formative assessment. It helps learners become aware of any gaps that exist between their desired goal and their current knowledge, understanding, or skill and guides them through actions necessary to obtain the goal [1989 Sadler]. The most helpful feedback on tests and homework provides specific comments about errors and specific suggestions for improvement and encourages students to focus their attention thoughtfully on the task rather than on simply getting the right answer [1991 Bangert-Drowns]. This type of feedback may be particularly helpful to lower achieving students, because it emphasizes that students can improve as a result of effort rather than be doomed to low achievement due to some presumed lack of innate ability [1997 Fuchs].

While feedback generally originates from a teacher, learners can also play an important role in formative assessment through self-evaluation. Two experimental research studies have shown that students who understand the learning objectives and assessment criteria and have opportunities to reflect on their work show greater improvement than those who do not [1994 Fontana]. Students with learning disabilities who are taught to use self-monitoring strategies related to their understanding of reading and writing tasks also show performance gains [1992 McCurdy].

Implementing feedback is not an easy task and requires experience. Emberger [2002 Emberger] gives a few key attributes for feedback to be more likely to produce
the desired effect:

1. **Corrective in nature.** Students need to understand what they are doing correctly and incorrectly. “In fact, simply telling students their answers are right or wrong has a negative effect on achievement; providing students with the correct answers has a moderately positive effect; explaining what is correct and what is incorrect has a greater effect; and allowing students to continue working on a task until successful has the greatest effect.”

2. **Timely.** In general, the greater the delay between assignment and feedback, the less improvement occurs.

3. **Specific to the criteria.** Feedback is most effective when it is specific to the criteria the teacher has targeted (which are derived from the indicators) and describes exactly what the student did or did not learn.

Formative assessment, as a better way of teaching physics, has been widely accepted by PER researchers. Mestre [2001 Mestre] states that “formative assessment should be used frequently to monitor students’ understanding and to help tailor instruction to meet students’ needs”. Redish [2003 Redish] also suggests that homework, quizzes and exams should be designed as formative feedback.
2.2.3 Instructional Example

Many instructors have implemented formative assessment in their teaching. McConnell [2003 McConnell] used six methods of formative assessment (conceptual test, graphical diagram, image analysis, concept map, open-ended question, and evaluation rubrics) aimed at recognizing and correcting misconceptions during lecture. They also divided students into groups, and required students to provide feedback on their ongoing learning, thus giving the instructor an opportunity to highlight concepts that require additional explanation. They found that in the section where they used innovative formative assessment methods, the average score on the exams was 7% greater than the average of the traditional lecture section. They also found that the treatment section showed a statistically significant 6.3% improvement in average Group Assessment of Logical Thinking test (GALT; 1982 Roadrangka) scores over the length of the semester.

2.2.4 Influences on OSU Clicker Project

Clickers are useful tools to implement formative assessment in lectures, since instant feedback can be provided to both instructors and students [2004 Draper]. As discussed above, feedback plays an important role in formative assessment. It helps learners become aware of any gaps that exist between their desired goal and their current knowledge, understanding, or skill, and guides them through actions necessary to obtain the goal. By providing voting results in real time, clickers can help lecturers
understand whether a concept has been assimilated or additional effort is required. Clickers can also provide feedback to the students for self-evaluation.

Using question sequences is also a useful method to achieve formative assessment. The question sequences frequently have increasing difficulty and show concepts in different contexts. By using question sequences, students can divide the task of learning a concept into several small steps, each set in a different context. For each step, they will be provided with feedback which is specific to the criteria the teacher has targeted and describes exactly what the student did or did not learn. By combining the instant feedback of clickers and our question sequences, we can improve formative assessment in lectures.

2.3 Cognitive conflict can be used to stimulate conceptual change.

2.3.1 Early Work

Cognitive conflict, as originated by Piaget, is a “discrepancy between what the child believes the state of the world to be and what s/he is experiencing” [1969 Piaget]. Piaget proposes that humans desire a state of cognitive balance or equilibration. When the child experiences cognitive conflict, adaptation is achieved through assimilation or accommodation:
1. Assimilation involves incorporating new information into previously existing structures or schema (e.g., a child encounters a Dalmatian for the first time and incorporates Dalmatians into her existing schema for "dogs").

2. Accommodation involves the formation of new mental structures or schema when new information does not fit into existing structures (e.g., a child encounters a skunk for the first time and learns that it is different from "dogs" and "cats." She must create a new representation for "skunks").

2.3.2 PER Work

Influenced by Piaget, PER Researchers also have investigated how cognitive conflict affects students' changing of existing perceptions. Dykstra [1992 Dykstra] stated that Piaget’s theory “makes a lot of sense”. He proposed that people do not change their ideas about things until they decide their ideas do not work. They notice that something does not match how they expected things to be and they become disturbed to some degree. He noticed that people tend to respond so as to reduce this sense of disturbance. They can “walk away from it” or avoid it in some way, in which case they do not change their schemes. Or they can stop and consider the situation, imagine and test out some alternative schemes. When they find one that works satisfactorily to explain this novel situation, they are satisfied, re-equilibrated, and move on. He compared these processes of generating and adopting new schemes to Piaget’s theories of self-regulation and accommodation. Dykstra proposed that for physics instruction to be effective, “it must encourage the kind of learning that leads
to conceptual understanding.” In his view, such learning occurs when knowledge is constructed by the individual. He stated that “students can construct Newtonian conceptions if they experience situations that bring them to question their own conceptions and are then facilitated to develop what are for them more viable replacements”.

Redish [1994 Redish] discussed changing an existing mental structure in terms of Piaget’s "accommodation principle". Redish noticed that it is very difficult to change an established mental model substantially. It appears the mechanism critically involves prediction and observation. The prediction must be made by the individual and the observation must be a clear and compelling contradiction to the existing mental model. He stated that “The clearer the prediction and the stronger the conflict, the better the effect.”

Confronting students with discrepant events that contradict their existing conceptions has become one of the common instructional strategies to foster conceptual change. It is intended to invoke a disequilibration or conceptual conflict that induces students to reflect on their conceptions as they try to resolve the conflict. Hewson and Hewson [1984 Hewson] explicated the role of conceptual conflict in conceptual change and the design of science instruction citing two studies in which conceptual conflict was found to be effective in changing students’ alternative conceptions.
However, findings of other studies were equivocal. For example, Dreyfus [1990 Dreyfus] found that bright, successful students reacted enthusiastically to conceptual conflicts, but unsuccessful students ignored or tried to avoid them. Niaz [1995 Niaz] found that some students protected their conceptions by ignoring the conceptual conflict.

Anat Zohar [2005 Zohar] studied the conditions under which cognitive conflict is effective. His research examined the notion that cognitive conflict may have dissimilar effects for students of different academic levels. He compared the effectiveness of teaching the control of variables thinking strategy to students of two academic levels (low vs. high) by two different teaching methods [inducing a cognitive conflict (ICC) vs. direct teaching (DT)]. One hundred twenty-one students who learned in a heterogeneous school were divided into four experimental groups in a $2 \times 2$ design. The findings show that students with high academic achievements benefited from the ICC teaching method while the DT method hindered their progress. In contrast, students with low academic achievements benefited from the DT method while the ICC teaching method hindered their progress. The interaction effect was preserved in a retention test that took place 6 months after instruction.

In a study of the energy concept, Trumper [1997 Trumper] found that students reacted to conceptual conflicts in several different ways that did not lead to conceptual change: (a) failure to recognize the conflict, (b) recognizing the conflict but avoiding resolution by passively relying on others, (c) resolving the conflict
partially, and (d) resolving the conflict using alternative conceptions. Conceptual conflicts did not always produce conceptual change. For conflicts to lead to change, students need to reflect on and reconstruct their conceptions.

### 2.3.3 Instructional Examples

Many instructional strategies and methods have been developed particularly using cognitive conflict in teaching. A well-known Example is Physics By Inquiry (PBI). Designed by the Physics Education Group at the University of Washington [2000 McDermott], PBI is a set of laboratory-based modules that provide a step-by-step introduction to physics and the physical sciences. Starting from their own observations, students develop basic physical concepts, use and interpret different forms of scientific representations, and construct explanatory models with predictive capability. All the modules have been explicitly designed to target students’ misconceptions from real world phenomena to trigger their conceptual change. For instance, one of the common misconceptions among pre-service teachers is “current will be used up along the circuit”, PBI has an example as shown in picture 2.1 to specifically address this misconception:
Picture 2.1, an example of PBI to target student specific misconception.

Student 1: “I think D will be a lot dimmer than A; in fact, maybe it won’t light at all. There won’t be much current left after it passes through A, B, and C. Maybe D will be brighter and A will be dimmer; it depends on the direction of the flow through the circuit. This would be a good test to find the direction of the current.”

They ask students whether they agree with student 1 or not, and request them to explain their reasoning. Next, they ask the students to actually conduct this experiment, and determine whether their results agree with their prediction. By targeting students’ misconceptions, they create a conflict, which if resolved, will help students’ conceptual understanding.

2.3.4 Influences on OSU Clicker Project

As a widely-used instructional method, cognitive conflict is also implemented in our question sequence designing philosophy, especially in the “easy-hard-hard”
question sequence. The first question is easy, and almost every student answers correctly. The role of the first question is to review some basic concept and make students comfortable answering questions. This may reduce cognitive anxiety, which can possibly hinder student learning [2004 Kim]. The second question is usually hard, and only a fraction of students get the right answer. The purpose of this question is to correct students’ misconceptions and to trigger cognitive conflict, which may initiate concept change. A voting summary is shown to make sure students recognize the conflict. Students discuss with each other while voting. A class-wide discussion occurs after voting. A third question follows, which has the same concept as the other questions but different context features. This question provides the students do not resolve the conflict partially or resolved the conflict using alternative conceptions.

As too much cognitive conflict may hinder the progress of students with low academic achievements [2005 Zohar], we also designed “Rapid fire” question sequences, which usually contain questions that for experts are of more modest difficulty, so that students can gradually build knowledge structures. This type of conceptual change is closer to Piaget’s “assimilation” theory [1969 Piaget]. The cognitive conflict in this question sequence is not as strong as that in the “Easy-Hard-Hard” sequence. By using this kind of question sequence, we are attempting to reduce students’ cognitive anxiety [2004 Kim]. The “Rapid fire” question sequences can also help students organize information into related, interconnected structures.
2.4 Learning is context dependent.

2.4.1 Recent Work

Early approaches in psychology and cognitive science treat learning as highly general processes and provide less emphasis on the context or situation in which the learning takes place. In the past two decades, researchers have started to focus on the interactions between people and the historically and culturally constituted contexts [1991 Lave].

Lei Bao stated that “the context is always an important element involved in all stage of learning although the actual form of it might have different variations” [1999 Bao]. His model summarized the involvement of context in learning in three categories:

1. Context dependence of the form of mental elements.

The construction of one’s knowledge system starts with the very details of the physical world and is constrained by the physical context in which learning is taking place. Thus the formations of mental elements are originally from various physical contexts.

2. Context dependence in cueing.

Another vital role that the context plays is the cueing of appropriate knowledge. The initial triggering of our mental system is often certain physical features in a
specific context.


Since both formation and cueing of a mental element is dependent on context, once formed, the mental element itself also has context dependent features. For example, many concepts only work in certain contexts. When learning the conservation of kinetic energy, students also need to know that it works when there is no friction and outside work.

2.4.2 PER Work

Palmer surveyed and interviewed a group of 40 students to determine the effect of context on the reasoning which they used to solve problems concerning the forces acting on objects in linear motion [1997 Palmer]. He found that the students were influenced by contextual features such as the speed, weight and position of the moving object, the direction of the motion and their own personal experience of the context.

Steinberg & Sabella found learning is understood largely in terms of the achievement of appropriate patterns of behavior, which are strongly tied to and sustained by the contexts [1999 Sabella]. They asked students in engineering physics at the University of Maryland two equivalent questions involving Newton’s first law. In both questions, the students were asked to compare the forces acting on an object moving vertically at a constant velocity. One question was phrased in physics terms
using a laboratory example (“A metal sphere is resting on a platform that is being lowered smoothly at a constant velocity…”). The other was phrased in common speech using everyday experience (“An elevator is being lifted by a cable…”). In both problems, students were instructed to ignore friction and air resistance. On the physics-like problem, 90% of the students gave the correct answer that the normal force on the sphere is equal to the downward force due to gravity. On the everyday problem, only 54% chose the correct answer: the upward force on the elevator by the cables equals the downward force due to gravity. More than a third, 36%, chose the answer to this second problem reflecting a common incorrect model: the upward force on the elevator by the cables is greater than the downward force due to gravity.

The most context-dependent form of knowledge is the huge collection of personal experiences and real world examples. These experiences and examples are stored in people’s long term memory and each of them is strictly associated with a specific context [2001 Bao].

2.4.3 Instructional Examples

Many researchers are experimenting with novel problem types so that students can see a concept in different contexts. Many of these problems focus on conceptual development rather than calculation. For example, Van Heuvelen’s Active Learning Problem Sheets kit (ALPS kit) [1991 Van Heuvelen] requires students to perform qualitative redescriptions before attempting to enact solutions, and contains many
pages where students practice nothing but creating and interpreting representations on paper. Other examples of alternative problem types include ranking tasks (i.e. “rank these free body diagrams in order of the magnitude of their net force, from greatest to least”) and context rich problems [2003 Hsu] which provide a semi-realistic cover story and are often (intentionally) poorly defined, not explicitly asking for any particular unknown, or providing insufficient information for a solution, which prompts discussion and thought about how the problem should be approached.

2.4.4 Influences on OSU Clicker Project

Context dependency is imbedded in our question sequence design philosophy, because strong context dependence in student responses is common, and especially when students are just beginning to learn new material. Students are unsure of the conditions under which rules they have learned apply and they use them either too broadly or too narrowly. A single question usually fails to help students make context-dependent connections, and cannot test whether they have been made. We hypothesize that one concept needs to be seen in different contexts to be fully understood. Each of our clicker question sequences has three to four questions on the same concept or relationship between several concepts. The context looks different to students while the underlying concept looks equivalent to experts. By answering these questions in a short period of time (usually 5-8 minutes), students can understand how these conditions apply, which is a crucial part of learning a new concept.
The ALPS kit, because of its focus on conceptual problems and multiple step representations, provided a great deal of help during our design of question sequences. Many ranking and graphical questions were included so that students could experience different context features.

2.5 Comparison between Mazur’s “Peer Instruction” and our clicker program.

2.5.1 What is “Peer Instruction”?  

Eric Mazur’s program “Peer Instruction” (PI) [2001 Mazur] modifies the traditional lecture format by including questions designed to engage students and uncover difficulties with the material. A class taught with PI is divided into a series of short presentations, each focused on a central point and followed by a related conceptual question, called a Conceptual Test, which probes students’ understanding of the ideas just presented. Students are given one or two minutes to formulate individual answers and report their answers to the instructor. Students then discuss their answers with others sitting around them; the instructor urges students to try to convince each other of the correctness of their own answer by explaining the underlying reasoning. Finally, the instructor calls an end to the discussion, polls students for their answers again (which may have changed based on the discussion), explains the answer, and moves on to the next topic.
2.5.2 Results of PI

Mazur found that the students taught with PI significantly outperformed the students taught traditionally. The normalized gain on Force Concept Inventory (FCI) increased from 0.25 to 0.60 after being taught by PI. The improvement of the PI students over the traditional students corresponds to an effect size of 0.57. All measures indicate that students’ quantitative problem-solving skills achieved in PI are comparable to or better than those achieved with traditional instruction.

2.5.3 Similarities between “Peer Instruction” and our clicker project

1. “Peer Instruction” also uses active learning pedagogy.

“Peer Instruction” engages students during class through activities that require each student to apply the core concepts being presented, and then to explain those concepts to their fellow students. “Unlike the common practice of asking informal questions during a lecture, which typically engages only a few highly motivated students, the more structured questioning process of PI involves every student in the class.” [2006 Mazur]

2. “Peer Instruction” also tries to implement formative assessment in lectures.

Mazur also tries to implement formative assessment in lectures. During the discussion in lecture, students first need to formulate individual answers and report their answers to the instructor. Students then discuss their answers with others sitting
around them. Mazur uses the clicker as a tool to provide instant feedback. Finally, the instructor polls students for their answers again and then explains the answer. Initially using showing hands and cards as ways to provide feedback, Mazur eventually switched to clickers. He states that “the technology freed me to walk around and talk to students. It personalized the class for me and for them.”

Mazur also found that using clickers can give feedback to the instructors. “Standing in front of a class, I have no idea what conceptual difficulties a student faces,” Mazur admits. “When you understand the materials as well as I do, it’s hard to figure out what students don’t get, or why they don’t get it. The solution is to give students the opportunity to teach each other. And technology helps me do this, to have the classroom in the palm of my hand.”

3. “Peer Instruction” also uses formative assessment to stimulate conceptual change.

When designing ConceptTest questions, Mazur states that “incorrect answer choices should be plausible, and, when possible, based on typical student misunderstandings. A good way to write questions is by looking at students’ exam or homework solutions from previous years to identify common misunderstandings, or by examining the literature on student difficulties.” He also suggests that ConceptTests should be challenging but not excessively difficult. He admits “If more than 70% of the students can answer the question correctly alone, there is little benefit from
discussion.”

**2.5.4 Difference between “Peer Instruction” and our clicker project**

Mazur uses only a single question on one concept while we use question sequences for each concept.

We hypothesized that learning is context dependent. One question is not enough for our student to completely understand one concept, to know the conditions under which rules they have learned apply and to distinguish differences between concepts. By using a sequence of questions with difference surface features but the same underlying concept or several concepts, students improve their conceptual understanding and scientific reasoning.

Using question sequences also improves formative assessment in lectures. Using several questions can give instructors instant feedback about the students. By using question sequences, instructors can check whether students understand the concept in different contexts. Question sequences can also provide specific feedback to students. By answering several questions in a row, students can reinforce their understanding.

Occasionally, students have several misconceptions or difficulties with a single concept. For example, students have trouble understanding how to determine both the direction and relative strength of the electric field given equipotential surfaces. Question sequences can give students different looks concerning these specific misconceptions. Question sequences can also divide understanding a concept into
small little steps, thus help students decrease the difficulty of learning a new concept as a whole chunk of knowledge.

Finally, cognitive conflict will have a better effect if used in question sequences. In many “easy-hard-hard” question sequences, we used the first question to set up the cognitive conflict in the second question. We then use the third question to assess whether the cognitive conflict in the second question help students’ conceptual change. We hypothesized that answering the third question correctly will create more confidence.

2.6 Summary

Based on many years of research results from cognitive science and PER, we summarized four widely accepted teaching principles, which have formed the basis for our clicker project. We also included ideas from other new instructional methods. Among them, “Peer Instruction”, with several similar teaching principles, is a precursor of our clicker program. We studied the ConceptTest questions which were used by Mazur during PI when designing our question sequences.

The major difference is that we used question sequences while Mazur used one question per concept. There are many reasons for us to use question sequences. Among them, the most important reasons are overcoming the context dependence of learning and providing better formative assessment.
References:

1930 Vygotsky, “Primitive Man and his Behavior”, Harvester Wheatsheaf


1982 Roadrangka, V., Yeany, R., and Padilla, M., GALT, Group Test of Logical Thinking, Athens, Georgia, University of Georgia.


1989 D. Sadler “Formative assessment and the design of instructional systems” Instructional Science, 18 (2): 119-144


1996 Dalgarno, B., “Constructivist computer assisted learning: theory and technique”, ASCILITE Conference, 2-4 December


1997 Trumper, R. “Applying conceptual conflict strategies in the learning of the energy Concept”, Research in Science and Technology Education, 15, 5–18


1999 Lei Bao, “Dynamics of student modeling” Ph.D. Thesis

1999 M. Sabella “Using the context of physics problem solving to evaluate the 
coherence of student knowledge”. Ph.D. dissertation, University of Maryland

2000 L. McDermott and P. Shaffer, "Preparing teachers to teach physics and physical 
science by inquiry," in The Role of Physics Departments in Preparing K-12 Teachers, College 

2001 L. Bao and E. F. Redish, “Concentration Analysis: A Quantitative Assessment of 
Student States”, PERS of Am. J. Phys. 69 (7), S45-53

2001 C. Crouch and E. Mazur “Peer Instruction: Ten years of experience and results”
977 Am. J. Phys., Vol. 69, No. 9

2001 Jose P Mestre, “Implications of research on learning for the education of 
prospective science and physics teachers”, Physics Education


2003 L. Hsu, K. Heller, and A. Hasnudeen “Designing Interactive Problem-Solving 
Tutorials” Contributed Talk, AAPT Summer Conference (Madison, Wisconsin)

2003 E.F. Redish, “Teaching Physics: With the Physics Suite”, A copy of this book can 
be found at http://www2.physics.umd.edu/~redish/Book/


CHAPTER 3

USING NEW TECHNOLOGY IN TEACHING

With the development of new technologies such as personal computers, an increasing number of innovative tools are used in teaching physics. This chapter will begin with the introduction of two commonly used new technologies: computer simulation and web-based homework. Just as for clickers, these new technologies can increase students’ interaction and thus enhance the effectiveness of teaching. Also, they give students instant feedback for self assessment. This initial discussion will be followed by a detailed discussion of clicker technologies. Finally, specific problems that we encountered with our own clicker system are summarized, along with our solutions.

3.1 Why introduce these two new technologies?

There are many other innovating technologies that have been used in teaching physics. However, there are two reasons to select computer simulations and web-based homework for inclusion in this thesis:
1. Computer simulation can increase students’ interaction and thus enhance the effectiveness of teaching. As described in the previous chapter, active learning is more effective than passive learning; students learn better when they become involved.

2. Both computer simulation and web-based homework can give students instant feedback for self assessment. As described in the previous chapter, formative assessment has a powerful impact on student learning. Computer simulations give students instant feedback, because students see results immediately. The primary goal of web-based homework is to give instant feedback.

These two technologies have been chosen because they both use teaching principles described in chapter two. Studying the use of these technologies helped us devise our own clicker methodology.

3.2 Computer simulation

As personal computers become increasingly popular, physics instructors have begun using computer simulations to illustrate process and concepts. P. Gorsky [1992 Gorsky] and D. J. Grayson [1996 Grayson] tried to use computer simulations to restructure the students’ conception of force. P. W. Hewson [1985 Hewson] used a computer program to diagnose and remediate students’ understanding of kinematics. In general, there are two different kinds of computer simulations:
3.2.1 Different kinds of computer simulations

1. **Computer Applet.**

   In this type of simulation students do not need to write their own simulation. Instead, they can choose instruments from a bank, change parameters, and put them in corresponding places. For example, a typical example of a computer applet is lens and mirrors [2006 Davison College]. Students choose different types of lenses and mirrors and are able to change their focal lengths. This type of simulation usually shows experiments that are hard to achieve in lecture such as the simulation of potential energy and kinetic energy bar charts during harmonic oscillations. Students can vividly see how the energy distributes as a function of changing positions. Applets have the advantage that they are easy to use; students can focus on physics principles rather than spending time writing programs.

