The "Fully Interactive" Physics Lecture: Active-Learning Instruction in a Large-Enrollment Setting

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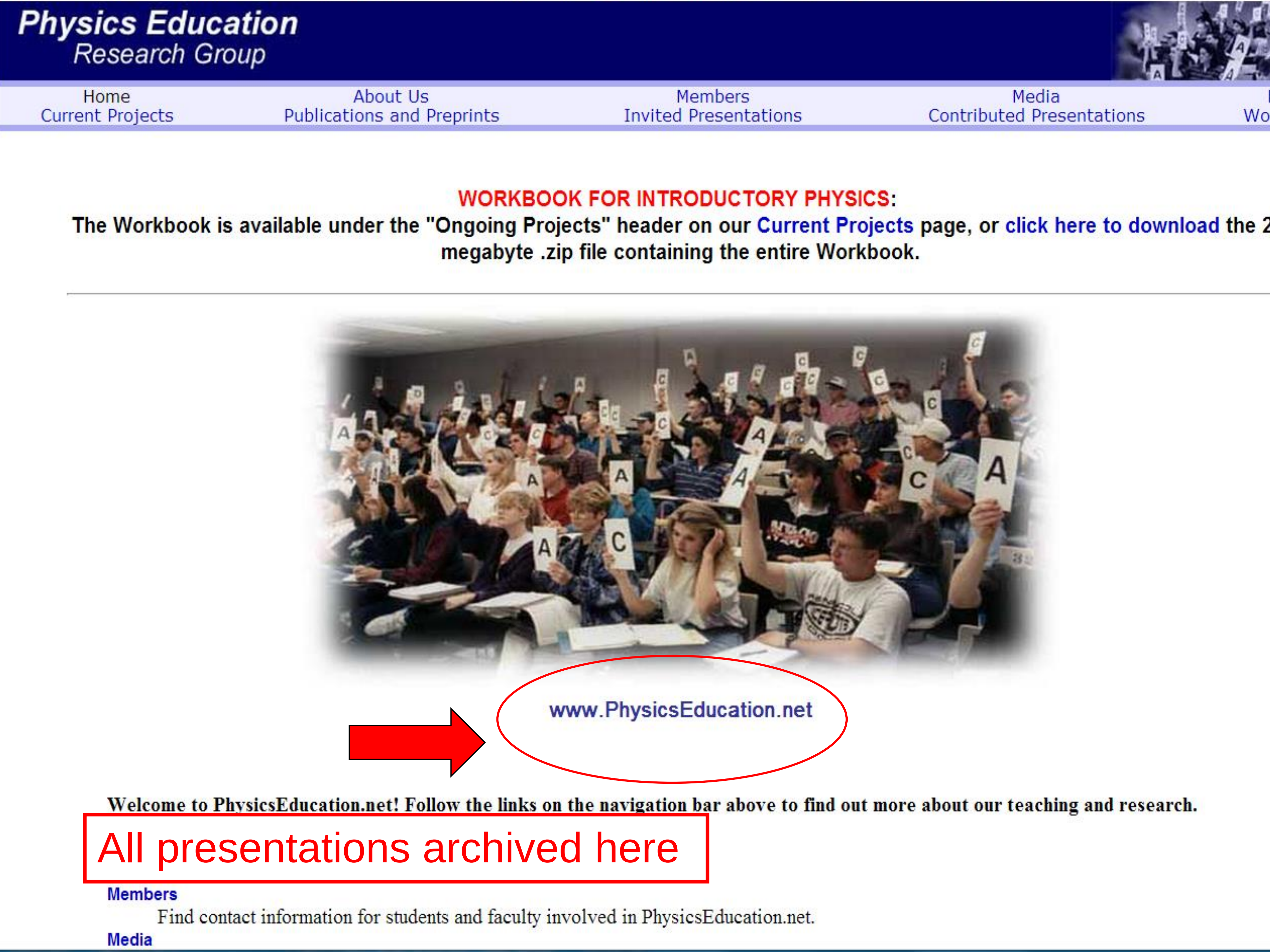

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Based on:

David E. Meltzer and Kandiah Manivannan, “Transforming the lecture-hall environment: The fully interactive physics lecture,” Am. J. Phys. **70**(6), 639-654 (2002).