2. **Simulations where students need to write their own programs.**

   A typical example asks students to write simulations using some simple language such as VPython. The advantage for this kind of simulation is that students need to incorporate physics principles inside the program, which will enhance their understanding of physics concepts. However, writing programs can be time consuming, and especially when students have weak programming skills.
3.2.2 Instructional Example

Noah Finkelstein and Wendy Adams [2006 Finkelstein] introduced a new suite of computer simulations to introductory physics. They then compared the use of computer simulations to the use of more traditional educational resources in lecture, laboratory, recitation and informal settings of introductory college physics. In each case they demonstrated that simulations are as productive, or more productive, for developing student conceptual understanding as real equipment, reading resources, or chalk-talk lectures. For example, they compared the performance between a control group and the “predict and play” group whose play with the simulation was implicitly guided by the prediction question. The fraction that answered questions correctly improved from 41% (control group) to 63% (predict and play group).

3.2.3 Teaching principles used in computer simulation

In order to be a successful instructional tool, computer simulations need to address six key characteristic features [2006 Finkelstein]. The simulations need to: “support an interactive approach, employ dynamic feedback, follow a constructivist approach, provide a creative workplace, make explicit otherwise inaccessible models or phenomena, and constrain students productively”. In short, computer simulations can provide students an active learning experience. For example, when using software applets for circuits, students can build their own circuit, predict the current or voltage, and then compare their predictions with the actual simulations.
3.3 Web based assessment and testing systems

In the past decade, use of World Wide Web as an information resource for teaching and learning or as a communication tool for interacting with others for educational purposes has become popular. Educators over the world have developed several web-based resources [1996 Weller; 2001 Blackboard; 2000 WebCT; 2007 Carmen]. While older methods of accomplishing tasks are still used, the internet offers unique advantages over previous traditional methods. It offers a medium that has the potential to be more responsive to students, encourages greater participation in their own learning, and gives them access to a broader range of information.

3.3.1 Instructional Example

North Carolina State University (NCSU) developed and used a web-based assessment and testing systems called WebAssign [2003 Bonham]. WebAssign uses a Sybase database in which homework questions are stored, assignments are organized, and grades are recorded. The majority of the questions it contains are standard problems from various physics textbooks. The database also includes survey questions and questions from well known physics diagnostic tests. Results from NCSU show that the students from the web sections consistently performed slightly better on the tests. Researchers from NCSU also found that students in the web sections reported spending substantially more time on homework than those in the paper sections.
Our surveys in Freshman Engineering Honor (FEH) physics 132 class show that students appear to appreciate web-based homework more than regular homework. In winter 2003 and winter 2004, students used the regular homework system. As determined by end-of-quarter surveys, the average student rating for the usefulness of homework was 2.51 out of 4. In winter 2006, when students used WebAssign, the average rating for the usefulness of homework was 3.16 out of 4.

3.3.2 Some Concerns about web-based homework

One of the concerns about computer-based homework is that it further reduces the incentive for students to write systematic solutions, explain steps, work algebraically, and keep track of units. Writing systematic solutions is good practice for students, since it both helps them to communicate clearly what was done and also can aid in preventing errors. Clearly labeling quantities—including the use of words can minimize later confusion. Mistakes can be avoided or more easily caught by working algebraically through the solution step by step instead of jumping steps or substituting numbers as soon as possible. Including units in all the calculations and doing a unit check at the end is also a valuable error-checking procedure. [2003 Bonham] Many web-based homework systems use standard textbook problems. Unfortunately, students still use plugging numbers into equations when solving these problems.
3.3.3 Teaching Principles used in web-based homework

The most important teaching principle used by web-based instruction is that it can provide instant feedback to students. Convenient access allows students to get feedback whenever they want. Many on-line instruction systems also have detailed hints which were written by experienced instructors based on students’ common misconceptions. Some web-based instruction systems divide solving problems into several small steps, each with their own hints [2005 Warnakulasooriya]

3.4 Clicker Technology

3.4.1 History

“Clickers” is a generic name for an increasing number of commercial and privately-built in-class polling systems used to answer multiple-choice questions during lectures. It can be traced back to class activities like showing hands or cards. A disadvantage for showing hands or cards is that students who do not want others to see them make mistakes may not participate. To engage all students, classroom communication systems such as ClassTalk emerged in 1985 [1985 ClassTalk]. Since then, continued clicker hardware and software development has eliminated most technical and economic barriers since then. Now, there are many commercially available clicker systems such as the Personal Response System (PRS) [2007 PRS], Turning Point [2007 Turning Point], I-Clicker [2007 I-clicker], Qwizdom [2007
Qwizdom], and E-instruction [2007 E-instruction]. Some of these are even being offered by publishing companies as a teaching aid in support of their textbooks.

3.4.2 Different Types of Clickers

The purpose of this introduction is to give instructors who want to use clickers a general view of different hardware, software and costs.

**Hardware**

Based on hardware, different kinds of clickers can be divided into three major categories:

1. Primitive and sophisticated infrared (IR)
2. Radio frequency (RF)
3. “Virtual” clicker (software client installed on WiFi laptop/PDA)

**IR Clickers**

IR clickers use infrared light to transfer signals. Picture 3.1 shows an example of IR clickers and how it works in classroom. It has several advantages and disadvantages:

**Disadvantages:**

1. It needs a receiver to receive signals from clicker hand pads. Students have to carefully aim their hand pad at the receiver to transfer signals.
2. The range for IR clicker is usually less than 50 feet, which is not suitable for a large lecture room with several hundred students.

3. Primitive IR clickers transfer signals only from clicker hand pad to the receiver. This is a one-way communication system. Students in large classes are unable to tell whether their votes have been received. This problem can be solved by using new-generation, two-way communicating IR clickers.

Advantages:

IR clickers are less expensive than other types of clickers. A typical IR clicker usually costs less than $20, while most RF clickers cost more than $30.

![An example of the IR clicker and how it works in lecture.](image)

*Picture 3.1 An example of the IR clicker and how it works in lecture.*

**RF Clickers**

RF clickers use radio frequency waves to transfer signals. Picture 3.2 shows an example of RF clickers, and how they work in classrooms. They also have several
advantages and disadvantages:

Advantages:

1. Generally only one receiver is required, and students do not need to aim their hand pads at the receiver.

2. It is a two-way communication system. Students get feedback to indicate whether their answers go into the receiver.

3. The range for RF clickers is larger than the range for IR clickers. Most RF clickers have a range of over 200 feet, suitable for even the largest classrooms.

Disadvantage:

1. It could have some interference problems with wireless signal or cell phone signal. The RF clickers we used do not have interference problems. An interference test was conducted at Ohio State where clickers vote at the same time at the central peak of WiFi signal [2005 OSU clicker report]. Results showed that the RF signals generated by Turning Point clickers did not interfere with WiFi signals and cell phone signals. Also, WiFi signals and cell phone signals did not interfere with clicker signals.
“Virtual” clicker

“Virtual” clickers are software clients installed on WiFi laptops or PDAs. This software allows students’ laptops or PDAs to communicate with the instructor’s computer. Picture 3.3 shows an example of a “virtual” clicker.

“Virtual” clickers do not need receivers; their working range is limited only by the range of the WiFi signal. Interference is eliminated by assigning an IP number to each laptop or PDA. They are particularly useful in small class rooms, because the instructor can show text answers from students [2006 Burnstein]. An increasing number of schools are installing wireless networks, and almost all students now have their own laptop or PDA. “Virtual” clickers in the future may become the favored technology.
3.4.3 Software

Different companies use different software platforms. Some companies (such as I-clicker) use their own software. An increasing number of companies (such as Turning Point, E-instruction and Qwizdom) use PowerPoint integrated software to make their product more user-friendly. Most of this software also permits instructors to track students’ individual responses. Some of them also have various analysis options. For example, Turning point can generate various reports in Excel, which makes easier for instructors to analyze students’ response patterns. Picture 3.4 and 3.5 show examples of using Turning Point software.
3.4 Costs

The cost of using clickers is more than just the cost of hand units. For example, in a big lecture room (capacity >60), if you use IR clickers, you may need to use several receivers, whose cost is usually 70–120 dollars. You may also need a technician to check these receivers periodically. If you use RF clickers, you need only one receiver. Thus, IR clickers may cost less for a small lecture room but more for a
big lecture room. Most companies have switched to RF technologies. If you use virtual clickers, the main cost is for software. But you may need to include the costs for the students to buy a notebook or PDA. You may also need to include the costs for the school to maintain a reliable wireless network.

3.4.5 Why choose Turning Point?

There are many aspects needs to be considered when choosing clickers. We considered technologies, unit costs, software costs, software, and customer service.

We fixed on RF over IR clickers because of their suitability for large lecture classrooms. We eventually selected RF clickers from Turning Point because of that company’s sophisticated software and excellent support, though their handheld devices cost somewhat more than those from I-Clicker. (A complete report of clicker systems, their instructional uses, what policies and procedures regarding their use and why we choose Turning Point can be found at [2005 OSU clicker report]

3.5 Ohio State Clicker FAQs

In this section, I will summarize common problems that we encountered during the year-long clicker project, and present working solutions. These may be useful for people who are interested in using Turning Point clickers in their lectures. Before getting started, we should discuss the Turning Point system.
3.5.1 Turning Point system

We used a commercially-available RF clicker system called Turning Point as shown in picture 3.6. Each key pad costs about $35. Turning Point coupled their response software with Microsoft PowerPoint, which is friendly to users. Software can be downloaded from the Turning Point website once you purchase the hand pads, and there is no additional charge for updates. Each RF receiver costs $90. One class typically needs three receivers (one used in the lecture room, one used by the instructor on his or her own computer and one spare in case there is a failure).

Picture 3.6 shows the turning point RF clicker and receiver.

3.5.2 The distribution systems used

In winter 2004, clicker handholds were given to all students at the beginning of the quarter. Students frequently forgot to bring their units to class, or stopped using them when they malfunctioned. Over the quarter, the number of students voting dropped from 90% to approximately 60% of those attending lectures [2005 Reay].
So, we decided to change the distribution system. Holders were placed along the walls in the lecture hall for each handheld. Students picked up and returned the units before and after each lecture, and the units were periodically checked by lab demonstration personnel. Each student was assigned a certain clicker. Picture 3.7 shows examples of our distribution system. During our year-long test, three students took their clickers away from class but returned them immediately after we e-mailed them. The number of hand pads lost was zero.

*Picture 3.7, an example of our distribution system (continued next page)*
Figure 3.1, Students’ voting percentage over the fall 2006 quarter. *X* axis is the week; *Y* axis is the average voting percentage of the corresponding week.
After this distribution system were used, more than 90% of students attending lectures voted without an appreciable decrease in this percentage throughout all quarters as shown in figure 3.1.

### 3.5.3 Clicker Usage Facts

1. Clicker questions are used in almost every lecture, make voting a habit for the students. Typically no more than two clicker question sequences (about six questions) are used in a single lecture. From our empirical experience and students’ survey results (which will be shown in chapter 5), the time for using clickers in each lecture should not exceed 10 minutes (based on a 48-minute lecture).

2. We occasionally used clicker questions at the beginning of the class to review the previous materials, but predominately used them in the middle of the class to illustrate a concept as they were introduced. We seldom use them at the end of the class because students are getting ready to leave and lose concentration.

3. Students were encouraged to compare answers with their peers during voting, and answers usually were discussed with students after they saw the voting summary. Discussions were brief if most of the students selected the right answer. However, it is important to discuss all answers, or otherwise risk disenfranchising lower achieving students. Frequently, students were asked to revote questions after discussion.

4. We usually use questions with picture illustrations rather than questions that are pure text. There are two reasons for this: Anecdotally, we found that students do
not like to read, a pure-text problems take more time and effort for students to understand. A picture both stimulates their curiosity and is easy to understand, thus students can put more focus on understanding the physics principles.

5. Before using clicker question sequences, we first test them on our own computer. It is always better to find the mistakes before showing them to the students.

6. We usually go to the lecture room at least 10 minutes before class starts, upload the clicker questions, insert a “participants list” (discussed in the following section), and go though clicker tests.

3.5.4 How to get data

If you do not need to analyze individual responses, choose “Auto” for “participants list”. If you want to record students’ individual votes, you need to set up a “participants list”. Go to “participants list wizard”, create your new “participants list”. Then go to “edit a participants list”, input “student name” and “device ID”. “Device ID” is the serial number at the back of the clicker hand pad. You need to choose a “participants list” every time you try to record individual responses using clickers.

Save the session file after using clickers. To get data, click “open session” on the turning point tools bar, open the session you saved. Then go to “tools” → “turning report”, choose the turning report you want. I usually choose “results by questions” if I want to see summary response information by questions; choose “results by
participants” if I want to get individual responses by students.

3.5.5 Remaining Turning Point Problems

During the year-long test we had several problems, but most of them were solved by Turning Point’s excellent support staff. There are still a few remaining problems, but most of these have work-arounds.

1. It is easy to change the frequency on the turning point hand unit. Initially, you needed to press “go” and a two digit number to change the frequency to the number you pressed. During our test, we found many students pressed “go” by accident thus changing the frequency of the hand unit. In the first quarter that we used this hand unit, we found this problem happened almost 2 or 3 times every lecture. Turning Point changed the frequency changing procedure to “go”, a two digit number and “go” again. The number of students who accidentally changed hand unit frequencies decreased dramatically. However, we have this students accidentally changing frequency problem. In a winter 2007 end-of-quarter survey, we asked “During this quarter, how many times was your clicker either missing or didn't work?” on the clicker survey. Out of 154 students, 128 students picked “0 times”, 22 students chose “1 to 3 times”. 4 students selected “more than 3 times” [2007 Lee]. Most of the problems were due to changed frequency. A better method for changing RF frequency needs to be developed by Turning Point.
2. We occasionally had problems with receiver dropped in the middle of the lecture. The receiver dropped twice in fall 2005, about four times in winter 2006 and two times in spring 2006. We found that computers can turn off power to USB ports. The solution to this problem is to open “Control Panel” → “system” → “Device Manager” → “USB Root Hub” → “Power Management”, check off “Allow the computer to turn off this device to save power”.

Another treatment to this problem is downloading a “Set Serial” patch from turning point website. We tried to run this program every time after plugging in the receiver. The Turning Point add-on needs to recognize the receiver to transfer data. The most updated version of the Turning Point software has already included this program. Thus the patch no long exits.

Following Turning Point’s advice, we also used a 3-foot USB extension cord instead of plugging receiver directly to the USB port. Using USB extension cord can filter some noise which could make the receiver drop. The new Turning Point receiver does not need a USB extension cord.

In winter 2007, two instructors used Turning Point. One instructor had zero receiver drops. The other instructor had receiver dropping problem twice. However, the instructor who had the dropping problem also used a Macintosh to present his lectures and switched to a PC when using voting machines. It is possible that the receiver dropping out may have something to do with the switch, but at present it is an
unsolved problem. Dropping is cured by repeatedly unplugging and replugging the receiver until it is recognized by the computer. Occasionally, the computer itself has to be rebooted. In spring 2007, the instructor using only the PC again had zero drops.

3. Pressing the “?” button can make the software freeze (not responding) during voting. We had 3 incidents where the software stopped responding during the voting. We later found that the “?” button in the hand unit was designed to allow students to give feedback (which no one actually uses). But each time the “?” button is pressed, one line is added to a spreadsheet generated automatically by Turning Point software. Students were able to overload the software by pressing “?” many times during voting. One solution of this problem is: in the Turning point add-on, click “Display setting” → “Presentation” → “allow user feedback”, choose “false”. By doing this, the software will not recognize user feedback, and thus will not freeze during voting.

4. The Turning Point software, which is integrated with Microsoft PowerPoint, is easy to use but not very stable. It constantly freezes when you try to make many commands during drawing a picture. Now we design all question slides in regular PowerPoint, and then convert them to Turning Point slides. One instructor has had zero program-not-responding problems while making and converting more than a hundred question slides.

5. Turning Point software has a function to make chosen pictures as answers but it is fragile. As shown in picture 3.8, the slides could stop working if you copy and
paste slides several times. It is also not reversible. If you want to add another choice, you have to start over and redo all the work. One way to solve this problem as shown in picture 3.9 is making the picture slide in PowerPoint, choosing a generic slide with answers A, B, C, etc, and then adding text “A”, “B”, “C”, etc near the pictures.

Which of the following graphs shows a capacitor discharging?

Picture. 3.8 An example of using picture as answers in turning point. Notice that Turning Point these arrows to point to the pictures. This slide is fragile and not changeable after being created.
3.6 Summary

This chapter starts with two examples of new technologies used in teaching physics: computer simulation and web-based homework. An introduction of clicker history, along with different types of clickers is followed with a discussion of how we chose and used the Turning Point system. Finally, a list of common questions and solutions during OSU clicker project has been summarized. It is hoped that these will be beneficial to instructors who want to use clickers in their lectures. Clicker question sequences will be discussed in Chapter 4 for those who are also interested in using our question sequences.

Picture. 3.9 One walk-around is pasting the picture first, then adding “A, B, C and D” as text.
References:


2005 N.W. Reay, L. Bao, P. Li and G. Baugh, "Toward the effective use of voting
machines in physics lectures, Am. J. Phys. 73, 554


2006 Davidson College, a link can be found at:
http://webphysics.davidson.edu/Course_Material/Py230L/optics/lenses.htm


2007 Albert Lee, private discussion.

2007 Carmen https://carmen.osu.edu/

2007 E-instruction www.einstruction.com

2007 I-clicker www.iclicker.com

2007 PRS http://www.gtcocalcomp.net/interwriteprs.htm

2007 Qwizdom www.qwizdom.com/

2007 Turning Point www.turningtechnologies.com
In this chapter, we will discuss our designing philosophy, and then give the question sequence examples. For each question sequence we will discuss students’ possible misconceptions and present voting summaries. The shift of answers between questions in one sequence will be discussed to validate our design hypothesis. Finally, a summary of all our clicker question sequences for Electromagnetism is listed. The polling results of the Electromagnetism question sequences presented in this chapter are based on the fall 2005 class, but the winter and spring 2006 classes show similar results. The polling results of the Mechanics and Wave course and the Optics and model physics course presented in this chapter are based on the “waves” quarter in spring 2006 and the “Mechanics” quarter in fall 2006.
Designing Methodology

We usually started by looking for students’ common misconceptions and difficulties in literature and from various instructors’ teaching experiences. We then designed questions based on these misconceptions and difficulties, using the pedagogies described in chapter 2. After using clicker question sequences in lectures, we modified our questions based on students’ responses, making sure there is no misunderstanding of the questions and also designing better distracters. We also corrected our understanding of students’ misconceptions and difficulties and then modified our questions based on this updated information. This design loop has been taken for several years. The question sequences in this thesis are updated through spring 2006.

In general, our designing methodology can be divided into four steps:

1. Looking for misconceptions and difficulties.

2. Designing questions to address misconceptions and difficulties.


4. Analyzing students’ response and modifying questions both to improve clarity and to replace poor distracters. This sequence is illustrated in Picture 4.1
4.1 Question sequences in Electromagnetism

4.1.1 Coulomb’s law and Electric field

Almost all courses in electromagnetism begin with an introduction of Coulomb’s law:

\[ F = \frac{kq_1q_2}{r^2} \]
In classical mechanics, it is well known that Newton’s third law in certain context settings provides a substantial barrier to the understanding of its meaning. Students often think that a larger, heavier object exerts more force than a smaller, lighter object [1992 Hestenes]. This can be thought of as a mental model that students form based on their everyday experience. We hypothesize this misconception can be carried on to the context involving charges.

After Coulomb’s law students study electric field, which is the first abstract concept in electromagnetism. Because students do not experience electric field, they develop several misconceptions.

Misconception 1:

Students interpret formulas as if the quantities mentioned to the right of the equal sign were the cause of those mentioned to the left. In the case of electric fields, we first introduce electric fields by using the equation:

\[ \vec{E} = \frac{\vec{F}}{q} \]

Students are often been asked to think of using charge \( q \) as a probe to determine if an electric field is present at a point in space. Many students think that test charge \( q \) is the cause of electric field. If there is no test charge, there will be no electric field [2003 Raduta].
Misconception 2

Because electric field is an abstract concept which students do not see or feel during real-life experiences, they have trouble understanding it. Frequently, they mix up the concept of force and electric field. When asked about the electric field, many students start with: “while, the force by charge A is going this way, the force by charge B is going that way, so the field is ……” Some of them continue to have trouble with electric field as a vector. They simply add the value of individual electric fields when they calculate the net electric field using superposition [1992 Viennot]. Based on these misconceptions, we designed a rapid-fire question sequence as shown in picture 4.2 involving both electrical force and electric field.

Tom places a negative charge at the top corner of the triangle to test the electric field produced by the +Q and –Q charges at the top of the triangle. What is the direction of the net force on the negative charge on the top?

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

Picture 4.2 the EField_RF sequence (continued)
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 direction of the electric field at the origin, as shown by the black dot. The electric field there points

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

(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

1. 
2. 
3. 
4. 
5.

This first question is the addition of electrical force. 66% of the students got the right answer (1). Students generally do not have trouble with force addition. Note that 10% of the students chose “the electric force is zero,” which means they still viewed force as a scalar.

The second question asks what the electric field is if we remove the test charge. This time, only 45% of the students chose the right answer (3). Twenty nine percent of the students choose: “the electric field is zero.” This could mean two possibilities: 1. Students think that the test charge is the cause of electric field. In other words, if you remove the test charge there will be no electric field [2003 Raduta]. 2. Students were still using the old habit of adding the value together. They continued to use electric field as a scalar [1992 L. Viennot]. After a careful look at the response data, we found that only 3
of these 29 students also chose “Net force is zero” in the previous question. This indicates that most of these students started using electric field as a vector, but had the misconception that test charge is the cause of the electric field.

Question 3 is the superposition of the electric field. Sixty eight percent of the students get the right answer (4). Twenty percent of the students thought the electric field was in the opposite direction. This may be because they still have trouble with “the electric field goes out from a positive charge and goes in to a negative charge”.

Question 4 is also about the superposition of the electric field. It is a harder question than question 3 because students not only needed to consider directions but also the magnitudes of the electric field. Ninety four percent of students got the right answer, which indicates that students may have corrected their misconceptions. After working through the first three problems, most of the students could effectively use superposition of the electric fields.

4.1.2 Electric field integration

Even the best students have trouble with electric field integration problems. Most of their difficulties come from setting up the integral. Researchers found that the total cognitive load is too high for many students at the transition from the mathematics form to physics problems [2006 Manogue]. To probe where most students have difficulty, we divided integration into several steps and designed a rapid-fire question sequence as shown in picture 4.3.
A total charge $Q$ is uniformly distributed over the length $L$ of a line charge distribution. The charge density $\lambda$ per meter of length is given by

\[ \lambda = \left( \frac{Q}{L} \right) dx \]

1. $\frac{Q}{L}$
2. $\left( \frac{Q}{L} \right) dx$
3. $\frac{L}{Q}$
4. $Q$
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 created by a short element $dx$ is given by

1. $\frac{KQ}{L} \frac{dx}{r^2} \times \frac{a}{r}$

2. $\frac{KQ}{L} \frac{dx}{r^2} \times \frac{x}{r}$

3. $\frac{KQ}{L} \frac{dx}{r^2} \times \frac{a}{x}$

4. $\frac{KQ}{L} \frac{dx}{r^2} \times \frac{x}{a}$
The first question asks about linear charge density. Sixty four percent of the students chose the right answer (1). The fact that 31% of the students chose answer (2) shows that they had trouble distinguishing charge density and total charge inside a small element. After a brief discussion, 93% of the students chose the right answer in the second question. The third question asks about the Y component of electric field created by a short element. This time the answer pattern resembled a random guess, only 34% of the students chose the right answer (1). The fact that there is no preferred wrong answer shows that students do not have a misconception in electric field integration. What they are lacking are skills and experiences that they can rely on to carry their cognitive load at the transition from the mathematics form to physics problems. After peer discussion, 74% of the students chose the right answer during a revote, which is still unsatisfactory.

4.1.3 Charge distribution

One of the difficulties students have while studying electromagnetism is charge distributions on conducting surfaces such as a sphere. Most students realize that the electric field inside a conductor is zero. However, they cannot figure out the charge distribution using this principle [1997 Guraswamy]. We designed an easy-hard-hard question sequence based on these difficulties as shown in picture 4.4:

The first question is easy; students can simply get the right answer using symmetry, and ninety nine percent of the students chose the right answer. The second question is hard. Students needed to first determine the charge distribution on the inner surface using the electric field inside a conductor is zero. So there will be more negative charges near
the off-center positive charge. Then, because the electric field inside the conductor is zero, the inside charge can not exert force on the outside charge. This is the “shielding effect”. Only 12% of the students chose the right answer A. More than 70% of the students chose answer B and C. An extended discussion followed. In the third question, the charge was brought from the outside, but the conducting sphere still acted as a shield. A strong majority (90%) of the students selected the right answer.

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]
5. ![Diagram 5]

*Picture 4.4 the EFieldSpheres_3Q sequence (continued)*
The positive charge is now moved and kept fixed 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. 

2. 

3. 

4. 

5. 

The positive charge $+Q$ is now kept fixed at the center of a spherical neutral conducting shell. A negative charge $-Q$ is brought near the outside of the sphere. Which of the following represents the charge distributions?

1. 

2. 

3. 

4. 

5. 

90%
4.1.4 Equipotential Surface

Students have difficulty understanding the concept of equipotential surfaces. This may be caused by the fact that equipotential surfaces are an abstract concept which students can not see or feel in their real life. David P. Maloney [2001 Maloney] found that students do not seem to be able to deduce the direction of the electric field from a change in potential, and confuse whether an increase or a decrease in potential determines direction. Thus, we designed a rapid fire question sequence as shown in picture 4.5 to help students understand equipotential surfaces.

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.

Picture 4.5 the EquiPotentialSurface_RF sequence (continued)
What is the amount of work needed by external force to move an electron from B to C?

1. 0 eV
2. 100 eV
3. -100 eV
4. -50 eV
5. 50 eV

What is the amount of work needed by external force to move an electron from D to C?

1. 0 eV
2. 200 eV
3. 100 eV
4. 50 eV
5. -100 eV
6. -200 eV
Which set of equipotential surfaces matches this electric field?

1. 2. 3. 4. 5. 6.

Which set of arrows best describes the relative magnitudes and directions of the electrical fields at points A and B?

0% 1. A → B →
6% 2. A → B →
2% 3. A ← B ←
77% 4. A → B ←
13% 5. A → B ←
2% 6. A → B →
In the first question equipotential surfaces were given, and students were asked to deduce how a charge moves. This kind of problem can be solved in two ways. Students can determine the direction of electric field first, and then determine the force. They can also use energy, the charge will move to the position where it has lower potential energy. We can see that 56% of the students chose the right answer 1. The fact that about 24% of the students chose 2 indicates that these students may still be associating a constant velocity with a constant force. Seventeen percent of the students chose 3, which implies that they made a mistake in the direction of the field or the sign of energy.

The second question concerns the work supplied by an external force when moving the charge. Sixty nine percent of the students chose the right answer 3. The fact that 20% of the students chose 2 indicates students may not distinguish between the work done by the electrical force and the work done by the external force. They also may have neglected the negative sign of the electron. Ten percent of the students chose 1. This can be a random guess or very possibly a student’s confuse of moving along the equipotential surface with moving perpendicular to the potential surface. This also indicates that most students do believe that no work is needed if you move charge along the equipotential surface.

In the third question, we kept the potential difference between B and C the same but doubled the distance. We then asked the work done by the external force when moving an electron from D to C, where D is a point on the same potential surface of B. Sixty nine percent of the students chose the right answer 5. Twenty four percent of the students doubled the work done by the external force. This indicates that some students still had
trouble with the relationship between electric field and potential. They did not realize that because the potential difference does not change, the work does not change. The electric field between B and C actually decreases to half compared to the field in question 2.

The fourth question gives the direction and magnitude of the electric field and asks students to pick the right distribution of equipotential surfaces. Students need to know two concepts: 1. the electric field always goes from high potential to low potential. 2. Stronger field means that equipotential surfaces are closer together. Only 41% of the students chose the right answer. Thirty six percent of the students choose answer 4, which indicated that they only considered the fact that stronger field means that equipotential surface will be spaced more closely. Twenty percent of the students chose answer 5, which indicated that they only considered the direction of the electric field.

Question 5 is the opposite of question 4, we gave students equipotential surfaces, and asked them to pick the right electric field. This time, more students considered both aspects. Seventy seven percent of the students picked the right answer. A few (13%) of the students had trouble with stronger electric field means more closely packed equipotential surfaces.

4.1.5 Electric field is a vector, electric potential is a scalar

One of the common mistakes students make when studying Electromagnetism is that they can not distinguish between electric field and potential [1995 Galili]. Electric field is a vector; electric potential is the integration of electric field along a certain path,
hence is a scalar. We designed a rapid-fire sequence as shown in picture 4.6 to specifically address this difference.

The point P is in the middle between two charges +Q and –Q. What is the electric potential at point P?

1. 0
2. \( \frac{kQ}{R^2} \)
3. \( 2\frac{kQ}{R} \)
4. \( 2\sqrt{2}\frac{kQ}{R} \)
5. \( 2\frac{kQ^2}{R} \)
6. \( \frac{kQ}{R} \)
7. None of the above

*Picture 4.6 the EvsV2_3Q sequence (continued)*
The point P is in the middle between two charges \(+Q\) and \(-Q\). What is the magnitude of \textbf{the electric field} at point P?

1. 0
2. \(kQ/R^2\)
3. \(2kQ/R^2\)
4. \(2\sqrt{2} \, kQ/R^2\)
5. \(2kQ/R\)
6. \(kQ/R\)
7. None of the above

P is in the middle of four charges with values \(+Q\) or \(-Q\) as shown. The distance from each charge to P is R. What is the \textbf{electric potential} at point P?

1. 0
2. \(kQ/R\)
3. \(2kQ/R\)
4. \(2\sqrt{2} \, kQ/R\)
5. \(2kQ^2/R\)
6. \(4kQ^2/R\)
7. None of the above
P is in the middle of four charges with values $+Q$ or $-Q$ as shown. The distance from each charge to P is R. What is the magnitude of the electric field at point P?

1. 0
2. $kQ/R^2$
3. $2kQ/R^2$
4. $2\sqrt{2}kQ/R^2$
5. $2kQ/R$
6. $4kQ/R$
7. None of the above

The first question asks about the potential in the middle of two equal but opposite charges. Forty percent of the students chose right answer (1). However, 30% of the students chose distracter (3), which is exactly as if they treated potential as a vector. The instructor then had a discussion with students about the fact that electric field is a vector and electric potential is a scalar. After discussion, 81%, 90% and 86% of the students chose the right answer in questions 2, 3 and 4 respectively.
4.1.6 Redrawing circuits to figure out the relationship between circuit elements

Students frequently have trouble with circuits. Reay [2005 Reay] found that students frequently were confused if they could not immediately redraw an electrical circuit so that its elements were either in series or parallel. Tracing wires to see how elements were placed into circuits was not a popular strategy. We designed an easy-hard-hard sequence which is easy to answer by tracing wires, but quite difficult to convert to series and parallel circuit component. This sequence is shown in picture 4.7.

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.

![Circuit Diagram]

1. V/R
2. V/2R
3. V/3R
4. 2V/R
5. 3V/R

*Picture 4.7 the TracingWires_3Q sequence (continued)*
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. A similar question was used at a high school Science Olympiad.

1. V/R
2. V/2R
3. V/3R
4. 2V/R
5. 3V/R

Consider the circuit given below. Again, 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. This is similar to another Science Olympiad question.

1. V/R
2. V/2R
3. V/3R
4. 2V/R
5. 3V/R
Consider the circuit given below. Again, 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.** This is similar to another Science Olympiad question.

1. $V/R$
2. $V/2R$
3. $V/3R$
4. $2V/R$
5. $3V/R$

In the first question, the bare wire shorts out two of the resistors, so the correct answer is $V/R$. The fact that 91% of the students chose the right answer indicates that most students understand the concept “short”.

In the second question, all three resistors are in parallel, and the correct answer is $3V/R$. Seventy eight percent of the students actually chose answer $V/R$. This indicates that the students having trouble redrawing the circuit, and may have made an educated guess. The lecturer then traced the wires under the direction of the students, to determine how each particular resistor was connected in the circuit.
The third problem at first seems different than the first two. However, the resistor on the right-hand side is shorted out as occurred in the first question, and the other three resistors are in parallel as in the second question. The correct answer is again $3V/R$. This time, 40% of the students voted for the correct answer, which indicates students benefited from the discussion of question 2, but many students still may have had difficulty tracing wires as 24% of the students choose answer $2V/R$. After peer discussion, 69% of the students chose the right answer during the revote. 17% of the students choose $2V/R$, which indicates that some students still needed additional practice on tracing wires.

### 4.1.7 Capacitors in parallel or Series

Many students have trouble with capacitors in parallel or series. The fact that capacitors in parallel (series) have the opposite relation as compared to resistors in parallel (series) initially is difficult for students. They are particularly confused by the facts that two capacitors in series have the same charge, and the equivalent capacitor has the same charge as either one of the capacitors in the serial circuit. We designed the following easy-hard-hard as shown in picture 4.8 sequence to address this issue.

Students can get the first question by simply using $Q=CV$. 88% of the students selected the right answer (2). The second question is hard. Students need to first find that equivalent capacitor of $C_2$ and $C_3$, which is 1.2 microfarads. They then need to realize that the equivalent capacitor has the same charge as either one of the capacitor in the serial circuit. Thus the correct answer is (4). The fact that only 59% of the student picked the right answer after the instructor gave some hints indicates that many students had
difficulty with understanding capacitors in series. The third question is an extension of the second question. Students need to realize that $C_2$ and $C_3$ have the same charge, thus the one with a bigger capacitance will have a smaller voltage, since $Q=CV$. Only 64% of the students chose the right answer, and additional discussion was required.

$V$ is 10 volts, and $C_1$, $C_2$ and $C_3$ are 1, 2 and 3 microfarads, respectively. The charge on $C_1$ is

1. $5 \mu C$
2. $10 \mu C$
3. $15 \mu C$
4. $20 \mu C$
V again is 10 volts and $C_1$, $C_2$, and $C_3$ and 1, 2, and 3 microfarads, respectively. The charge is \textit{greatest} on which capacitor?

1. $C_1$
2. $C_2$
3. $C_3$
4. $C_2$ and $C_3$

(Continued)
4.1.8 Magnetic fields created by Currents

Many students have difficulty visualizing magnetic fields as created by currents. The fact that magnetic fields circle around the current requires students to visualize in 3 dimensions. We designed a rapid-fire sequence as shown in picture 4.9 to probe students’ difficulties on this concept.

The first question asks about the direction of the magnetic field at a point exactly in the middle between two parallel wires. 51% of the students chose the right answer (1). The fact that 41% of the students chose answer (5) shows that many of the students did not know how to use the right-hand rule, so they guessed that the magnetic field created by two wires with currents traveling in opposite directions cancelled each other.

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 in
2. Goes out
3. Goes left
4. Goes right
5. There is no magnetic field at point P.

*Picture 4.9 the BFieldRHR_RF sequence (continued)*
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 in
2. Goes out
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 in
2. Goes out
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 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

The second question is hard. Student need to consider both the magnitude and direction of the magnetic field. Only 31% of the students chose the right answer “goes out”. 29% of the students picked answer “goes in”, they may think that a longer wire will create a larger magnetic field. 39% of the students selected answer “the field is zero”, which indicates that they did not consider magnitude at all. After peer discussion, 65% of the students chose the right answer during the revote, which means that additional instruction was still needed. The third question is an extension of the second question. The fact that 71% of the students picked the right answer shows that most students know how to determine the direction and estimate the magnitude of the magnetic field created by the current.
4.1.9 Ampere’s Law

Students frequently have difficulty interpreting Ampere’s law. This may come from the requirement of line integration, since any integration problem in physics is difficult for students. Corinne A. Manogue [2006 Manogue] found that the total cognitive load is too high for many students at the transition from the mathematics form to physics problems. Students also have a common misconception that the current enclosed has to be the current perpendicular and inside the Ampere’s loop. The current enclosed is any current passing through the loop, so the angle between the current and the loop does not make any difference. An easy-hard-hard sequence was designed as shown in picture 4.10 to target this misconception.

An Amperian loop is drawn around two current carrying wires as shown below. What is the value of $\int B \, ds$ around the loop?

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

*Picture 4.10 the AmpereLaw_3Q sequence (continued)*
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 $\int B \cdot d\vec{s}$ around the loop?

1. $\mu_0 I$
2. $\mu_0 I \sin(\theta)$
3. $\mu_0 I \cos(\theta)$
4. $m_0 I \tan(\theta)$
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 in places folded over, 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 $\int B \cdot d\vec{s}$ 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. $\mu_0 (I_2 - I_1)$

(Continued)
In the first question, current $I_1$ and $I_2$ are in the opposite directions. 76% of the students chose the right answer 3. In the second question, only 10% of the students chose the right answer, 50% of the students chose $I \cos(\theta)$ which indicates that they believe that the current enclosed in the Ampere’s loop is the current perpendicular to the loop. The third question is a combination of the first question and the second question. This time 62% of the students voted for F, the correct answer, and 34% for E, which was almost correct, but did not take into account that the path of the loop around current 1 was reversed. Question 3 revealed that additional work is needed.

4.1.10 Using the right hand rule for forces on charged particles moving in a magnetic field

Students usually need practice to get familiar with the right hand rule. There are several common misconceptions:

1. The forces that the students have learned were always along the direction of the two objects. So they tend to just make force along the field. [2003 Raduta]

2. Magnet charge will attract or repel charges. [1985 Maloney]

3. In the Lorentz force expression, the velocity and the magnetic field must be perpendicular to each other. [2003 Raduta]
We designed a rapid-fire sequence as shown in picture 4.11 to give students practice in using the right hand rule for forces on charged particles moving in a magnetic field.

A permanent magnet has field lines as shown above. An electron moves out of the slide toward you at point A. The magnetic force on the electron is best represented by:

*Picture 4.11 the ChargedParticle_in_BField_RF sequence (continued)*
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 at point C. The magnetic force on the electron is best represented by:

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

(Continued)
A proton is at rest at point D. The magnetic force on the proton is best represented by:

The question sequences was given right after students had heard the right hand rule discussed, and was the first time that they actually practiced it themselves. In the first question, only 23% of students correctly selected answer (4), while an additional 35% of students selected answer (3), which indicates that they ignored the electron’s negative charge. In the second question, 63% of students correctly selected answer (5). In the third question, 73% of students correctly selected answer (6), even though students generally find it difficult to select “none of the above” unless they feel that they really understand the concept. In the last question, almost 99% of students answered the correct answer. The monotonically increasing percentage of correct answers is a characteristic pattern for rapid-fire question sequences.
4.1.11 Faraday’s Law

Students viewing Faraday’s Law for the first time have difficulty differentiating between magnetic flux and the rate of change of magnetic flux. As a result they may connect larger induced voltages to larger loops rather than to the rate of change of flux in a loop [2001 Maloney]. The following three-question set as shown in picture 4.12 was developed primarily to address this difficulty.

This first question is an easy question, because the largest loop also has the largest rate of flux change. 82% of the students selected answer (3), the correct answer. However, some students may choose this answer because they believed that larger loops result in larger induced voltages. The second question reveals whether they really understood that electromotive force depends on the rate of changing flux. 59% of students correctly selected (4), but 30% of students selected (2), which connects the emf generated directly to the total area of the loops. The third question assumed that if students really understand Faraday’s Law they, they should be able to apply it to different loop shapes even though the book and homework problems concentrated on rectangular loops. It also brings in graphs, which is a second barrier. 62% of students correctly guessed answer (1), but 24% of students selected answer (5), which meant that additional discussion was required. More than 90% of students switched to answer (1) after peer discussion with neighboring students, even though the right answer was not yet revealed.
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 after 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

*Picture 4.12 the LenzsLawRanking_3Q sequence (continued)*
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. \[ \varepsilon \]

4.2 Question sequences in Mechanics

4.2.1 Newton’s first Law

One of student’s major conceptions from their daily experience is that force is the cause of movement [1987 Gunstone]. We designed an easy-hard-hard question sequence as shown in picture 4.13 to specially address this misconception.
A block sits **at rest** on a frictionless surface. Which of the following sketches most closely resembles your freebody diagram for all forces acting on the block? Each red arrow represents a force. Observe their number and direction, but ignore their lengths.

![Freebody Diagrams](Image)

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

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

![Freebody Diagrams](Image)

1. A
2. B
3. C
4. D
5. None of the above
Now, the block moves with a **constant** velocity **to the right** on a surface **that has friction**. Which of the following most closely resembles your freebody diagram for all forces acting on the block? Can you attach names to these forces?

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

The first question asks students to draw a free-body diagram of a block at rest. 94% of the students chose the right answer. The second question asks for a free-body diagram of a block with constant velocity. The fact that 50% of the students chose the major distracter (2) indicates that half of the students may have the misconception that force is the cause of motion. The third question is an extension of the second question. It asks the free body diagram when the block is moving with constant velocity on a surface with friction. 58% of the students chose the right answer. 42% of the students chose answer (1), which indicated that they still had trouble with Newton’s first law.
4.2.2 Free-body diagram analysis

Many students tend to use their intuitive or daily experience when they are working on free-body diagram analysis [1985 Halloun]. To help students form a habit of using free-body diagrams, we designed an easy-hard-hard question as shown in picture 4.14.

A block sits at rest on a slide with non-zero friction. Which of the following sketches most closely resembles your freebody diagram for all forces acting on the block? Each red arrow represents a force. Observe their number and direction, but ignore their lengths.

![Free-body diagram analysis question](image)

*Picture 4.14 the Free_body Analysis sequence (continued)*
The block sits at rest on the slide. What is the direction of the sum of all forces, *i.e. the resultant force*, that the block exerts on the slide?

![Diagram of a block on a slide](image)

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

![Diagram of a block on a slide](image)

1. Moves to the right
2. Moves to the left
3. Doesn’t move
4. Can move either way.
The first question asks about the free body diagram for a block at rest on a slide. 82% of the students chose the right answer. The second question asks the direction of the sum of all forces that the block exerts on the slide. Only 38% of the students selected the right answer (A) even after they had the free-body diagram from the first question. 43% of the students picked the answer (B), which is based on students’ intuitive and daily experience. The third question asks where the slide will go if there is no friction between the slide and the ground. Only 61% of the students chose the right answer “Doesn’t move”. There are still 31% of the students who chose “Moves to the right”, which is from their intuitive and daily experiences. Responses to this question sequence indicate that students prefer using intuitive and daily experiences instead of using free-body diagrams when analyzing motion.

4.3 Question sequences in Waves, Optics and Model Physics.

4.3.1 Wave traveling along a string

Many students know how to plug the wave speed equation \( V = \sqrt{\frac{T}{\mu}} \). In our teaching experience, one of the most common misconceptions for wave traveling on a string is that students do not realize that frequency, as a property of the wave, does not change during traveling. This can be extended from an impulse traveling on the strings to light traveling in different mediums. We designed an easy-hard-hard question as shown in picture 4.15 to specifically address this misconception.
Two strings with different unit mass are tied together as shown. What is the ratio of the wave’s speed in the two strings?

\[ \frac{V_1}{V_2} = \frac{3}{5} \]

1. \( \frac{V_1}{V_2} = \frac{9}{25} \)
2. \( \frac{V_1}{V_2} = \frac{3}{5} \)
3. \( \frac{V_1}{V_2} = \frac{25}{9} \)
4. \( \frac{V_1}{V_2} = \frac{5}{3} \)
5. \( V_1 = V_2 \)

Two strings with different unit mass are tied together as shown. What is the ratio of the wave’s frequency in the two strings?

\[ \frac{f_1}{f_2} = \frac{3}{5} \]

1. \( \frac{f_1}{f_2} = \frac{9}{25} \)
2. \( \frac{f_1}{f_2} = \frac{3}{5} \)
3. \( \frac{f_1}{f_2} = \frac{25}{9} \)
4. \( \frac{f_1}{f_2} = \frac{5}{3} \)
5. \( f_1 = f_2 \)
Two strings with different unit mass are tied together as shown. What is the ratio of the wave’s frequency in the two strings?

\[
\frac{f_1}{f_2} = \frac{9}{25}
\]

1. \( \frac{f_1}{f_2} = \frac{9}{25} \)
2. \( \frac{f_1}{f_2} = \frac{3}{5} \)
3. \( \frac{f_1}{f_2} = \frac{25}{9} \)
4. \( \frac{f_1}{f_2} = \frac{5}{3} \)
5. \( f_1 = f_2 \)

Two strings with different unit mass are tied together as shown. What will waves look like in the two strings?

A. [Wave diagram A]
B. [Wave diagram B]
C. [Wave diagram C]
D. [Wave diagram D]
The first question is simply plugging in the formula, and 70% of the students chose (4) as the right answer. 17% of students picked (2), which seems an algebraic mistake. The second question asks about the frequency in two different strings. Only 45% of the students selected the right answer (5), which indicates that believing frequency will change during wave’s propagation is a common misconception. Further, the fact that only 66% of the students picked the right answer even after peer discussion shows that “frequency change” is a strong misconception. The third question is an extension of the second question, and 92% of the students chose the right answer.

4.3.2 Convex and Concave lens

Many students have difficulties with ray tracing for convex and concave lenses. One of the most common practices when students study convex and concave lens is simply plugging numbers into equations [1987 Goldberg]. We found that drawing three special light trajectories is particularly helpful for students to understand the physics principles behind convex and concave lens. Based on this, we designed a rapid-fire sequence as shown in picture 4.16 to probe students’ difficulties.
For the figure below, determine the type of lens and sign of the magnification $M$.

1. Convex Lens, $M$ is positive
2. Convex Lens, $M$ is negative
3. Concave Lens, $M$ is positive
4. Concave Lens, $M$ is negative

Same figure: determine the type of image and compare the absolute size of the object and image.

1. Real image, object bigger than image
2. Real image, object smaller than image
3. Virtual image, object bigger than image
4. Virtual image, object smaller than image

*Picture 4.16 the Ray Tracing sequence (continued)*
For the figure below, determine the type of lens and sign of the magnification $M$.

1. Convex Lens, $M$ is positive
2. Convex Lens, $M$ is negative
3. Concave Lens, $M$ is positive
4. Concave Lens, $M$ is negative
Same figure: determine the type of image and compare the absolute size of the object and image.

1. Real image, object bigger than image
2. Real image, object smaller than image
3. Virtual image, object bigger than image
4. Virtual image, object smaller than image

For the figure below, determine the type of lens and sign of the magnification M.

1. Convex Lens, M is positive
2. Convex Lens, M is negative
3. Concave Lens, M is positive
4. Concave Lens, M is negative
Same figure: determine the type of image and compare the absolute size of the object and image.

1. Real image, object bigger than image
2. Real image, object smaller than image
3. Virtual image, object bigger than image
4. Virtual image, object smaller than image

The first question asks students to determine the type of lens and the sign of the magnification $M$. This usually is the first case studies, and 87% of the students chose the right answer (2). The second question asks students to determine the type of image and compare the absolute size of the object and image. 61% of the students picked the right answer. The fact that 35% of the students selected answer (1) shows that many students still had trouble using ray tracing to determine the size of the image. The third question is a case where the object is inside the focal length of a convex lens. The fact that 79% of the students chose wrong answer (3) shows that most students were not familiar with this case. They simply picked concave lens once they see the rays do not converge. After a brief instruction, 87% of the students picked the right answer during the revote. The
fourth question asks students to determine the type of image and compare the absolute size of the object and image. 79% of the students chose the right answer (4), but 18% of the students selected “object bigger than the image”, which shows that some students were still having trouble with how to determine the size and location of the image [1987 Goldberg]. The fifth and sixth questions are cases for concave lenses. Most students chose the right answer. The fact that only 82% of the students picked the right answer (3) in the sixth question shows that the location and size of the image is a common difficulty for students. Even after six questions and associated discussions, some students still had trouble with the location and size of the image.

4.4 Summary

The use of question sequences has shown a promising pattern of student learning pathways. Many of the question sequences are based on a particular students’ misconception or try to probe students’ specific difficulties during learning a concept. After three years of question designing and testing, we have a complete set of question sequences in Electromagnetism. A list of Electromagnetism questions with their subjects and contents are listed in table 4.1.
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<td>EField_RF</td>
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<td>TracingWires_3Q</td>
<td>Using tracing wire method to simply circuits</td>
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Table 4.1 A list of Electromagnetism questions and their subjects and contents (continued)
Table 4.1 (continued)

<table>
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<th>Current does not need to be perpendicular to the loop</th>
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<td>LenzsLawRanking_3Q</td>
<td>Practice of Faraday’s law</td>
</tr>
</tbody>
</table>

We also have designed many questions in Mechanics, and Waves, Optics and modern physics. They are not as complete, well tested and modified as the electromagnetism sets. Building complete sets for the calculus-based introductory physics will be a future goal for our research.

The increasing numbers of correct answers in polling results suggest that using clickers and question sequences in the lecture not only increase students’ interaction but also help students learn concepts. There also is a promising indication that the students using clicker devices and question sequences tended to perform better on concept-oriented questions. This will be discussed in the next chapter.
References:


2005 N.W. Reay, L. Bao, P. Li and G. Baugh, "Toward the effective use of voting machines in physics lectures, Am. J. Phys. 73, 554

CHAPTER 5

RESULTS OF A CONTROLLED QUANTITATIVE STUDY

In this chapter the results of a year-long controlled quantitative study will be presented. The main goal of this research was to determine whether using clickers helps students learn and whether students perceive that clicker has a positive effect on their own learning process. These questions can be further divided into several research questions:

1. Whether students using clickers perform better on Concept Survey on Electricity and Magnetism (CSEM) [2001 Maloney].

2. Whether students using clickers perform better on common exam questions.

3. Do students benefit differently from different types of questions? Do “easy-hard-hard” sequences and “rapid-fire” sequences have the same benefit on students with different academic levels?

4. Is there a difference in performance between male and female students when using clickers?

5. Whether students perceive that clicker has a positive effect on their own
learning process.

The answers to the first four of the above questions were answered using a variety of tests that compared the clicker lecture section to a lecture section with a similar population of students taught without clickers in a traditional manner. The last question was answered using an end-of-quarter attitude survey in all clicker sections. In this chapter, the research methodology will be presented and research results will be analyzed. Quantitative analysis shows that during three quarters of testing, clicker sections consistently scored higher than non-clicker sections both on common examination questions and on post-quarter concept inventories. Results also show that female students seem benefit more from the use of clicker than male students. In addition, results show that students with a better academic level benefit both from the “easy-hard-hard” sequences and “rapid-fire” sequences; while students with lower academic level seem benefit only from “rapid-fire” sequences. Finally, end-of-quarter surveys indicate that students enjoyed using clickers, and believed that this tool helped them learn. These surveys also suggested that attaching credits to clicker responses and/or overusing clickers may lower student enthusiasm.

5.1 Research context

A three-quarter (fall, winter and spring) test was conducted in the year-long calculus-based introductory physics course (E & M section) at The Ohio State University. Because Ohio State has many students, the same E & M course is taught
in two lecture sections during each quarter. Only one of the two lecture sections used clickers. A total of approximately 40 question sequences consisting of 130 individual questions were used to cover all major E & M topics. Voting and subsequent discussions occupied less than 20% of the total lecture time in fall and winter quarters. As the lecturer added a considerable number of his own questions in addition to question sequences designed for this study, more than 40% of the total lecture time was used for clickers in the spring, Non-clicker lecturers had access to question sequence material, but otherwise taught in a traditional manner.

We attempted to make sure that clicker and non-clicker lecture sections devoted the same time to each concept, but this was difficult to manage. In fall quarter, it was regulated by class observation and by weekly discussions between the clicker and non-clicker lecturer. Lecturers in winter and spring quarters used the same book and the same syllabus, but were less tightly controlled.

All lecture sections were separately graded on a curve with mean grades ranging from C+ to B-. Recitation teaching assistants, questions and teaching methodologies were the same for all lecture sections, homework was almost identical, and students from clicker and non-clicker lecture sections were mixed into common laboratories. All the above managements were executed to make sure that using clickers was the single intervention between these two sections.
5.2 Research question 1

1. Do students using clickers have better performances on Concept Survey on Electricity and Magnetism? (CSEM) [2001 Maloney].

The Conceptual Survey of Electricity and Magnetism (CSEM), developed by physics education researchers, is a widely used tool to assess student’s knowledge about topics in electricity and magnetism. The survey is a 32-question, multiple-choice test that can be used as both a pretest and posttest. Comparing students’ performances on CSEM between clicker section and non clicker section helped us understand the effectiveness of using clickers in lectures.

5.2.1 Research Design

At the Ohio State University, the CSEM test was taken in a calculus-based introductory physics course to evaluate the effectiveness of instruction. For two years, the CSEM test was administered in the lab without giving students any credit. Students took the pretest at the beginning of the first lab in the second week and posttest at the beginning of the final lab in the last week. The average pre test score was 11.32, and the average for each quarter ranged from 10.74 to 11.86. The average post test score was 15.17, and the average for each quarter ranged from 14.47 to 15.72. The average gain for each quarter was 3.86, and the average gain for each quarter ranged from 3.46 to 4.48 as shown in table 5.1.
Table 5.1 CSEM pretest, posttest, and gain results for the 03-05 academic years.

Note that the errors for the summer quarters are higher than those of other quarters because these quarters have fewer students.

The ANOVA test gives a P-value of 0.696, which means that there are no significant differences between gains for these eight quarters. A fitting between the density function of the two-year data and a Gaussian distribution also shows that the distribution of students’ gains is almost normal (as shown in figure 5.1). Therefore, the two lecture sections in a given quarter can be treated as two equivalent random samples from a single population.
Figure 5.1 A fitting between the density function of two-year data and a Gaussian distribution.

In our research, students took pre and post CSEM inventories administered in the same manner for clicker and non-clicker lecture sections in each quarter. However, there are two issues in our test design. The first issue is that the timing of the exams and incentives offered for taking them varied between quarters. The uncontrolled timing and incentives were largely due to the departmental course structure change and instructor preferences.
In fall 2005, students took the pretest in the first lab, when they already had three or four lectures. Students took the posttest in the final lab, and no incentives were given. Because students were allowed to drop the final lab, about 20% of students actually did not take the posttest. In winter 2006, the pretest was given in the first recitation before any instruction. Students were offered a small number of points for taking the post-test without regard to their scores. As a result, only 10% of the students did not take the posttests. In spring 2006, the pretest was also given in the first recitation, but this time students already had attended one lecture. Students were told that their CSEM score, only if sufficiently high, would be appropriately scaled and would replace their lowest quiz score. This time, about 35% of the students did not take the posttest.

Another issue is the low lecture attendance, which is typical at OSU and also common among universities similar to OSU. This introduced another uncertainty, since our treatment in this design is solely in the lectures. Clicker responses were not graded in fall and winter quarters, so there were no score-based incentives for students in clicker sections to attend class. The average clicker-lecture-section attendance was 75% in the fall, and 50% in the winter quarter, respectively. In spring quarter the clicker class was at 8:30 AM, so clicker responses were graded to enhance attendance. The average clicker-lecture-section attendance was 70%. Attendance in non-clicker sections averaged 10 to 15% lower than attendance in clicker sections. The impact on student learning due to attending lectures is not addressed and was not controlled.
Some preliminary research was conducted to investigate the impact on student learning due to attending lectures. One method is to compare the CSEM gains for the students who went to class regularly and students who did not. Table 5.2 shows the CSEM gains for the students who went to class regularly and students who did not in fall 2005 class. As shown in figure 5.2, results from spring 2007 first midterm also indicate that students who went to class regularly have better exam scores [2007 Lee].

<table>
<thead>
<tr>
<th>Groups</th>
<th>Numbers</th>
<th>CSEM raw gain</th>
<th>T-Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Students who went to class regularly</td>
<td>73</td>
<td>6.85 ± 0.59</td>
<td>P=0.002</td>
</tr>
<tr>
<td>Students who did not go to class regularly</td>
<td>25</td>
<td>3 ± 0.92</td>
<td></td>
</tr>
</tbody>
</table>

*Table 5.2 Students who went to class regularly have significantly better gains than students who did not go to class regularly.*
Figure 5.2 Students’ midterm scores versus their clicker usage for the first midterm of spring 2007[2007 Lee].

The concern in this study is that a significant portion of students in the clicker section did not actually receive the intended treatment. Therefore, the signals obtained were “noised” downward.

It is well known that that the manner of administering conceptual tests can sometimes impact test results, depending on the content of the test and the course structure. However, there have not been documented results on how certain administering variables may impact CSEM pre-post test results. Evidence of such impact will be discussed in the analysis section.
This test has some controlling variables issues. However, in field testing under real education settings, such constraints are often inevitable. Therefore, the result from this experiment is still a valuable piece of information which will help researchers and instructors understand how clicker-based methods perform in real teaching environments.

5.2.2 Results and Analysis

Results for CSEM pre and post testing and the standard error of each section are shown in Table 5.3. The results are raw scores out of 32. The percentage of students who took both the pre and post test are shown in table 5.4.

<table>
<thead>
<tr>
<th>Quarter</th>
<th>VM Section</th>
<th></th>
<th></th>
<th>Non-VM Section</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-Test</td>
<td>Post-Test</td>
<td>Gain</td>
<td>Pre-Test</td>
<td>Post-Test</td>
<td>Gain</td>
</tr>
<tr>
<td>Fall</td>
<td>12.1</td>
<td>17.9</td>
<td>5.8</td>
<td>11.2</td>
<td>15.6</td>
<td>4.4</td>
</tr>
<tr>
<td></td>
<td>(± 0.36)</td>
<td>(± 0.57)</td>
<td>(± 0.52)</td>
<td>(± 0.43)</td>
<td>(± 0.55)</td>
<td>(± 0.41)</td>
</tr>
<tr>
<td>Winter</td>
<td>9.3</td>
<td>15.8</td>
<td>6.5</td>
<td>9.3</td>
<td>15.0</td>
<td>5.7</td>
</tr>
<tr>
<td></td>
<td>(± 0.25)</td>
<td>(± 0.35)</td>
<td>(± 0.34)</td>
<td>(± 0.29)</td>
<td>(± 0.47)</td>
<td>(± 0.42)</td>
</tr>
<tr>
<td>Spring</td>
<td>10.9</td>
<td>19.7</td>
<td>8.8</td>
<td>8.9</td>
<td>17.6</td>
<td>8.7</td>
</tr>
<tr>
<td></td>
<td>(± 0.44)</td>
<td>(± 0.64)</td>
<td>(± 0.69)</td>
<td>(± 0.34)</td>
<td>(± 0.50)</td>
<td>(± 0.51)</td>
</tr>
</tbody>
</table>

Table 5.3 exhibits pre and post-tests results for the three quarters where clickers were used. For comparison, scores for pre/post CSEM tests that were given in 2nd week/last week laboratories for two previous non-clicker years (16 lecture sections) of the same course averaged 11.3/15.2.
<table>
<thead>
<tr>
<th>Quarter</th>
<th>(Pre+post)/total VM</th>
<th>(Pre+post)/total Non-VM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fall</td>
<td>98/130 (75.4%)</td>
<td>98/126 (77.7%)</td>
</tr>
<tr>
<td>Winter</td>
<td>162/184 (88%)</td>
<td>174/193 (90%)</td>
</tr>
<tr>
<td>Spring</td>
<td>57/76 (75%)</td>
<td>95/157 (61%)</td>
</tr>
</tbody>
</table>

Table 5.4 the ratio between the number of students who took both pre and post CSEM tests and the total number of students who took the final exam.

In fall 2005, the pretest was taken in the first lab and the posttest was taken in the final lab, which is the same time frame as for historical data from the two previous years. The pre (post) test scores of 11.2 (15.6) for the non-clicker section were consistent with historical results of 11.3(15.2) from two previous years of testing. The clicker section scored 0.9 questions higher on the pretest. Through detailed item analysis of the pre-test as shown in Figure 5.3, it was found that the increase of 0.9 questions, though statistically insignificant, was mostly on material that had been presented during the lectures in the first week before the pre-test was given. (The sum of the differences between the clicker and non-clicker based on the first 16 questions of the CSEM test is 0.8; the sum of the differences between the clicker and non-clicker based on the last 16 questions of the CSEM test is 0.1) The clicker lecture
section post-test score was 2.3 questions higher than that of the non-clicker class. The two-tailed T-test gave a P-value of 0.005, indicating that it is highly unlikely that these classes come from distributions with the same mean. Approximately 76% of students took both pre and post tests, and attempted to answer at least 85% of all questions.

Most of the differences are on material that had been presented during the lectures in the first week before the pre-test was given.

Figure 5.3 Fall 2005 differences between clicker section and non-clicker section on individual question response on pre CSEM test

During winter quarter the book was changed for both lecture sections, and homework was switched to an online system: Webassign [2003 Bonham]. All other aspects of the course remained as before. Pre-tests were administered in the first recitation, which by accident occurred before the first lecture and hence before
presentation of any course material. Both clicker and non-clicker classes scored 9.3 on the pre-test, a score that was approximately 2 questions lower than that for the two previous years of testing. A two-tailed T-test between these two pretests and the previous two-year pretests gives a P-value of $5 \times 10^{-13}$, indicating that if a pre-test given before any instruction takes place, the average is significantly lower than the average of the previous two-year pretests. Finally, the clicker section scored 0.8 questions higher on the post test than the non-VM section on an examination administered in the last recitation section. The P-value for this is 0.131. It is gratifying to note that the clicker class earned a higher score, but this difference is not statistically significant.

In spring, the pre-test was given the day after the first lecture. The non-clicker section pre-test score, 8.9, was consistent with winter-quarter pre-tests, but the clicker section score of 10.9 was 2.0 questions higher. This significant increase was entirely on the materials presented in the first VM lecture that, unbeknownst to the lecturer, was strikingly similar to several questions on the CSEM inventory. (As shown in figure 5.4, the sum of the differences between the clicker and non-clicker based on the first 16 questions of the CSEM test is 1.64; the sum of the differences between the clicker and non-clicker based on the last 16 questions of the CSEM test is 0.35) Lecture content was determined both from the lecturer’s notes and from notes taken by project researchers who had observed the first lectures. The clicker section scored 19.7 on the post test administered in the final recitation section, which was
2.1-question higher than for the non-VM section. The two-tailed T-test gives a P-value of 0.009, indicating that it is highly unlikely that the clicker and non-clicker classes come from distributions with the same mean.

This significant increase was mostly on material presented in the first clicker lecture that, unbeknownst to the lecturer, was strikingly similar to several questions on the CSEM inventory.

The above results also indicate that using post minus pre test gains to evaluate new teaching strategies requires that pretests be given prior to presentation of any course material. They further indicate that incentives played a major role in post testing. In two years of post-testing prior to using clicker, individual lecture section scores varied only by a standard deviation of 0.35 questions, which was not statistically significant. The two-year average post-test score also agreed with the

Figure 5.4 Spring 2006 differences between clicker section and non-clicker section on individual question response on pre CSEM test
non-clicker class score during fall quarter. However, even when clicker and non-clicker sections were averaged, post-test scores still fluctuated with a standard deviation of 1.5 questions during fall, winter, and spring quarters. In part, this may be due to the fact that incentives for taking pre and post tests impact the percentage of students taking these tests. The uncontrolled incentives were largely due to the departmental course structure change and instructor preferences.

No incentives were offered in fall quarter. Approximately 76% of students both took pre and post-tests in labs, and answered at least 27 questions on the post-test. In winter, students were offered a small number of points for taking the post-test without regard to their scores. The percentage of students taking both tests rose to 89%, and CSEM post-test scores both for clicker and non-clicker sections dropped. In spring, students were told that their CSEM score, if sufficiently high, would be appropriately scaled and would replace their lowest quiz score. The number of students taking both pre and post-tests dropped, but average scores increased significantly when compared to fall quarter both for clicker and non-clicker sections. The average total course score in the spring clicker class was 576 out of 720, a grade of B, for students who took both pre- and post-tests, as compared to 448, a grade of D+, for students who missed at least one of these tests. There was a similar distribution for the non-clicker class. The grade shift is a strong indicator that conceptual post-test scores increased in the spring because a significant number of lesser-achieving students were not included.
Based on the fact that 15 non-clicker lecture sections tested under identical conditions were consistent with coming from the same sample, it seems reasonable that clicker and non-clicker comparisons can be made on the basis of post-test scores alone. Averaged over a year, clicker classes scored approximately 1.3 questions (8.7%) higher on the CSEM post-test. The two-tailed T-test for this gives a P-value of 0.001. It is statistically likely that giving students the opportunity to see and vote on each clicker sequence once and only once in a quarter has had a positive impact on their level of understanding.

5.3 Research question 2

Do students using clickers perform better on common exam questions?

5.3.1 Research Design

Common exam questions were also used in the research design as an alternative measure to gauge the performance difference between clicker and non-clicker classes, in addition to the pre-post testing method, which has been biased by several environmental constraints. An identical set of 16~20 multiple choice questions were given on the midterm and final exams of both the clicker and non-clicker class in a given quarter. These questions cover most topics in the course and are designed to have similar formats as the clicker questions.

Among these 16~20 questions, about 20% were questions neither the clicker section nor the non-clicker section have seen, 30% were questions that were similar to
clicker questions used in lectures, and 50% were questions that were identical to the clicker questions used in lecture. Therefore, students in clicker section are expected to have better performance on these questions. Better score on the common exam questions is a necessary but not sufficient condition to prove the effectiveness of using clickers.

5.3.2 Results and analysis

The results of student performances on these common exam questions are shown in Table 5.5.

<table>
<thead>
<tr>
<th>Common Exams</th>
<th>Clicker</th>
<th>Non-Clicker</th>
<th>Raw Difference</th>
<th>Scaled Difference*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fall quarter</td>
<td>72%±1.5%</td>
<td>64%±1.5%</td>
<td>8%</td>
<td>22%</td>
</tr>
<tr>
<td>(20 questions)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Winter quarter</td>
<td>68%±1.1%</td>
<td>56%±0.9%</td>
<td>11%</td>
<td>26%</td>
</tr>
<tr>
<td>(16 questions)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spring quarter</td>
<td>63%±2.4%</td>
<td>52%±1.4%</td>
<td>11%</td>
<td>23%</td>
</tr>
<tr>
<td>(19 questions)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* scaled difference=(100%)
\[
\frac{\text{Raw difference}}{1-(\text{nonVM Score})}
\]

Table 5.5: Performance on questions connected with major concepts that were used on tests both in clicker and non-clicker lecture sections.

As shown in Table 5.5, clicker lecture sections scored higher than non-clicker sections on relevant multiple-choice conceptual examination questions during all three quarters. “Scaled Difference”, which is based on the concept of normalized gain
as used by Hake to evaluate pre/post testing results, was used to compare the
difference between clicker and non-clicker classes. Here, the raw difference refers to
the difference of average score between classes using and not using clicker. The
scaled difference is basically the ratio between the raw score difference and the
possible maximum score difference based on the score of the non-clicker class. Data
shows that using clicker in a lecture-based class increases performance on related
conceptual questions by 22% to 26%.

As stated previously, the common exam questions can be divided into several
categories: (1) Questions that are exactly the same as the clicker questions, (2)
Questions that are completely different from the clicker questions and (3) Questions
that are similar to the clicker questions. We expect questions that are exactly as the
clicker questions will have the most gain on the common exam since many students
will remember the answer. Questions that are completely different with the clicker
questions will have the least gain or no gain since clicker questions will not benefit
students on uncovered topics. Questions that are different but similar to the clicker
questions are the best examples to show learning gains. The results of student
performances on these common exam questions are shown in Table 5.6.
Table 5.6 Differences between clicker sections and non-clicker sections using only the similar questions on exams

Table 5.6 shows that clicker lecture sections scored higher than non-clicker sections on questions that are different but similar to the clicker questions during all three quarters.

5.4 Research Question 3

Do students benefit differently from different types of questions? Do “easy-hard-hard” sequences and “rapid-fire” sequences have same effects on students with different academic levels?

Confronting students with discrepant events that contradict their existing conceptions has become a common instructional strategy to foster conceptual change. This approach is intended to invoke a disequilibration or conceptual conflict that induces students to reflect on their conceptions as they try to resolve the conflict. Hewson and Hewson explicated the role of conceptual conflict in conceptual change and the design of science instruction citing two studies in which conceptual conflict
was found to be effective in changing students’ alternative conceptions [1984 Hewson].

However, findings from other studies were equivocal. For example, Dreyfus found that bright, successful students reacted enthusiastically to conceptual conflicts, but unsuccessful students ignored or tried to avoid them [1990 Dreyfus]. Niaz found that some students protected their conceptions by ignoring the conceptual conflict [1995 Niaz].

One assumption of the “easy-hard-hard” sequences is that it will create cognitive conflict to stimulate students’ conceptual changes. On the other hand, the “Rapid-Fire” sequences tend to create less conceptual conflict because all questions are usually less difficult. Therefore, they may have a different effect on higher and lesser achieving students.

Whether students actually have high cognitive conflict during “easy-hard-hard” sequences and lower cognitive conflicts during “Rapid-Fire” sequences is unknown, because it is difficult to measure the level of conflict. However many researchers have found that conflict is induced by presenting information that clearly—for the teacher—contradicts students’ ideas, beliefs or theories. Thus, confronting students with contradictory results usually indicates high cognitive conflicts for the students. [1992 Dykstra]
Different difficulty is an important and measurable difference between “easy-hard-hard” sequences and “Rapid-Fire” sequences. The second question of the “easy-hard-hard” sequence is usually difficult for the students, as measured by the fraction of correct answers. The “Rapid-Fire” sequences usually have questions with more modest difficulty as indicated by a high fraction of correct answers. Thus, another goal of our research was to find out whether students with different academic levels benefit differently from questions with different difficulties.

5.4.1 Research Design

We use students’ performances on common exam questions as our measurement instrument. As discussed above, clicker and non-clicker section used common multiple choice questions on the exams. Some of the questions are identical to the clicker questions used in clicker section, some of the questions are similar to the clicker questions, and some of the questions are new to both students in clicker section and non-clicker section. Picking performance on questions can be tricky because we cannot use questions that are completely new to both sections. On the other hand, we can not use identical questions because clicker-section students tend to remember answers for these questions. After carefully selection, we picked three questions that are similar to “easy-hard-hard” sequences used in class and three questions that are similar to “Rapid-Fire” sequences used in class. These questions are shown in picture 5.1 and 5.2.
MC.3) [6] Two large parallel plates are placed a short distance apart and charged uniformly to the same positive surface charge density \( \sigma \) as shown. What are the electric fields in the three regions? Use to the right as the positive direction.

a) Left: \(-\sigma/\varepsilon_0\)  
   middle: 0  
   right: \(+\sigma/\varepsilon_0\)

b) Left: \(+\sigma/2\varepsilon_0\)  
   middle: \(+\sigma/2\varepsilon_0\)  
   right: \(+\sigma/2\varepsilon_0\)

c) Left: 0  
   middle: \(+\sigma/\varepsilon_0\)  
   right: 0

d) Left: \(-\sigma/2\varepsilon_0\)  
   middle: 0  
   right: \(+\sigma/2\varepsilon_0\)

e) Left: \(+\sigma/\varepsilon_0\)  
   middle: \(+\sigma/\varepsilon_0\)  
   right: \(+\sigma/\varepsilon_0\)

f) None of the above

Left  Middle  Right

MC.4) [6] A positive charge is placed on the thick-walled conducting sphere shown to the right. Which of the following sets of graphs best represent the electric field \( E \) and potential \( V \) as a function of radius:

MC.5) [6] The following capacitors are hooked as shown to a 10 volt battery. \( C_1 = 1 \mu \text{F} \), \( C_2 = 2 \mu \text{F} \) and \( C_3 = 3 \mu \text{F} \). The voltage is least across which capacitor?

a) \( C_3 \)
b) \( C_2 \)
c) \( C_1 \)
d) \( C_2 \) and \( C_3 \)
e) All three have the same voltage

Picture 5.1 Three questions that are similar to “Rapid-Fire” sequences used in class.
MC5, 6 points. Circle the letter beside the set of equipotential lines that provides the best qualitative match for the electric field lines given at the top. Don’t worry about the exact voltage values, but rather whether the voltage is increasing or decreasing when moving from left to right, and whether the equipotential lines are getting closer together or further apart.

*Picture 5.2 Three questions that are similar to “easy-hard-hard” sequences used in class. (continued)*
There are three categories in this experiment. Clicker or non-clicker, upper half students or lower half students (we used total course score to divide students into upper half and lower half), and performance on questions that are similar to “easy-hard-hard” sequences or similar to “Rapid-Fire” sequence. The data set is a 2 by 2 by 2 matrix. A comparison of the same group of students on the same group of questions between clicker section and non clicker section is required to see the different effects of two types of question sequences.
5.4.2 Results and Analysis

Students’ performance on common exam questions that are similar to clicker question sequences are presented in the table 5.7. The numbers under 0,1,2,3 give the number of students who answer 0,1,2,3 questions right respectively. P values for the two-tailed T-tests are also presented in table 5.7.

<table>
<thead>
<tr>
<th></th>
<th>“easy-hard-hard”</th>
<th>“Rapid-Fire”</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Clicker upper</td>
<td>1</td>
<td>15</td>
</tr>
<tr>
<td>Non-clicker upper</td>
<td>5</td>
<td>18</td>
</tr>
<tr>
<td>P</td>
<td>0.006</td>
<td></td>
</tr>
<tr>
<td>Clicker Lower</td>
<td>5</td>
<td>25</td>
</tr>
<tr>
<td>Non-clicker Lower</td>
<td>7</td>
<td>21</td>
</tr>
<tr>
<td>P</td>
<td>0.818</td>
<td></td>
</tr>
</tbody>
</table>

Table 5.7 P-values of students’ performance on different types of questions.

First, look at lower half students’ performance on “easy-hard-hard” sequence questions. The P-value between lower half students in the clicker section and non-clicker section is 0.818, which is not significant. On “Rapid-Fire” sequence questions, the P-value between lower half students in the clicker section and non-clicker section is 0.004, which is significant. Therefore, lower half students benefit mostly from “Rapid-Fire” sequence. The “easy-hard-hard” sequence questions, either because of the cognitive conflicts or question difficulty, benefit lower half
students little, if at all.

On the other hand, for the “easy-hard-hard” sequence and the “Rapid-Fire” sequences, P-values between the upper half students in the clicker and non-clicker section are 0.006 and 0.036, respectively, which are both statistically significant. Therefore, the upper half students benefit both from the “easy-hard-hard” sequence and the “Rapid-Fire” sequence. The P-value of the “Rapid-Fire” sequence is not as significant as the P-value of the “easy-hard-hard” sequence, which may due to the ceiling effects: half of all students in the clicker section got perfect scores on “Rapid-Fire” sequences.

Chi-square homogeneity tests as shown in table 5.8 were also given to compare the similarity between distributions. The P-value of the chi-square test between the lower half students of clicker and non-clicker section on the “easy-hard-hard” sequence is 0.891, which is not significant. This means that there is no difference between the distributions of the lower half students’ performance on the “easy-hard-hard” sequence. The P-value of the chi square test between the upper half students of clicker and non-clicker section on the “Rapid-Fire” sequence is 0.204, which is also not significant. This could due to the ceiling effect: many of the higher achieving students in the clicker section attained perfect scores.
### Chi Square Test

<table>
<thead>
<tr>
<th></th>
<th>Hard</th>
<th></th>
<th>Rapid fire</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>VM Upper</td>
<td>1</td>
<td>15</td>
<td>19</td>
<td>21</td>
</tr>
<tr>
<td>NonVm Upper</td>
<td>5</td>
<td>18</td>
<td>20</td>
<td>8</td>
</tr>
<tr>
<td>P</td>
<td>0.035</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VM Lower</td>
<td>5</td>
<td>25</td>
<td>14</td>
<td>5</td>
</tr>
<tr>
<td>NonVm Lower</td>
<td>7</td>
<td>21</td>
<td>13</td>
<td>5</td>
</tr>
<tr>
<td>p</td>
<td>0.891</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Table 5.8 P-values of the distributions of students’ performances on different types of questions.*

Because the error function used in chi-square tests usually requires that the frequency in each category be larger than 5, we also combined the number of students who got zero and one question right, and the chi-square test of the combined categories is given in table 5.9. As the original chi-square test, the combined chi-square test also shows that there is no difference between the distributions of the lower half students’ performance for the “easy-hard-hard” sequence.

The above data indicates that higher and lower achieving students benefit differently from different types of question sequences. Upper half students benefit
both from the “easy-hard-hard” sequence and the “Rapid-Fire” sequence. On the other hand, lower half students benefit mostly from the “Rapid-Fire” sequence.

**Chi Square Test**

<table>
<thead>
<tr>
<th></th>
<th>Hard</th>
<th>Rapid fire</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0 and 1</td>
<td>2</td>
</tr>
<tr>
<td>VM Upper</td>
<td>16</td>
<td>19</td>
</tr>
<tr>
<td>NonVm Upper</td>
<td>23</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>0 and 1</td>
<td>2</td>
</tr>
<tr>
<td>VM lower</td>
<td>30</td>
<td>14</td>
</tr>
<tr>
<td>NonVm Lower</td>
<td>28</td>
<td>13</td>
</tr>
<tr>
<td>P</td>
<td>0.032</td>
<td>0.102</td>
</tr>
<tr>
<td>p</td>
<td>0.994</td>
<td>0.010</td>
</tr>
</tbody>
</table>

*Table 5.9 P-values of the distributions of students’ performances on different types of questions when using different binning.*

These results have already been used by us to determine the weight of the “easy-hard-hard” sequence and the “Rapid-Fire” sequence in our instruction. We used many “Rapid-Fire” sequences because lower half students usually do not benefit from the “easy-hard-hard” sequence. On the other hand, we used a few “easy-hard-hard” sequences, because many upper half students will answer most “Rapid-Fire” questions correctly. Upper half students needed challenging questions to understand
concepts more deeply. In practice, we used about 70% “Rapid-Fire” sequences and 30% “easy-hard-hard” sequences.

5.5 Research Question 4

Is there a gender performance difference between male and female students when using clickers?

Gender difference in science learning has long been emphasized in physics and science education research. It is generally recognized that females tend to be less interactive and are more intimidated by scientific and mathematical topics. In this study, we collected gender information to explore how male and female students may differ in reacting to the use of clickers.

5.5.1 Research Design

Gains on the CSEM pre and post tests were used to compare the gender differences. One issue for this design is that there are very few female students in the calculus-based introductory physics class, which will cause a much bigger standard error for the mean on female students’ CSEM gains. One solution to this problem is summing results from all three quarters of testing.

5.5.2 Results and Analysis

In table 5.10, pre-post CSEM average score gains for male and female students are shown, along with the numbers of students and calculated standard errors.
Table 5.10. Pre-Post CSEM score gains for females and males in clicker and non-clicker lecture sections, shown separately for each of the three quarters of the test.

The numbers of male and female students participating are shown in parentheses for each lecture section. Average results weighted by the number of participating students are given in the bottom row. The standard error of the mean and the sample size are also given. The fact that male gains appear comparable in fall and spring clicker and non-clicker sections is due to the fact that pretest scores were significantly higher in clicker sections when pretests were given after the start of instruction.

For clicker sections, males had an average gain only 0.5 questions larger than for the females, which is not significant. In non-clicker sections, males had a gain that was 2.3 questions larger than the females. Two-tail T-test gives p value 0.001, which shows a significant difference. This result is consistent with the anecdotal evidence shared from other groups [2006 Wieman]. It was suggested that women may feel more comfortable participating anonymously with clicker. Another possibility is that female students usually have a much higher attendance rate than male students (the average attendance rate for female students is usually about 90%, while the

<table>
<thead>
<tr>
<th>Quarter</th>
<th>VM section</th>
<th>Non-VM section</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Female</td>
<td>Male</td>
</tr>
<tr>
<td>Fall</td>
<td>5.9±1.4 (14)</td>
<td>5.8±0.6 (84)</td>
</tr>
<tr>
<td>Winter</td>
<td>5.3±0.8 (23)</td>
<td>6.6±0.4 (139)</td>
</tr>
<tr>
<td>Spring</td>
<td>9.1±1.2 (9)</td>
<td>8.8±0.8 (48)</td>
</tr>
<tr>
<td>Average</td>
<td>6.2±0.9 (46)</td>
<td>6.7±0.4 (271)</td>
</tr>
</tbody>
</table>
average attendance rate for male students range from 40% to 65%), and may benefit 
more form clickers because they see more question than male students [2007 Lee]. 
Research to identify more solid evidence to support this and/or other hypotheses will 
be pursued in future studies.

5.6 Research Question 5

Whether students perceive that clicker has a positive effect on their own 
learning process.

Affective and motivational factors are also very important aspects of learning 
because in order to succeed in one area, students must have interests and enthusiasm 
in that area. Students’ self-reporting of preferences and attitudes has been used for 
decades as supplemental information while evaluating education innovations.

5.6.1 Research Design

In this study, students using clicker were given an end-of-quarter attitude survey 
soliciting their views about using clicker. Twelve questions in the fall and 15 
questions in winter and spring were answered using a 5-point scale ranging from -2 
(totally disagree) to +2 (totally agree). To validate the survey, each type of preference 
or attitude includes several similar questions worded differently and sometimes in 
both positive and negative tones. Three slightly different versions of end-of-quarter 
attitude surveys are attached in appendix 3.
5.6.2 Results and Analysis

Results for all the 5-point scale survey questions are shown in table 5.11.

<table>
<thead>
<tr>
<th>Statement</th>
<th>Fall Average</th>
<th>Winter Average</th>
<th>Spring Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>I like using clickers.</td>
<td>+1.79</td>
<td>+1.59</td>
<td>+0.83</td>
</tr>
<tr>
<td>Clickers helped me understand lectures better</td>
<td>+1.72</td>
<td>+1.46</td>
<td>+0.64</td>
</tr>
<tr>
<td>Clickers help me stay focused during lecture.</td>
<td>+1.63</td>
<td>Not used</td>
<td>Not used</td>
</tr>
<tr>
<td>Clickers made me feel involved in the course.</td>
<td>Not used</td>
<td>+1.51</td>
<td>+0.96</td>
</tr>
<tr>
<td>Clickers helped me get instant feedback on what I knew and didn’t know.</td>
<td>Not used</td>
<td>+1.66</td>
<td>+1.19</td>
</tr>
<tr>
<td>Using clickers helped me think more deeply about course materials.</td>
<td>Not used</td>
<td>+1.27</td>
<td>+0.66</td>
</tr>
<tr>
<td>Clickers facilitated good interaction among students in the class.</td>
<td>Not used</td>
<td>+1.38</td>
<td>+0.85</td>
</tr>
<tr>
<td>I prefer questions that confirm what I already know.</td>
<td>+0.64</td>
<td>+0.58</td>
<td>+0.42</td>
</tr>
<tr>
<td>I prefer questions that require me to extend and make an intelligent guess.</td>
<td>+1.33</td>
<td>+1.18</td>
<td>+0.5</td>
</tr>
<tr>
<td>We should do more clicker questions with numbers.</td>
<td>+0.22</td>
<td>Not used</td>
<td>Not used</td>
</tr>
<tr>
<td>It bothers me if I get a question wrong, even though I may learn something.</td>
<td>-0.70</td>
<td>-0.35</td>
<td>+0.23</td>
</tr>
<tr>
<td>I would take another course that uses clickers.</td>
<td>Not used</td>
<td>+1.43</td>
<td>+0.52</td>
</tr>
<tr>
<td>I would recommend using clickers in all future introductory physics courses.</td>
<td>+1.77</td>
<td>+1.43</td>
<td>+0.52</td>
</tr>
<tr>
<td>Using clickers is a waste of time.</td>
<td>Not used</td>
<td>-1.42</td>
<td>-0.77</td>
</tr>
<tr>
<td>I will avoid classes using clickers in the future.</td>
<td>Not used</td>
<td>-1.54</td>
<td>-0.73</td>
</tr>
</tbody>
</table>

Table 5.11: Question with a 5-point scale on clicker attitude survey results. Complete surveys are attached in appendix 3. Details are discussed in the text.
The results show that students like using clicker and think using clicker help them understand the questions better. When asked “Do you like using clickers?” the average summed over the year of testing is 1.5. In fall 2005, all the survey statements were positive. “Negative” survey statements were added in winter to address possible bias due to the positive question style. The concern that students might rate clicker more highly when all questions were positive did not show up in winter and spring results.

The survey results decreased from fall and winter to spring, which suggests that the attitude survey did measure something that can be systematically varying.

Students were less positive toward use of clickers in spring than in fall and winter quarters, which could be explained by several possible reasons: 1) the spring clickers section started at 8:30 AM. In an attempt to enhance attendance clicker participation was lightly graded based on attendance. 34% of students complained about being graded in the survey. 2) The spring lecturer added his own questions, more than doubling the percentage of lecture time used for clickers. In the end-of-quarter anonymous survey, 21% of students felt that clicker took too much time. 3) The lecturer also made his own survey, which students took using clickers despite the fact that this method is not anonymous. Students responded that clickers were being used about twice as much as they would have preferred.
This evidence suggests that grading clickers and/or using them for almost 50% of lecture time may have contributed to a less positive student attitude. This conclusion also agrees with the results by instructors in Ohio State chemistry department who also overused clicker questions. [2005 Callam]

In this study, the attitude survey results play a supporting role in quantitative analysis. They provide a look from the student’s direction and indicate directions for future exploration.

5.7 Summary and Conclusions

At The Ohio State University, a new methodology of using clickers (using question sequences) was assessed in the electromagnetism quarter of a year-long introductory class. Two lecture sections were taught, but only one of them used clickers. Two types of questions sequences: “easy-hard-hard” sequences and “Rapid-Fire” sequences were designed to specifically address students’ misconceptions and difficulties.

Data from pre-post CSEM tests and common exam questions indicate that students using clickers achieved a small but significant gain in conceptual learning. Results from common exam questions also show that different types of question sequences have different effects on students with different academic levels. Upper half students benefit both from the “easy-hard-hard” sequence and the “Rapid-Fire” sequence. On the other hand, lower half students benefit mostly from “Rapid-Fire”
sequences. In addition, gender specific CSEM results showed that using clickers reduces the gap between male and female students’ performances on tests: in the traditional lecture section, female gains were significantly lower than male gains. In clicker section, female gains were similar to male gains. Results from a spring 2007 continuation test indicate that this may have been to the fact that a higher percentage of female students attended lectures [2007 Lee].

Attitude surveys show that students like using clicker and using clickers help them understand learn. The results also show that instructors with no or little clicker experience can use clickers effectively. Finally, attitude surveys show that grading clicker responses and/or overusing clickers may lower student interest.
References:


2005 C. Callam, Private communication.

2006 Carl E. Wieman, private discussion

2007 Albert Lee, private discussion.
CHAPTER 6

SUMMARY OF THESIS AND SUGGESTIONS FOR FUTURE RESEARCH

As part of ongoing research by the Physics Education Research Group (PERG) at the Ohio State University, this dissertation project has been conducted to develop and evaluate a new clicker methodology. Previous chapters in this thesis motivated clickers, discussed how they are used, presented examples of a new clicker methodology and discussed a year-long period of evaluation. In this chapter, the conclusions from our three-year clicker project will be summarized and suggestions provided for future research. It is hoped that this information will be useful for PER researchers and instructors who are interested in using clickers.

6.1 Summary of thesis

“Clickers”, an in-class polling system, has been used by many instructors to add active learning and formative assessment to previously passive traditional lectures. Researchers have shown that using clickers improves classroom dynamics and increase active engagement in the classroom [2004 Draper] [2004 Wood]. While
considerable research has been conducted on clicker increasing student interaction in class, less research has been reported on the effectiveness of using clicker to help students understand concepts. This thesis reported a systemic project by the OSU Physics Education group to develop and test a new clicker methodology.

Clickers question sequences based on a constructivist model of learning were used to improve classroom dynamics and student learning. They also helped students and lecturers understand in real time whether a concept had been assimilated or more effort was required.

Chapter 1 provided an introduction to the clicker project. Chapter 2 summarized widely-accepted teaching principles that have arisen from a long history of research and practice in psychology, cognitive science and physics education. The OSU clicker methodology described in this thesis originated partly from our years of teaching experience, but mostly was based on these teaching principles.

Chapter 3 provided an overview of the history of clicker technology and different types of clickers. Also, OSU’s use of clickers was summarized together with a list of common problems and corresponding solutions. These technical details may be useful for those who want to use clickers.

Chapter 4 discussed examples of the type and use of question sequences based on the new clicker methodology. In several years of research, we developed a base of clicker materials for calculus-based introductory physics courses at OSU. These
materials include:

A. 45 question sequences for the E & M quarter. These sequences are complete and have been tested for several years. They can be found in Appendix 1.

B. 20 question sequences for the Mechanics quarter.

C. 10 question sequences for the Waves and Model Physics quarter. Question sequences for the latter two quarters have not been included in Appendix 1 because they are not complete and fully tested.

Many researchers have shown that learning is context dependent [1991 Lave] [1999 Bao]. We believe (though it has not yet been proved) that question sequences are better than single questions in helping students understand concepts. We have developed two types of question sequences: the “easy-hard-hard” and in “Rapid fire” question sequences. These question sequences address student common misconceptions from our teaching experience and results from other PER researchers.

As discussed in chapter 5, a year-long controlled quantitative study was conducted to determine whether using clickers helps students learn, how using clickers helps students learn and whether students perceive that clicker has a positive effect on their own learning process. The strategy for this test was based on comparing clicker lecture sections using the new methodology to lecture sections with a similar population of students taught without clickers in a traditional manner. The results of this test can be summarized as follows:
A. Data from pre-post CSEM [2001 Maloney] tests and common exam questions indicate that students using clickers achieved a small but significant gain in conceptual learning. On average, students in the clicker section score 8.7% better than students from non-clicker section on CSEM post test; students in the clicker section also score about 10% better on all common exam multiple choice questions and about 7% better on common exam multiple choice questions that are similar to clicker questions used in lectures (excluding questions that are exactly the same as or completely different from clicker questions).

B. Pre and Post test scores depend strongly on the timing and incentives when the test was offered. For example, the pretest score, when taken in the second week in lab, averaged 11.32 over two years. In winter 2006, the pretest was taken in the first recitation, where no instruction has been given, the average dropped to 9.3. In winter, students were offered a small number of points for taking the post-test without regard to their scores. The percentage of students taking both tests rose to 89%, and CSEM post-test scores both for clicker and non-clicker sections dropped. In spring, students were told that their CSEM score, if sufficiently high, would be appropriately scaled and would replace their lowest quiz score. The percentage of students taking both pre and post-tests dropped to 65%, but average scores increased significantly when compared to fall quarter both for clicker and non-clicker sections.

C. Performance on exam questions similar to hard clicker questions by lower half students was compared for clicker and non-clicker lecture sections. A P value of
0.818 on two-tailed t-test indicated that the two lecture sections had the same performance. In short, lower-half students did not benefit from seeing “easy-hard-hard” question sequences. In contrast, comparing lower half student performance on exam questions similar to “Rapid fire” question sequences had a P value of 0.004, indicating that the clicker class performed better on exams for this type of question.

Using the same form of statistical analysis, it was demonstrated that upper half students in the clicker section performed better on exams than upper half students in the non-clicker section for both types of questions. These results indicated that “Rapid-Fire” question sequences, with their more modest difficulty level, benefited students at all levels of achievement, while more difficult “easy-hard-hard” sequences appear to benefit only students in the upper half of the class.

D. Gender-specific CSEM results showed that using clickers reduced the gap between male and female students’ performances on tests: Summed over a year of testing, female gains were significantly (2.3 questions) lower than male gains in the traditional lecture section. In the clicker section, female gains were similar to male gains (0.5 questions lower). One possible reason is that women may feel more comfortable using clickers to participate anonymously. Another possibility is that female students may have a much higher attendance rate than male students, and may benefit more from clickers because they see and vote on more questions than do male students [2007 Lee].
E. Finally, attitude surveys as enclosed in Appendix 3 show that students like using clickers and believed using clickers help them understand questions better. When asked “Do you like using clickers?” the average summed over the year of testing is 1.5 based on a 5-point scale ranging from -2 (totally disagree) to +2 (totally agree). The results also indicate that grading clicker responses and/or overusing clickers may lower student enthusiasm.

6.2 Suggestions for Future Work

Our research showed that using clickers in lectures can increase students’ interaction in class and suggested that using clickers with carefully designed questions sets can help students understand concepts. This is a small step in a long journey. To form a systematic methodology of using clickers for different instructors, we must take additional steps in the future. I wish to suggest an exploration of the following promising areas:

1. Interview students to validate the answer choices.

Most of our question sequences have been tested and modified for several years. But students may choose the right answer for an unknown variety of reasons, and we have not adequately replaced weak distracters. Since our team has grown and now contains researchers with considerable interviewing experience, the clicker team will begin interviewing students to better understand why they choose particular answers.
2. Design questions for Mechanics, Waves and Modern Physics.

We have a complete set of Electromagnetism question sequences (About 45 question sequences). However, we have developed only 20 question sequences for Mechanics and an additional 10 question sequences for Waves and Modern Physics. Thus, we are only halfway to our ultimate goal of designing a sufficient number of question sequences to cover an entire year of introductory physics. Further, these newly designed question sequences should be tested and modified for several quarters.

3. Cooperate with other universities.

Students from different schools have different academic backgrounds. Thus, instructors need to pick a set of question sequences that is best for their own students. The Physics Education Research group at OSU will collaborate with Chicago State University, University of DuPage and Wright State University. The ultimate goal is to form a clicker question sequence pool suitable for students at a variety of institutes.

4. Conduct a better controlled quantitative study.

Our controlled quantitative study is the first attempt to test the effectiveness of using clickers in lectures. Due to administrative reasons, the timing of the exams and incentives offered for taking them varied between quarters, which gave us difficulty in comparing students’ performance between quarters. In future research, we need to better control the timing and incentives of taking CSEM test. In particular, the pretest
must be given before presentation of any course material. The posttest should be given on final exams so that students will have equal and maximum incentive. A better controlled study has already been conducted by PER group at OSU during spring 2007 quarter. The CSEM pre test was given in the first lecture before any instruction, and the post test was included as part of the final exam. Results are under analysis.

5. Are question sequences really better than single questions?

This crucial question may be difficult to answer. A survey given in spring 2007 [2007 Lee] shows that students would rather vote on multiple questions than single questions for each concept. But do students learn more from question sequences than from single questions? A controlled study could be made to test this question.

However, such a test would be difficult to implement because of the noise level of human subject testing. From the 2005-2006 controlled quantitative study, we found that the effect of using clickers and question sequences in lectures resulted in an average increase of only 8.7% on the CSEM test. The difference between using question sequences and single questions may be too small to detect.

Finally, we wish to point out that widespread use of clickers has emerged mostly during the last decade, and research studying the effect of using clickers is still in its infancy. This dissertation is just a pilot study. A complete exploration of the pedagogy and methodologies for using clickers remains for the future.
References:


1999 Lei Bao, “Dynamics of student modeling” Ph.D. Thesis


2007 Albert Lee, private discussion.
BIBLIOGRAPHY

1930 Vygotsky, “Primitive Man and his Behavior”, Harvester Wheatsheaf


1982 Roadrangka, V., Yeany, R., and Padilla, M., GALT, Group Test of Logical Thinking, Athens, Georgia, University of Georgia.


1989 D. Sadler “Formative assessment and the design of instructional systems” Instructional Science, 18 (2): 119-144


1996 Dalgarno, B., “Constructivist computer assisted learning: theory and technique”, ASCILITE Conference, 2-4 December


1997 Trumper, R. “Applying conceptual conflict strategies in the learning of the energy Concept”, Research in Science and Technology Education, 15, 5–18


1999 Lei Bao, “Dynamics of student modeling” Ph.D. Thesis


1999 M. Sabella “Using the context of physics problem solving to evaluate the coherence of student knowledge”. Ph.D. dissertation, University of Maryland


2001 C. Crouch and E. Mazur “Peer Instruction: Ten years of experience and results” 977 Am. J. Phys., Vol. 69, No. 9


2001 Jose P Mestre, “Implications of research on learning for the education of prospective science and physics teachers”, Physics Education


2003 L. Hsu, K. Heller, and A. Hasnudeen “Designing Interactive Problem-Solving Tutorials” Contributed Talk, AAPT Summer Conference (Madison, Wisconsin)


2003 E.F. Redish, “Teaching Physics: With the Physics Suite”, A copy of this book can be found at http://www2.physics.umd.edu/~redish/Book/


2005 C. Callam, Private communication.


2005 N.W. Reay, L. Bao, P. Li and G. Baugh, "Toward the effective use of voting machines in physics lectures, Am. J. Phys. 73, 554


2006 Davidson College, a link can be found at: http://webphysics.davidson.edu/Course_Material/Py230L/optics/lenses.htm


2006 Carl E. Wieman, private discussion

2007 Albert Lee, private discussion.

2007 Carmen https://carmen.osu.edu/

2007 E-instruction www.einstruction.com

2007 I-clicker www.iclicker.com
2007 PRS http://www.gteocalcomp.net/interwriteprs.htm

2007 Qwizdom www.qwizdom.com/

2007 Turning Point www.turningtechnologies.com
APPENDIX A

ELECTROMAGNETISM QUESTION EXAMPLES
Which figure below best shows $\vec{A_1} + \vec{A_2} + \vec{A_3}$?

1.  
2.  
3.  
4.  
5.  

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

1.  
2.  
3.  
4.  
5.  

175
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
Two charges, \(-Q\) and \(+2Q\) are placed a distance \(R\) apart. 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?

Two charges, \(-Q\) and \(+2Q\) are placed a distance \(R\) apart. The force \(F\) on the \(-Q\) charge is shown by the arrow. 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 \textbf{bottom} \(+2Q\) charge?
Two charges, \(-Q\) and \(+2Q\) are placed a distance \(R\) apart. The force \(F\) on the \(-Q\) charge is shown by the arrow. The charges are then moved to a separation distance of \(R/2\). Which arrow represents the new force on the \(+2Q\) charge?

1. 
2. 
3. 
4. 
5. 
6. None of the above
Four equal charges $+Q$ are fixed to the corners of a square, as shown above. Select the direction of the net force on the left-hand (red) charge.

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 above. Select the direction of the net force on the left-hand (red) charge.

1. 1
2. 2
3. 3
4. 4
5. 5
6. 6
7. 7
8. 8
9. None of the above
Finally, the left-hand (red) charge also is made negative, but its magnitude isn’t determined. Select the direction of the net force on the left-hand (red) charge.

1. 1
2. 2
3. 3
4. 4
5. 5
6. 6
7. 7
8. 8
9. None of the above
Two identical metal balls A and B initially have charge 4Q and zero, as shown below. What is the charge on B after you let A touch B and set them apart?

- A. 4Q
- B. 2Q
- C. Q
- D. 1.5Q
- E. 2/3Q
- F. 0.5Q
- G. Zero
- H. None of the above

Three identical metal balls A, B and C have charge 4Q, -2Q and zero, as shown below. What is the charge on C after you let A first touch B, and then remove A and let B touch C?

- A. 4Q
- B. 2Q
- C. Q
- D. 1.5Q
- E. 2/3Q
- F. 0.5Q
- G. Zero
- H. None of the above
Three identical metal balls A, B and C have charge 4Q, -2Q and zero, as shown below. What is the charge on C after you let A first touch C, and then remove A and let B touch C?

A. 4Q  
B. 2Q  
C. Q  
D. 1.5Q  
E. 2/3Q  
F. 0.5Q  
G. Zero  
H. None of the above
Two **uncharged** metal spheres located on top of insulating poles are initially in contact as shown above. A positively charged insulator is brought up and removed, **and then** the spheres are separated. What are the signs of the final charges on the two spheres?

1. Q1 is + and Q2 is –
2. Q1 is 0 and Q2 is –
3. Q1 is – and Q2 is –
4. Q1 is + and Q2 is 0
5. Q1 is 0 and Q2 is 0
6. Q1 is – and Q2 is 0
7. Q1 is + and Q2 is +
8. Q1 is 0 and Q2 is +
9. Q1 is – and Q2 is +

Two **uncharged** metal spheres located on top of insulating poles are initially in contact as shown above. A positively charged insulator is brought up and then the spheres are separated **before the positively charged insulator is removed**. What are the signs of the final charges on the two spheres?

1. Q1 is + and Q2 is –
2. Q1 is 0 and Q2 is –
3. Q1 is – and Q2 is –
4. Q1 is + and Q2 is 0
5. Q1 is 0 and Q2 is 0
6. Q1 is – and Q2 is 0
7. Q1 is + and Q2 is +
8. Q1 is 0 and Q2 is +
9. Q1 is – and Q2 is +
Tom places a negative charge at the top corner of the triangle to test the electric field produced by the +Q and −Q charges at the top 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 direction of the electric field at the origin, as shown by the black dot. The electric field there points

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

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
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

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

1. 3<2<1
2. 1<2<3
3. 2<1<3
4. 1=2<3
5. 2=3<1
6. 1=2=3
At which point, A or B, will the magnitude of 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.
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.

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 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.
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 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.
A total charge $Q$ is uniformly distributed over the length $L$ of a line charge distribution. The charge density $\lambda$ per meter of length is given by

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

1. $\frac{Q}{L}$
2. $\left(\frac{Q}{L}\right) dx$
3. $\frac{L}{Q}$
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

$$\frac{Q}{L} dx$$

1. $\frac{Q}{L}$
2. $\left(\frac{Q}{L}\right) dx$
3. $\frac{L}{Q}$
4. $Q dx$
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 created by a short element $dx$ is given by

1. \[ \frac{K Q}{L} \frac{dx}{r^2} \times \frac{a}{r} \]

2. \[ \frac{K Q}{L} \frac{dx}{r^2} \times \frac{x}{r} \]

3. \[ \frac{K Q}{L} \frac{dx}{r^2} \times \frac{a}{x} \]

4. \[ \frac{K Q}{L} \frac{dx}{r^2} \times \frac{x}{a} \]
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. $\frac{Q}{2\pi R} d\theta$
2. $\frac{Q}{\pi R} d\theta$
3. $\frac{Q}{\pi R} d\theta$
4. $\frac{Q}{\pi} d\theta$
5. $\frac{Q}{2\pi} d\theta$
6. $\frac{Q}{\pi} d\theta$

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

1. $kQd\theta \sin \theta \frac{1}{\pi R^2}$
2. $kQd\theta \cos \theta \frac{1}{\pi R^2}$
3. $kQd\theta \sin \theta \frac{1}{\pi R^3}$
4. $kQd\theta \cos \theta \frac{1}{\pi R^3}$
5. $0$ of 200
6. $0$ of 200
A total charge $Q$ is uniformly distributed over a ring with radius $R$. Without integration, the total electric field created by this ring is given by:

1. $\frac{kQ}{R^2}$
2. $\frac{kZQ}{R^3}$
3. $\frac{kQ}{R^2 + Z^2}$
4. $\frac{kZQ}{(R^2 + Z^2)^{3/2}}$
A thick-walled electric sphere has a charge +Q placed at its center. The electric field in the region enclosed by the metal sphere (R<R_B) is:

1. E = kQ/R^2
2. Zero
3. Goes to zero near the metal.
4. None of the above.

A thick-walled electric sphere has a charge +Q placed at its center. The electric field outside of the metal sphere (R>R_A), is:

1. E = kQ/R^2
2. Zero
3. Goes to zero near the metal surfaces.
4. None of the above.
A charge -2Q is brought near a conducting sphere. The electric field inside the conducting sphere is:

1. -2kQ/R²
2. +2kQ/R²
3. Requires integration due to image charges.
4. Zero
5. None of the above.

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.
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. 2. 3. 4.

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

The positive charge is now moved and kept fixed 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. 2. 3.

1. 1 2. 2 3. 3 4. 4 5. 5

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

1. 
2. 
3. 
4. 

1. 1
2. 2
3. 3
4. 4
The red arrows indicate electric field lines. What charge is inside the yellow box?

1. Positive
2. Negative
3. Zero
4. Can not be determined

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. 35
3. -35
4. -40
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 $\vec{E} = 50\hat{j}$. What is the net flux through the cube?

1. 100 N-m$^2$/C
2. 50
3. 0
4. -50
5. -150
The following figure shows cross sections of three blue cylinders, each with charge Q uniformly distributed throughout its volume. Concentric with each cylinder is a red cylindrical Gaussian surface, all three have the same radius. Rank the Gaussian surfaces according to the electric field at any point on the surface.

The following are two-dimensional cross sections through several three-dimensional closed spheres and one cube. Rank order, from largest to smallest, the electric fluxes $\Phi_a$ to $\Phi_e$ through surfaces a to e.
A ball with charge \(-50e\) lies at the center of a hollow spherical metal shell that has a net charge of \(-100e\). What are the charges on the shell’s inner surface and outer surfaces, 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

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 surfaces, 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?

1. Left $-\eta/2\varepsilon_0$, right $0$
2. Left $-\eta/2\varepsilon_0$, right $\eta/2\varepsilon_0$
3. Left $\eta/2\varepsilon_0$, right $\eta/2\varepsilon_0$
4. Left $0$, right $\eta/2\varepsilon_0$
5. None of the above

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 is positive?

1. Left $-\eta/\varepsilon_0$, middle $\eta/\varepsilon_0$, right $\eta/\varepsilon_0$
2. Left $-\eta/2\varepsilon_0$, middle $\eta/2\varepsilon_0$, right $\eta/2\varepsilon_0$
3. Left $0$, middle $\eta/\varepsilon_0$, right $0$
4. Left $0$, middle $\eta/2\varepsilon_0$, right $0$
5. Left $-\eta/\varepsilon_0$, middle $0$, right $\eta/\varepsilon_0$
Two large parallel conducting plates are kept a short distance apart as shown below. 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?

1. Left - \( \eta /\varepsilon_0 \), middle \( \eta /\varepsilon_0 \), right \( \eta /\varepsilon_0 \)
2. Left - \( \eta /2\varepsilon_0 \), middle \( \eta /2\varepsilon_0 \), right \( \eta /2\varepsilon_0 \)
3. Left 0, middle \( \eta /\varepsilon_0 \), right 0
4. Left 0, middle \( \eta /2\varepsilon_0 \), right 0
5. Left - \( \eta /\varepsilon_0 \), middle 0, right \( \eta /\varepsilon_0 \)
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. $J_b > J_a = J_d > J_c$
4. $J_c > J_b > J_a > J_d$
5. $J_c > J_b > J_a = J_d$

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 $\sigma_I: \sigma_{II}$ 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. $R_I:R_{II}=4:1$
2. $R_I:R_{II}=2:1$
3. $R_I:R_{II}=1:2$
4. $R_I:R_{II}=1:4$
5. $R_I:R_{II}=1:1$
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 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 \textit{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.

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 is the best qualitative match to the electric field shown above?

1. 0 V 50 V
2. 50 V 0 V
3. 0 V 50 V
4. 50 V 0 V
5. 0 V 50 V
6. 50 V 0 V

Which set of arrows best describes the relative magnitudes and directions of the electrical fields at points A and B?

1. A → B
2. A → B
3. A → B
4. A → B
5. A → B
6. A → B
A 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 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 to the test charge?

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 distance between B and C also is 0.5m. How much work was done in moving the test charge from A to C?

1. 1.5J
2. 0J
3. –1.5J
4. 2.12J
5. –2.12J
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. How much work was done on the test charge this time?

-1.5 J of work was done moving the -0.6 C test charge from B to C. What is the voltage difference between B and C, and at which point is the voltage larger?

1. 1.5 J
2. 0 J
3. -1.5 J
4. Infinitely big
5. Do not know at this time.
The distance between two parallel plates is increased **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.
For more review, let's plot $E$ and $V$ for the capacitor used in Wednesday's lecture:

1. $E = 4500 \text{N/C}$, $V = 90 \text{v}$
2. $E = 4500 \text{N/C}$, $V = 90 \text{v}$
3. $E = 4500 \text{N/C}$, $V = 90 \text{v}$
4. $E = 4500 \text{N/C}$, $V = 90 \text{v}$

Now place a neutral 1 cm conducting slab symmetrically between the plates, and again draw $E$ and $V$:

1. $E = 9000 \text{N/C}$, $V = 90 \text{v}$
2. $E = 4500 \text{N/C}$, $V = 90 \text{v}$
3. $E = 4500 \text{N/C}$, $V = 90 \text{v}$
4. $E = 4500 \text{N/C}$, $V = 90 \text{v}$

The plates are 2 cm apart.
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 $V$:

1. $E = 4500 \text{N/C}$, $V = 45 \text{v}$, $22.5 \text{v}$

2. $E = 9000 \text{N/C}$, $V = 90 \text{v}$

3. $E = 9000 \text{N/C}$, $V = 90 \text{v}$

4. $E = 4500 \text{N/C}$, $V = 45 \text{v}$

The plates are 2 cm apart.
You have the electric field shown in the top graph on your right. What does the corresponding shape of the potential look like if the potential at R=20 is 0 volts? (Don’t worry about the actual voltage, but just the shape as a function of x.)

You put some charge on a hollowed spherical conductor. How and where will the charge be distributed? You need to know this to answer the following question. Which one of the following graphs shows how the shape of the electric field (in red) and potential (in blue) change with the radius R?
Instead putting the charge on the surface of the conductor, you put a point charge at the center. Which one of the following graphs shows how electric field and potential change with the radius $R$? You will need to figure out the image charges on the sphere to answer this question.

1.  
2.  
3.  
4.  
5.
The point P is in the middle between two charges +Q and –Q. What is the electrical potential at point P? (In this and all of the following questions assume the electrical potential at infinity is zero)

1. 0
2. kQ/R²
3. 2kQ/R
4. 2\sqrt{2} kQ/R
5. 2kQ²/R
6. kQ/R
7. None of the above

The point P is in the middle between two charges +Q and -Q. What is the magnitude of the electric field at point P?

1. 0
2. kQ/R²
3. 2kQ/R²
4. 2\sqrt{2} kQ/R²
5. 2kQ/R
6. kQ/R
7. None of the above
P is in the middle of four charges with values +Q arranged in a square as shown. The distance from each charge to point P is R. What is the **electric potential** at point P?

1. 0
2. kQ/R
3. 2kQ/R^2
4. 2\sqrt{2}kQ/R
5. 2kQ/R
6. 4kQ/R
7. None of the above

P is in the middle of four charges with values +Q arranged in a square as shown. The distance from each charge to point P is R. What is the magnitude of the **electric field** at point P?

1. 0
2. kQ/R^2
3. 2kQ/R^2
4. 2\sqrt{2}kQ/R
5. 2kQ/R
6. 4kQ/R^2
7. None of the above
V is 10 volts, and C₁, C₂ and C₃ are 1, 2 and 3 microfarads, respectively. The charge on C₁ is

1. 5 μC
2. 10 μC
3. 15 μC
4. 20 μC

V is 10 volts, C₂ and C₃ are 2 and 3 microfarads, C_{eq} is the equivalent capacitor of C₂ and C₃. Which of the following statement is true?

1. Q_{eq} = Q₂ = Q₃
2. Q_{eq} = Q₂ + Q₃
3. Q_{eq} > Q₂ > Q₃
4. Q_{eq} > Q₃ > Q₂
5. None of the above
V again is 10 volts and $C_1$, $C_2$ and $C_3$ and 1, 2, and 3 microfarads, respectively. The charge is **greatest** on which capacitor?

1. $C_1$
2. $C_2$
3. $C_3$
4. $C_2$ and $C_3$

V again is 10 volts, and $C_1$, $C_2$ and $C_3$ are 1, 2 and 3 microfarads, respectively. The voltage is **least** on which capacitor? (Remember $V = Q/C$)

1. $C_1$
2. $C_2$
3. $C_3$
4. $C_2$ and $C_3$
Calculate the equivalent capacitance between A and B. All capacitors have the same value C.

1. C/2
2. C
3. 2C
4. 4C

Calculate the equivalent capacitance between A and B. All capacitors have the same value C. It is almost the same sketch as before, but we’ve added a horizontal connection.

1. C/2
2. C
3. 2C
4. 4C
Calculate the equivalent capacitance between A and B.

1. C/2
2. C
3. 4C/3
4. 3C/2

Calculate the equivalent capacitance between A and B. It is almost the same sketch as before, but we’ve added a horizontal connection.

1. C/2
2. C
3. 4C/3
4. 3C/2
V is 10 volts and $C_1$ and $C_2$ are both 2 microfarads. The switch is first at 1, then is switched to 2. The final charge on $C_1$ is:

1. 5 µC
2. 10 µC
3. 6.67 µC
4. 3.33 µC
5. 0 µC

V is 10 volts. $C_1$ is 2 microfarads. $C_2$ is 4 microfarads. The switch is first at 1, then is switched to 2. The final charge on $C_1$ is:

1. 5 µC
2. 10 µC
3. 6.67 µC
4. 13.33 µC
5. 0 µC
V is 10 volts, while $C_1$, $C_2$, and $C_3$ are all 2 microfarads. The switch is first at 1, then is switched to 2. The charge on $C_1$ is:

1. 5 µC  
2. 10 µC  
3. 6.67 µC  
4. 13.33 µC  
5. 0 µC

V is 10 volts, $C_1$, $C_2$, and $C_3$ are both 2 microfarads. The switch is first at 1, then is switched to 2. The charge on $C_1$ is:

1. 5 µC  
2. 10 µC  
3. 6.67 µC  
4. 13.33 µC  
5. 0 µC
Which of these following graphs shows a capacitor charging to a higher voltage?

1. ![Graph 1](image1)
2. ![Graph 2](image2)
3. ![Graph 3](image3)
4. ![Graph 4](image4)
5. ![Graph 5](image5)

Which of the following graphs shows a capacitor discharging?

1. ![Graph 6](image6)
2. ![Graph 7](image7)
3. ![Graph 8](image8)
4. ![Graph 9](image9)
5. ![Graph 10](image10)
What is the time constant for the discharge of the capacitors in the following Figure?

1. 1ms
2. 1s
3. 2ms
4. 2s
5. 4ms
6. 8ms
7. None of the above.
What is the equivalent resistance between points a and b?

![Diagram showing a series connection of 20.0 Ω resistors between points a and b.]

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

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

![Diagram of a voltage divider circuit with R connected between V_{in} and V_{out} where V_{out} = 100 Ω.]

1. 1100 Ω
2. 1000 Ω
3. 900 Ω
4. 500 Ω
5. 100 Ω
6. None of the above
The 10 Ω resistor in the following figure is dissipating 40W of power. How much power is the 5 Ω resistor dissipating?

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

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.
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. \( C = D > B > A \)

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. \( C = D > B > A \)
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

Which of these diagrams represent the same circuit?

1. a and b
2. a and c
3. b and c
4. a, b, and c
5. a, b, and d
What is the equivalent resistance?

1. 5 Ω
2. 7 Ω
3. 8 Ω
4. 6.2 Ω
5. None of the above

What is the equivalent resistance between points a and b?

1. 7 Ω
2. 6.67 Ω
3. 17 Ω
4. 13 Ω
5. 5 Ω
6. None of the above
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. $3V/R$

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. A similar question was used at a high school Science Olympiad.

1. $V/R$
2. $V/2R$
3. $V/3R$
4. $2V/R$
5. $3V/R$
Consider the circuit given below. Again, 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.* This is similar to another Science Olympiad question.

1. \( \frac{V}{R} \)
2. \( \frac{V}{2R} \)
3. \( \frac{V}{3R} \)
4. \( \frac{2V}{R} \)
5. \( \frac{3V}{R} \)
An Amperian loop is drawn around two current carrying wires, as shown below. What is the value of \[ \oint \mathbf{B} \cdot d\mathbf{s} \] moving CCW viewed from above around the loop? (Note that \( i_1 \) and \( i_2 \) don’t have to be the same magnitude)

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 \[ \oint \mathbf{B} \cdot d\mathbf{s} \] moving CCW viewed from above around the loop?

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 $\int B \cdot d\mathbf{s}$ 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. $\mu_0 (I_2 - I_1)$
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?

Current upward on side nearest you
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)

1. Current clockwise; north pole on top
2. Current counterclockwise, north pole on top
3. Current clockwise; north pole on bottom
4. Current counterclockwise, north pole on bottom
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 in
2. Goes out
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 in
2. Goes out
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 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
A permanent magnet has field lines as shown above. An electron moves out of the slide toward you at point A. The magnetic force on the electron is best represented by:

1. One
2. Two
3. Three
4. Four
5. Five
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. One
2. Two
3. Three
4. Four
5. Five
6. None of the above
An electron moves vertically upward at point C. The magnetic force on the electron is best represented by:

A proton is at rest at point D. The magnetic force on the proton is best represented by:
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 negative charged particle is moving horizontally to the right in a uniform magnetic field which is pointing in the same direction of 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 negative charged particle is moving upward 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. One
2. Two
3. Three
4. Four
5. Five
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. One
2. Two
3. Three
4. Four
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. None
2. Two
3. Three
4. Four
5. Five
6. Six

5. Zero
6. None of the above
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.

An airplane viewed from above flies through a small magnetic field oriented vertically downward toward the ground, as shown to the right. Which of the following statements is true?

1. The plane’s front becomes positively charged.
2. The tip of the left wing becomes positively charged.
3. The tip of the right wing becomes positively charged.
4. The top of the plane becomes positively charged.
5. None of the above, there’s no charging mechanism.
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.
What is the direction of the magnetic force on the particle?

1.  
2.  
3.  
4.  
5.  
6.  

A proton experiences upward force in an uniform magnetic field, what could be the direction of the magnetic field?

1.  
2.  
3.  
4.  
5.  
6.  

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What is the direction of the magnetic force on the particle?

1. 
2. 
3. 
4. 
5. 
6. 
7.

• 1
• 2
• 3
• 4
• 5
• 6
• 7

The magnetic force is zero

You have two parallel currents with the same direction. What is the direction of the magnetic field on I₂ that is created by I₁?

1. 
2. 
3. 
4. 
5. 
6.

• 1
• 2
• 3
• 4
• 5
• 6
You have two parallel currents with the same direction. What is the direction of the magnetic force due to $I_1$ that acts on $I_2$?

- 1
- 2
- 3
- 4
- 5
- 6
A proton enters a uniform magnetic field into the page as shown, which of the following could be its subsequent trajectory?

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

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?

1. A
2. B
3. C
4. D
5. E
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?

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

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
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

Which of the following graphs best represents the current in the loop as it moves at constant speed from position a to position d?

1. 1
2. 2
3. 3
4. 4
5. 5
What is the value of the voltmeter just after the switch is closed? Both resistors have the same value.

1. 0 V
2. 3.33 V
3. 5 V
4. 10V
5. None of the above

What is the value of the voltmeter reading a long time after the switch has been closed? Remember that there are two resistors with the same value.

1. 0 V
2. 3.33 V
3. 5 V
4. 10V
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. 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.
Is there an induced current in this circuit? If so, what is its direction?

1. Yes, clockwise.
2. Yes, counterclockwise.
3. No.

A rectangular loop could move in three directions near a straight long wire with current I. In which direction will this loop have an induced current?

A. only.
B. 1 and 2 only.
C. 2 only.
D. 1 and 3 only.
E. All of the above.
F. None of the above.
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?

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 is the wires increases, but the loop doesn't move.
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

When 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
The loop below starts to rotate 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 \textit{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. \( \varepsilon \) vs. \( t \)
2. \( \varepsilon \) vs. \( t \)
3. \( \varepsilon \) vs. \( t \)
4. \( \varepsilon \) vs. \( t \)
5. \( \varepsilon \) vs. \( t \)
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
APPENDIX B

COMMON EXAM MULTIPLE-CHOICE QUESTIONS
MC1, 6 points. Four charges with the same magnitude but differing signs are connected to the corners of a square, as shown below. The rightmost charge is positive, but the other three are negative. Circle the number of the arrow corresponding to the direction of the net force on the leftmost charge due to the other three charges.

MC2, 6 points. Two large-area thin parallel conducting plates are connected to a battery. A thick neutral conducting plate is then inserted into the center so that it is equally separated on both sides from the outside plates and never touches either of them. The final assembly is shown on the right. Which of the four sets of graphs below would qualitatively best represent $E$ and $V$ versus position? The graphs start at the left thin plate and end at the right one.

MC3, 6 points. Which of the following arrows best represents the direction of the electric field at the position represented by the black dot?

(a) (b) (c) The electric field is zero.

(d) (e) (f) None of the above.
MC4, 6 points. A positive charge is kept fixed off-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?

(a)  
(b)  
(c)  
(d)  
(e)  

MC5, 6 points. Circle the letter beside the set of equipotential lines that provides the best qualitative match for the electric field lines given at the top. Don’t worry about the exact voltage values, but rather whether the voltage is increasing or decreasing when moving from left to right, and whether the equipotential lines are getting closer together or further apart.

(a)  
(b)  
(c)  
(d)  
(e)  
(f)  

Electric Field Lines

+50 volts 0 volts +50 volts 0 volts +50 volts 0 volts

0 volts +50 volts +50 volts 0 volts +50 volts 0 volts
MC1, 6 points. Two wires with the same diameters and the same lengths are connected in series, as shown below. The ratio of their conductivities is $\sigma_1:\sigma_2 = 1:3$. The ratio of their resistances is therefore:

(a) $R_1:R_2 = 1:3$  
(b) $R_1:R_2 = 3:1$  
(c) $R_1:R_2 = 1:9$  
(d) $R_1:R_2 = 9:1$

(e) $R_1:R_2 = 1:1$  
(f) None of the previous answers.

MC2, 6 points. The capacitor in the circuit given below initially has zero charge, and then the switch S is closed at time $t=0$. Which of the following sets of curves best represents the current $i$ through the resistor and the voltage $V$ across the capacitor as a function of time.

(a)  
(b)  
(c)  
(d)  

MC3, 6 points. In the following figure, all five resistances have the same value $R$ and the emf for the ideal battery is $\varepsilon$. Find the total current flow through the battery. The loop in one of the diagonal wires means that it jumps over and is not connected to the other diagonal wire. In this question, tracing wires could be helpful.

(a) $\frac{\varepsilon}{3R}$  
(b) $\frac{\varepsilon}{2R}$  
(c) $\frac{\varepsilon}{R}$

(d) $\frac{2\varepsilon}{R}$  
(e) $\frac{3\varepsilon}{R}$  
(f) None of the above.
MC4, 6 points. The field of a permanent bar magnet is shown below. A proton moves to the right at point P. The direction of the magnetic force on the proton is best represented by which vector?

(a) \[\rightarrow\] (b) \[\rightarrow\]

(c) \[\uparrow\] (d) \[\downarrow\]

(e) Zero. (f) None of the above.

MC5, 6 points. A proton traveling to the right enters a uniform magnetic field directed into the page, and subsequently follows the trajectory indicated by the letter B. A deuteron and an alpha particle also traveling to the right enter the magnetic field at the same point and with the same velocity as the proton. Deuterons have the same charge and twice the mass of protons, while alpha particles have twice the charge and four times the mass of protons. Which of the following combinations give the right trajectories both for the deuteron and alpha particles?

(a) deuteron: D, alpha: A
(b) deuteron: B, alpha: C
(c) deuteron: B, alpha: B
(d) deuteron: C, alpha: C
(e) deuteron: C, alpha: B
(f) deuteron: B, alpha: E
MC1, 6 points. A +2μC and a -1μC charge are placed on the corners of a right triangle with two equal sides, as shown below. The direction of the force on a -3μC negative charge placed at the lower left-hand corner is best represented by which of the arrows?

a)  

b)  

c)  

d)  

e)  

f)  

b)  

c)  

d)  

e)  

MC2, 6 points. A -2Q charge is brought to within a distance R of a neutral thick-walled conducting sphere, as shown on the right. The direction of the electric field at the center of the large sphere is:

a) Toward the -Q charge  

b) Away from the -2Q charge  

C) Can’t tell without adding the fields from the induced charges  

d) Zero  

e) None of the above.

MC3, 6 points. Two large parallel plates are placed a short distance apart and charged uniformly to the same positive surface charge density σ as shown on the right. What are the electric fields in the three regions? Use to the right as the positive direction.

a) Left: \(-\frac{\sigma}{\epsilon_0}\), middle: 0, right: \(+\frac{\sigma}{\epsilon_0}\)

b) Left: \(+\frac{\sigma}{2\epsilon_0}\), middle: \(+\frac{\sigma}{2\epsilon_0}\), right: \(+\frac{\sigma}{2\epsilon_0}\)

c) Left: 0, middle: \(+\frac{\sigma}{\epsilon_0}\), right: 0

d) Left: \(-\frac{\sigma}{2\epsilon_0}\), middle: 0, right: \(+\frac{\sigma}{2\epsilon_0}\)

e) Left: \(+\frac{\sigma}{\epsilon_0}\), middle: \(+\frac{\sigma}{\epsilon_0}\), right: \(+\frac{\sigma}{\epsilon_0}\)

f) None of the above
MC4, 6 points. Positive charge is placed on the thick-walled conducting sphere shown to the right. Which of the following sets of graphs best represent the electric field $E$ and potential $V$ as a function of radius:

![Graphs of electric field and potential vs. radius](image)

a) E [Graph]
   V [Graph]
   R
   b) E [Graph]
      V [Graph]
      R
   c) E [Graph]
      V [Graph]
      R
   d) E [Graph]
      V [Graph]
      R
   e) E [Graph]
      V [Graph]
      R
   f) None of the above.

MC5, 6 points. The following capacitors are hooked as shown to a 10 volt battery. $C_1 = 1 \mu F$, $C_2 = 2 \mu F$ and $C_3 = 3 \mu F$. The voltage is least across which capacitor(s)?

a) $C_1$
   b) $C_2$
   c) $C_3$
   d) $C_2$ and $C_3$
   e) All three have the same voltage

![Capacitor diagram](image)
MC6, 6 points. What is the magnitude and direction of the current in the fifth wire (the one with a question mark)?

![Diagram of current flow](image)

a) 1A out of the junction.  
b) 1A into the junction.  
c) 15A into the junction  
d) 15A out of the junction  
e) None of the above

MC7, 6 points. A plane viewed from above flies to the right through a small magnetic field oriented downward toward the ground, as shown. Which of the following statements is true?

![Diagram of a plane](image)

a) The plane’s front becomes positively charged.  
b) The plane’s rear becomes positively charged.  
c) The tip of the left wing becomes positively charged.  
d) The tip of the right wing becomes positively charged.  
e) The top of the plan becomes positively charged.  
f) None of the above; there’s no mechanism to make charges move.
MC8, 6 points. All of the loops below carry the same current I. The current goes to the left on the top part of the loop and toward the right on the bottom side of the loop. Rate the loops according to the magnitude of magnetic field at the dot, with the largest first.

A

B

C

a) A>B>C  b) A>C>B  c) B>C>A  d) B>A>C  e) C>B>A  f) C>A>B

MC9, 6 points. What is the direction of the magnetic field at the point P, which is exactly in the middle between two parallel wires carrying equal currents I in opposite directions. The wires are drawn as arrows to indicate the direction of the current.

P

a) Left  b) Right  c) Up  d) Down  e) Into the page  f) The magnetic field is zero at P.

MC10, 6 points. 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, largest first.

A  B  C  D

X X X X X X X X X X X X
X X X X X X X X X X X X
X X X X X X X X X X X X
X X X X X X X X X X X X
X X X X X X X X X X X X
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X X X X X X X X X X X X
X X X X X X X X X X X X
X X X X X X X X X X X X
X X X X X X X X X X X X
B into page

a) C>D>B>A  b) C=D>B=A  c) D>C>B>A

d) C>D=B>A  e) C>D>B=A
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1) In the figure below the charge in the middle is $Q = -3.7 \text{ nC}$. For what charge $q_1$ will $q_2$ be in static equilibrium?

A) 1.9 nC  
B) 3.7 nC  
C) 7.4 nC  
D) 15 nC  
E) 30 nC

2) X and Y are two uncharged metal spheres on insulating stands. A positively charged rod R is brought close to X as shown below in Figure 1. Sphere Y is now moved away from X, as shown in Figure 2. What is the nature of the final charge on spheres X and Y?

A) X neutral, Y positive  
B) X negative, Y positive  
C) Both X and Y are negative  
D) Both X and Y are neutral  
E) X is positive and Y is neutral
3) Four charged particles (two having charge \( +Q \) and two having charge \( -Q \)) are placed as shown below. Each charge is equidistant from the origin. In which direction is the net electric field at the point P, which is on the y axis?

A) directly to the left, in the \(-x\) direction
B) upwards and toward the left
C) the net field is zero, so there is no direction
D) upwards and toward the right
E) directly up (in the positive y direction)

4) The diagram shows the electric field lines arising from two small charged particles P and Q.

Consider the following three statements:

1) The magnitude of the charge on P is smaller than the charge on Q.
2) The electrostatic force on P is smaller than the electrostatic force on Q.
3) P and Q are repelling each other.

Which of the above statements are true?

A) All three are true
B) 1 and 2 are true
C) 1 and 3 are true
D) 2 and 3 are true
E) Only 1 is true
5) A charge of 8 nC is located inside a sphere with a radius of 1 cm. What is the flux through the sphere?

A) 900 N\cdot m^2/C
B) 0 N\cdot m^2/C
C) 0.9 N\cdot m^2/C
D) 8 \times 10^{-9} N\cdot m^2/C
E) 7 \times 10^{-11} N\cdot m^2/C

6) A fuse ‘blows’ if the current exceeds 1.0 A. It is made of material that melts if the current density exceeds 300 A/cm^2. What is the diameter of the wire in the fuse?

A) 0.65 mm
B) 0.90 mm
C) 0.98 mm
D) 1.02 mm
E) 1.3 mm
7) Four charged particles (two having charge $+Q$ and two having charge $-Q$) are distributed on the xy-plane as shown below. Each charge is equidistant from the origin. The potential is zero at infinity. The potential at location P, which is on the z-axis, is:

A) positive
B) negative
C) zero
D) impossible to determine based on the information given
E) opposite in sign to the potential at O

8) Two infinite sheets of charge are shown, with charge densities as given in the figure. Rank from highest to lowest the magnitude of the electric fields at points 1, 2, and 3.

![Diagram of two infinite sheets of charge]

\[ \eta_1 = -\eta_0 \quad \eta_2 = 3\eta_0 \]

A) 1, 2&3 (tie)
B) 1&3 (tie), 2
C) 2, 1&3 (tie)
D) 2&3 (tie), 1
E) 2, 3, 1
F) 3, 2, 1
9) Four charges with the same magnitude but differing signs are connected to the corners of a square, as shown below. The rightmost charge is positive, but the other three are negative. Write down the number of the arrow corresponding to the direction of the net force on the leftmost charge due to the other three charges.

10) Which of the following arrows best represents the direction of the electric field at the position represented by the black dot:

A)  

B)  

C) The electric field is zero.  

D)  

E)  

-Q  

-Q  

+Q  

+Q  

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11) A positive charge is kept fixed \textit{off-center} inside a fixed spherical \textit{neutral} conducting shell. Which of the following represents the charge distribution on the inner and outer walls of the shell?

(a) ![Charge Distribution A]
(b) ![Charge Distribution B]
(c) ![Charge Distribution C]
(d) ![Charge Distribution D]
(e) ![Charge Distribution E]

12) All the charges below are either $+Q$ or $-Q$. The points at the center of each figure have the same distance $R$ to all the charges. Which center point gives you the largest potential? Which center point gives you the largest electric field?

(1) ![Charge Distribution 1]
(2) ![Charge Distribution 2]
(3) ![Charge Distribution 3]
(4) ![Charge Distribution 4]

(a) Biggest potential: 3, biggest electric field: 4
(b) Biggest potential: 1, biggest electric field: 2
(c) Biggest potential: 2, biggest electric field: 3
(d) Biggest potential: 2, biggest electric field: 4
(e) Biggest potential: 3, biggest electric field: 2
(f) Biggest potential: 3, biggest electric field: 1
13) Circle the letter beside the set of equipotential lines that provides the best 
**qualitative** match for the electric field lines given at the top. Don’t worry about 
the exact voltage values, but rather whether the voltage is increasing or 
decreasing when moving from left to right, and whether the equipotential lines 
are getting closer together or further apart.

14) Charge Q is distributed uniformly throughout a hollow spherical insulating shell. The 
net electric flux through the inner surface of the shell is

A) 0  
B) Q/ε₀  
C) Q/2ε₀  
D) Q/(2πε₀)  
E) Q/(4πε₀)
15) A charge $Q$ is placed at the center of a cube whose edges have length $R$. The electric flux through one face of the cube is
   A) $Q/\varepsilon_0$
   B) $Q/4\varepsilon_0$
   C) $Q/6\varepsilon_0$
   D) $Q/(2\pi\varepsilon_0 R^2)$
   E) $Q/(4\pi\varepsilon_0 R^2)$

16) An electron traveling north enters a region where the electric field is uniform and points west. After crossing this region, the electron
   A) is going in the same direction with a higher speed
   B) is going in the same direction with a lower speed
   C) is moving to the northwest
   D) is moving to the northeast
   E) continues with the same speed in the same direction.
17) The equipotential surfaces associated with an isolated point charge are:
   A) cones directed radially outward from the charge
   B) vertical planes
   C) horizontal planes
   D) concentric spheres centered on the charge
   E) concentric cylinders with the charge on the axis

18) A light bulb carries a current of 0.75 A. The total charge passing through it in one hour is:
    A) 1125 C
    B) 2700 C
    C) 3600 C
    D) 4050 C
    E) 5400 C
19) A hollow spherical conducting shell has charge \( q \). A point charge \( Q \) is placed outside the shell. The charge on the *inner surface* of the shell and the charge on the *outer surface* of the shell are, respectively,

A) 0, \( q \)
B) \( q, Q-q \)
C) \(-Q, q\)
D) \(-Q, Q+q\)
E) \(-q, 2q\)

20) Three pithballs are suspended from thin threads. Various objects are then rubbed against other objects (nylon against silk, glass against polyester, etc.) and some or all of the pithballs are touched with one these objects. It is found that pithballs 1 and 2 attract each other, and that pithballs 2 and 3 repel each other. From this we can conclude that

A) 1 and 3 carry charges of opposite sign.
B) 1 and 3 carry charges of equal sign (2 has opposite sign).
C) all three carry the charges of the same sign.
D) one of the objects carries no charge.
E) we need to do more experiments to determine the sign of the charges.
1) A charge Q is distributed uniformly through an insulating sphere of radius R. The magnitude of the electric field at a point R/2 from the center is
   a) $Q/(4\pi\varepsilon_0 R^2)$
   b) $3Q/(4\pi\varepsilon_0 R^2)$
   c) $Q/(\pi\varepsilon_0 R^2)$
   d) $Q/(8\pi\varepsilon_0 R^2)$
   e) $Q/(16\pi\varepsilon_0 R^2)$

2) A charge Q is placed at the center of a cube whose edges have length R. The electric flux through one face of the cube is
   a) $Q/\varepsilon_0$
   b) $Q/4\varepsilon_0$
   c) $Q/6\varepsilon_0$
   d) $Q/(2\pi\varepsilon_0 R^2)$
   e) $Q/(4\pi\varepsilon_0 R^2)$
3) A hollow insulating thin spherical shell of inner radius $R_1$ and outer radius $R_2$ has charge $Q$ uniformly distributed through it. A point charge $Q/2$ is placed at the center of the hollow sphere. The magnitude of the electric field at a point $r\approx R_1$ from the center of the cavity is
   a) $Q/(4\pi\varepsilon_0 r^2)$
   b) $Q/(8\pi\varepsilon_0 r^2)$
   c) $3Q/(4\pi\varepsilon_0 r^2)$
   d) $3Q/(8\pi\varepsilon_0 r^2)$
   e) $Q/(4\pi\varepsilon_0 r^2)$

4) If 500 J of work is required to move a 40 C charge from one point to another, the magnitude of the potential difference between the two points is
   a) 20,000 V
   b) 12.5 V
   c) 0.08 V
   d) 500 V
   e) 40 V
5) If both the plate area and the plate separation of a parallel plate capacitor are doubled, the new value of the capacitance is
a) 1/4 the original capacitance
b) 1/2 the original capacitance
c) unchanged
d) twice the original capacitance
e) four times the original capacitance

6) What is the equivalent capacitance across the battery in the circuit below?
C1=800 μF; C2=200 μF; C3=400 μF

a) 114 μF
b) 133 μF
c) 343 μF
d) 933 μF
e) 1400 μF
7) A capacitor initially has a capacitance of 5 μF. It is charged to a potential of 1 V, then disconnected. The plates are then pulled apart so its capacitance becomes 2 μF. The magnitude of work done to move the plates is:
   a) 0
   b) $4 \times 10^{-6}$ J
   c) $8 \times 10^{-6}$ J
   d) $9 \times 10^{-6}$ J
   e) $18 \times 10^{-6}$ J

8) A 90 W light bulb carries a current of 0.75 A. The total charge passing through it in one hour is:
   a) 1125 C
   b) 2700 C
   c) 3600 C
   d) 4050 C
   e) 5400 C
9) A certain wire has resistance $R$. Another wire is made of the same material and has half the length and half the radius of the first wire. The resistance of the second wire is
   a) $R/4$
   b) $R/2$
   c) $R$
   d) $2R$
   e) $4R$

10) The diagram below shows a straight wire carrying current $i$ in a uniform magnetic field. The magnetic force on the wire is indicated by an arrow but the magnetic field is not shown. The magnetic field is
   a) toward the right
   b) up
   c) down
   d) into the page
   e) out of the page

   ![Diagram of a straight wire with current $i$ and force $F$]

   $F$
11) The figure below shows a configuration made up of 5 ohm resistors. The resistance from point F to point G is
a) 1 ohm
b) 2 ohms
c) 2.5 ohms
d) 3.125 ohms
e) 5 ohms

12) In the diagram below, a current flows through a wire with two straight segments and a semicircular segment as shown. The magnitude of the magnetic field at the center of the semicircle (point C) is:

a) \( \frac{\mu_0 i}{4R} \)
b) \( \frac{\mu_0 i}{2R} \)
c) \( \frac{\mu_0 i}{R} \)
d) \( \frac{\mu_0 i}{2\pi R} \)
e) \( \frac{\mu_0 i}{4\pi R} \)
13) The magnitude of the magnetic field at point C in the diagram below is:

a) \( \frac{\mu_0 i}{4} \left( \frac{1}{R_1} + \frac{1}{R_2} \right) \)

b) \( \frac{\mu_0 i}{4} \left( \frac{1}{R_1} - \frac{1}{R_2} \right) \)

c) \( \frac{\mu_0 i}{2} \left( \frac{1}{R_1} + \frac{1}{R_2} \right) \)

d) \( \frac{\mu_0 i}{2} \left( \frac{1}{R_1} - \frac{1}{R_2} \right) \)

e) none of the above

14) A straight conductor carrying a current \( i \) splits into two identical semicircular arcs as shown below, each of which carries half of the current. The radius of the arcs is \( R \). What is the magnitude of the magnetic field at the center of the resulting circular loop (point C)?

a) zero.

b) \( \frac{\mu_0 i}{2R} \)

c) \( \frac{\mu_0 i}{4R} \)

d) \( \frac{\mu_0 i}{2\pi R} \)

e) none of the above is correct
15) Which of the following is one of the correct loop equations for the circuit below with the currents as chosen in the diagram?
   a) \(-I_1R_1 + \mathcal{E}_1 + I_3R_3 = 0\)
   b) \(-I_2R_2 + \mathcal{E}_1 + I_3R_3 = 0\)
   c) \(-I_1R_1 + \mathcal{E}_2 + I_3R_3 = 0\)
   d) \(-I_1R_1 + \mathcal{E}_1 - I_3R_3 = 0\)
   e) \(-I_1R_1 + \mathcal{E}_2 - I_2R_2 = 0\)

16) A proton (charge=+e) traveling at some finite speed enters a region that contains a uniform magnetic field \(\mathbf{B}\) and a uniform electric field \(\mathbf{E}\) that are perpendicular to each other and also to the initial velocity \(v\) of the particle. Which of the following conditions is necessary for the proton to continue moving without any change in velocity?
   a) This is impossible—the proton’s velocity must change.
   b) \(\mathbf{B} = e\mathbf{E}\)
   c) \(\mathbf{E}\mathbf{B} = ev\)
   d) \(v = E/B\)
   e) \(Ev = E/B\)
17) 10 C of charge are placed on a spherical conducting shell. A -2 C point charge is placed at the center of the cavity. The net charge in Coulombs on the inner surface of the shell is:

a) 0
b) -2
c) +2
d) -8
e) +8

18) An ammeter $A$ is connected between points $a$ and $b$ in the circuit below, in which the four resistors are identical. The current through the ammeter is

- a) $I$
- b) $I/2$
- c) $I/4$
- d) zero
- e) need more information
19) The light bulbs in the circuit are identical. When the switch is closed,

![Circuit Diagram]

a) the intensity of light bulb $A$ increases.
b) the intensity of light bulb $A$ decreases.
c) the intensity of light bulb $B$ increases.
d) the intensity of light bulb $B$ decreases.
e) nothing changes.

20) Choose the correct statement:

a) If $E=0$ at a point $P$, then $V$ must be zero at $P$.
b) If $V=0$ at a point $P$, then $E$ must be zero at $P$.
c) A positive charge tends to go from a region of high potential to a region of low potential.
d) A negative charge initially at rest in a field will tend to move in the same direction as the field.
e) None of the above are correct.
21) A solid insulating sphere of radius R contains a uniform volume distribution of positive charge. Which of the graphs below correctly gives the magnitude E of the electric field as a function of r?

a) I
b) II
c) III
d) IV
e) V

22) All of the loops below carry the same current I. The current goes to the left on the top part of the loop and toward the right on the bottom side of the loop. Rate the loops according to the magnitude of magnetic field at the dot, with the largest first.

a) A>B>C
b) A>C>B
c) B>A>C
d) C>B>A
e) C>A>B
23) 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, largest first.

a) $C>D>B>A$

b) $C=D>B=A$

c) $D>C>B>A$

d) $C>D=B>A$

e) $C>D>B=A$

24) What is the value of the voltmeter reading after a long time after the switch has been closed? All resistors have the same value.

a) 0 V
b) 3.33 V
c) 5 V
d) 6.66 V
e) 10 V
25) Consider the circuit given below. Each resistor has the same value $R$ and the battery 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.*

a) $V/R$

b) $V/2R$

c) $V/3R$

d) $2V/R$

e) $3V/R$

26) 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

a) Right on $-2Q$, left on $+Q$

b) Zero force on $-2Q$, left on $+Q$

c) Zero on both charges

d) Right on $-2Q$, zero on $+Q$

e) None of the above.
27) The following capacitors are hooked as shown to a 10 volt battery. \( C_1 = 1 \mu F \), \( C_2 = 2 \mu F \) and \( C_3 = 3 \mu F \). The voltage is least across which capacitor(s)?

a) \( C_1 \)  
b) \( C_2 \)  
c) \( C_3 \)  
d) \( C_2 \) and \( C_3 \)  
e) All three have the same voltage

28) The resistors in the circuit shown each have a resistance of 500Ω. What is the equivalent resistance of the circuit?

a) 2000 Ω  
b) 1000 Ω  
c) 500 Ω  
d) 250 Ω  
e) 125 Ω
29) A solenoid 4.0 cm long consists of 7035 loops of wire. If the magnetic field inside the solenoid is 2.0 T, what is the magnitude of the current that flows through it?

a) 0.11 A  
b) 4.0 A  
c) 9.0 A  
d) 11 A  
e) 110 A

30) A wire carrying a current is shaped in the form of a circular loop of radius 3.0 mm. If the magnetic field strength at its center is 1.3 mT with no external magnetic fields contributing to it, what is the magnitude of the current that flows through the wire?

a) 6.2 A  
b) 11 A  
c) 15 A  
d) 19 A  
e) 27 A
MC.1) [6] A +2μC and a -1μC charge are placed on the corners of a right triangle with two equal sides, as shown below. The direction of the force on a -3μC negative charge placed at the lower left-hand corner is best represented by which of the arrows?

(a) (b) (c) (d) (e) (f)

MC.2) [6] Which of the following arrows best represents the direction of the electric field at the position represented by the black dot?

(a) (b) (c) (d) (e) (f) The electric field is zero.

MC.3) [6] Two large parallel plates are placed a short distance apart and charged uniformly to the same positive surface charge density η as shown. What are the electric fields in the three regions (left of the plates, between the plates, right of the plates)? Positive values indicate that the field is to the right, and negative values indicate that the field is to the left.

(a) Left: -η/ε₀, middle: 0, right: +η/ε₀
(b) Left: +η/2ε₀, middle: +η/2ε₀, right: +η/2ε₀
(c) Left: 0, middle: +η/ε₀, right: 0
(d) Left: -η/2ε₀, middle: 0, right: +η/2ε₀
(e) Left: +η/ε₀, middle: +η/ε₀, right: +η/ε₀

+11 +11

+ +

+ +

+ +

+ +

+ +

+ +

Left Middle Right
MC.4) [6] The following are two-dimensional cross sections through several three-dimensional closed spheres. Rank order, from largest to smallest, the electric fluxes $\Phi_a$ to $\Phi_d$ through surfaces a to d.

(a) $\Phi_c = \Phi_d > \Phi_a = \Phi_b$
(b) $\Phi_a > \Phi_b > \Phi_c > \Phi_d$
(c) $\Phi_d > \Phi_c > \Phi_a > \Phi_b$
(d) $\Phi_b = \Phi_d > \Phi_a = \Phi_c$
(e) $\Phi_b > \Phi_a > \Phi_c > \Phi_d$

MC.5) [6] Two wires made of different material are connected as shown. The left wire has half the diameter as the right wire. What must be the ratio of the conductivities, $\sigma_{\text{left}} / \sigma_{\text{right}}$, so that the electric field strength is the same in the two wires?

(a) 4
(b) 2
(c) 1
(d) 1/2
(e) 1/4
MC.1) [6] All the charges have the same magnitude. The potential at point P is:

- Positive (a)
- Negative (b)
- Zero (c)
- Pointing up (d)
- Pointing to the right (e)

MC.2) [6] An electron is released from rest at point B, where the potential is 0 V. Afterward, the electron...

- Moves toward A with an increasing speed (a)
- Moves toward A with a steady speed (b)
- Remains at rest at B (c)
- Moves toward C with a steady speed (d)
- Moves toward C with an increasing speed (e)

MC.3) [6] A, B, and C are identical bulbs. How will the brightness (power) of bulb B compare to that of bulb A?

- 4x (a)
- 2x (b)
- 1x (same) (c)
- 1/2x (d)
- 1/4x (e)
- Zero (f)
MC.4) [6] The distance between two parallel plates is increased while they remain hooked to a battery. Which one of the following statements is true?

(a) The voltage between the plates will decrease.
(b) The electric field between the plates will increase.
(c) The electric field between the plates will decrease.
(d) The charge on the plates will stay the same.
(e) The charge on the plates will increase.
(f) None of the above.

---

MC.5) [6] Which set of equipotential surfaces matches this electric field? Longer field lines are used to indicate stronger field.

(a) -20 V 30 V 30 V -20 V -20 V 30 V
(b)  
(c)  

(d) 50 V 0 V 0 V 50 V 50 V 0 V
(e)  
(f)  

---

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MC.1) [6] All the charges above have either +Q or -Q. The points at the center of each figure have the same distance R to all the charges. Which center point gives you the biggest electric field magnitude?

a) 1  
b) 2  
c) 3  
d) 4  
e) 3 & 4 are tied for biggest

MC.2) [6] All the charges above have either +Q or -Q. The points at the center of each figure have the same distance R to all the charges. For which of the figures is the potential at the center point equal to zero?

a) 1 and 3  
b) 2 and 4  
c) 1 and 4  
d) 1, 3 and 4  
e) 2 only

MC.3) [6] A negative charge is moving up the page. The page is filled with a uniform electric field (not magnetic field) pointing to the right. What is the direction of the electric force on the charge?

a) into the page  
b) out of the page  
c) up the page  
d) down the page  
e) left  
f) right  
g) no force
MC.4) [6] A positive charge is placed on the thick-walled conducting sphere shown to the right. Which of the following sets of graphs best represent the electric field $E$ and potential $V$ as a function of radius:

a) 

\[
\begin{align*}
\text{E} & \quad \text{R} \\
\text{V} & \quad \text{R}
\end{align*}
\]

d) 

\[
\begin{align*}
\text{E} & \quad \text{R} \\
\text{V} & \quad \text{R}
\end{align*}
\]

e) 

\[
\begin{align*}
\text{E} & \quad \text{R} \\
\text{V} & \quad \text{R}
\end{align*}
\]

MC.5) [6] Three resistors are connected as shown to a 10 volt battery. $R_1=1$ ohm, $R_2=2$ ohm, and $R_3=3$ ohm. The voltage is least across which resistor?

a) $R_1$
b) $R_2$
c) $R_3$
d) $R_1$ and $R_2$ are tied for least
e) All three have the same voltage
MC.9) [6] A very long wire with a 3/4 circle in the middle carries a current I. What is the magnitude of the magnetic field at the point P in the middle of the circle?

a) \[ \frac{\mu_0 I}{2\pi R} + \frac{3\mu_0 I}{8R} \]

b) \[ \frac{\mu_0 I}{2\pi R} - \frac{3\mu_0 I}{8R} \]

c) \[ \frac{\mu_0 I}{\pi R} + \frac{3\mu_0 I}{8R} \]

d) \[ \frac{\mu_0 I}{\pi R} - \frac{3\mu_0 I}{8R} \]

e) \[ \frac{3\mu_0 I}{8R} \]

MC.7) [6] An electron moves horizontally toward a screen. The electron moves along the path that is shown because of a magnetic force caused by a magnetic field. In what direction does that magnetic field point?

a) Toward the top of the page
b) Toward the bottom of the page
c) Into the page
d) The magnetic field is in the direction of the curved path
e) Out of the page
MC.8) [6] What is the direction of the magnetic field at the point P, which is exactly in the middle between two parallel wires carrying equal currents I in opposite directions. The wires are drawn as arrows to indicate the direction of the current.

a) left  
b) right  
c) up  
d) down  
e) out of the page  
f) into the page  
g) zero

MC.6) [6] A uniform magnetic field points out of the page and is confined to the region shown. What is the direction of the induced current in the rectangular loop of wire as it is pushed to the left into the magnetic field?

a) into the page  
b) out of the page  
c) clockwise  
d) counterclockwise  
e) no induced current

MC.10) [6] 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, largest first.

a) C>D>B>A  
b) C>D=B>A  
c) D>C=B>A  
d) D=C>B=A  
e) C>D>B=A

A B C D

\[ \text{X X X X X X X X} \]

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B into page
APPENDIX C

CLICKER SURVEY QUESTION FORMS
Clicker Survey Fall 2006

VOTING MACHINE SURVEY

-2 = strongly disagree, -1 = mildly disagree, 0 = neutral, +1 = mildly agree, +2 = strongly agree

1. I like using the voting machine.
   (choose one) -2 -1 0 +1 +2

2. The voting machine helps me understand lectures better.
   (choose one) -2 -1 0 +1 +2

3. The voting machine helps me stay focused during lecture.
   (choose one) -2 -1 0 +1 +2

4. I’ve talked about the voting machine to 0_____, 1-5_____, 6-10_____, >10_____ people.

5. I prefer questions that confirm what I already know.
   (choose one) -2 -1 0 +1 +2

6. I prefer questions that require me to extend and make an intelligent guess.
   (choose one) -2 -1 0 +1 +2

7. What would be the ideal proportion of type 5 and type 6 questions?
   Type-5(confirm)_____% Type-6(extend)_____%

8. We should do more voting machine questions with numbers.
   (choose one) -2 -1 0 +1 +2

9. When it looks like most or all of the class has gotten a particular question correct on the voting machine, how should we proceed? (Circle one)
   a. Move on to the next point.
   b. Make a quick check that students answered the question for the right reasons.
   c. Go over the question in depth regardless of how many students got it right/wrong.

10. It bothers me if I get a question wrong, even though I may learn something.
    (choose one) -2 -1 0 +1 +2

11. I would recommend using voting machines in all future introductory physics courses.
    (choose one) -2 -1 0 +1 +2

12. What are the most beneficial aspects you have received from using the voting machine? The least beneficial? Use the back side of this form if you have a long answer.
CLICKE SURVEY WINTER 2006
QUESTIONS ARE ON FRONT AND BACK SIDE OF THIS SHEET

-2 = strongly disagree, -1 = mildly disagree, 0 = neutral, +1 = mildly agree, +2 = strongly agree

1. I liked using clickers.  
   (choose one) -2 -1 0 +1 +2

2. Clickers helped me understand lectures better.  
   (choose one) -2 -1 0 +1 +2

3. Clickers made me feel involved in the course.  
   (choose one) -2 -1 0 +1 +2

4. Clickers helped me get instant feedback on what I knew and didn’t know.  
   (choose one) -2 -1 0 +1 +2

5. Using clickers helped me think more deeply about course materials.  
   (choose one) -2 -1 0 +1 +2

6. Clickers facilitated good interaction among students in the class.  
   (choose one) -2 -1 0 +1 +2

7. I prefer questions that confirm what I already know.  
   (choose one) -2 -1 0 +1 +2

8. I prefer questions that require me to extend and make an intelligent guess.  
   (choose one) -2 -1 0 +1 +2

9. When it looks like most of the class has answered a particular clicker question correctly, how should we proceed? (Circle one)  
   a. Move on to the next point.  
   b. Make a quick check that students answered the question for the right reasons.  
   c. Go over the question in depth regardless of how many students got it right/wrong.

10. It bothers me if I get a question wrong, even though I may learn something.  
    (choose one) -2 -1 0 +1 +2

11. I would take another course that uses clickers.  
    (choose one) -2 -1 0 +1 +2

12. I would recommend using clickers in all future introductory physics courses.  
    (choose one) -2 -1 0 +1 +2

13. Using clickers is a waste of time.  
    (choose one) -2 -1 0 +1 +2

14. I will avoid classes using clickers in the future.  
    Go to the back of this page to finish the questionnaire.
    (choose one) -2 -1 0 +1 +2

15. What are the most beneficial aspects you have received from using clickers? The least beneficial?
Clicker Survey Winter & Spring 2007

CLIKER SURVEY: QUESTIONS ARE ON THE FRONT AND BACK SIDES OF THIS SHEET

-2 = strongly disagree, -1 = mildly disagree, 0 = neutral, +1 = mildly agree, +2 = strongly agree

1. I liked using clickers.
   (choose one) -2 -1 0 +1 +2

2. Clickers helped me understand lectures better.
   (choose one) -2 -1 0 +1 +2

3. Clickers made me feel involved in the course.
   (choose one) -2 -1 0 +1 +2

4. Clickers helped me get instant feedback on what I knew and didn’t know.
   (choose one) -2 -1 0 +1 +2

5. Using clickers helped me think more deeply about course materials.
   (choose one) -2 -1 0 +1 +2

6. I prefer questions that confirm what I already know.
   (choose one) -2 -1 0 +1 +2

7. I prefer questions that require me to extend and make an intelligent guess.
   (choose one) -2 -1 0 +1 +2

8. When it looks like most of the class has answered a particular clicker question correctly, how should we proceed? (Circle one)
   a. Move on to the next point.
   b. Make a quick check that students answered the question for the right reasons.
   c. Go over the question in depth regardless of how many students got it right/wrong.

9. It bothers me if I get a question wrong, even though I may learn something.
   (choose one) -2 -1 0 +1 +2

10. I would take another course that uses clickers.
    (choose one) -2 -1 0 +1 +2

11. I would recommend using clickers in all future introductory physics courses.
    (choose one) -2 -1 0 +1 +2

12. I will avoid classes using clickers in the future.
    (choose one) -2 -1 0 +1 +2

13. Using clickers should be eliminated and the extra time used for more demonstrations.
    (choose one) -2 -1 0 +1 +2

Go to the back of this page to finish the questionnaire.
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 to3 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?