David E. Meltzer and Ronald K. Thornton, “Resource Letter ALIP-1: Active-Learning Instruction in Physics,” Am. J. Phys. **80**(6), 479-496 (2012).

RESOURCE LETTER

Resource Letter ALIP–1: Active-Learning Instruction in Physics

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This Resource Letter provides a guide to the literature on research-based active-learning instruction in physics. These are instructional methods that are based on, assessed by, and validated through research on the teaching and learning of physics. They involve students in their own learning more deeply and more intensely than does traditional instruction, particularly during class time. The instructional methods and supporting body of research reviewed here offer potential for significantly improved learning in comparison to traditional lecture-based methods of college and university physics instruction. We begin with an introduction to the history of active learning in physics in the United States, and then discuss some methods for and outcomes of assessing pedagogical effectiveness. We enumerate and describe common characteristics of successful active-learning instructional strategies in physics. We then discuss a range of methods for introducing active-learning instruction in physics and provide references to those methods for which there is published documentation of student learning gains.
[DOI: 10.1119/1.3678299]

I. INTRODUCTION

We provide a guide to the literature on research-based active-learning instruction in physics. This refers to instructional methods that are based on, assessed by, and validated through research on the teaching and learning of physics. Active-learning instruction involves students in their own learning more deeply and more intensely than does traditional instruction, particularly during class time, in ways we shall explicitly identify. Interest in and use of these instructional methods in the United States have grown dramatically over the past

laboratory activities that require all students to express their thinking through speaking, writing, or other actions that go beyond listening and the copying of notes, or execution of prescribed procedures; (3) they have been tested repeatedly in actual classroom settings and have yielded objective evidence of improved student learning. (Another term that has often been used for research-based active-learning instruction in physics is "Interactive Engagement" [Ref. 10]. We don't believe there are significant distinctions between the intended meanings of these terms.)

“Research-based Active-Learning Instructional Methods in Physics”

[often known as “Interactive Engagement”:

R. R. Hake, “Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses,” Am. J. Phys. **66**, 64-74 (1998).]

“Research-based Active-Learning Instructional Methods in Physics”

1) explicitly based on research in the learning and teaching of physics;

2) incorporate classroom activities that require all students to express their thinking through speaking, writing, or other actions;

3) tested repeatedly in actual classroom settings and have yielded objective evidence of improved student learning.

Common Characteristics:

A. Instruction is informed and explicitly guided by research regarding students' pre-instruction knowledge state and learning trajectory, including:

- *Specific learning difficulties related to particular physics concepts*
- *Specific ideas and knowledge elements that are potentially productive and useful*
- *Students' beliefs about what they need to do in order to learn*
- *Specific learning behaviors*
- *General reasoning processes*

B. Specific student ideas are elicited and addressed.

C. Students are encouraged to “figure things out for themselves.”

D. Students engage in a variety of problem-solving activities during class time.

E. Students express their reasoning explicitly.

F. Students often work together in small groups.

G. Students receive rapid feedback in the course of their investigative or problem-solving activity.

H. Qualitative reasoning and conceptual thinking are emphasized.

I. Problems are posed in a wide variety of contexts and representations.

J. Instruction frequently incorporates use of actual physical systems in problem solving.

K. Instruction recognizes the need to reflect on one’s own problem-solving practice.

L. Instruction emphasizes linking of concepts into well-organized hierarchical structures.

M. Instruction integrates both appropriate content (based on knowledge of students’ thinking) and appropriate behaviors (requiring active student engagement).

Research in physics education (and other fields) suggests that:

- “Teaching by telling” has only limited effectiveness
  - can inform students of isolated bits of factual knowledge
  - can (potentially) motivate and guide
- For deep understanding of
  - complex concepts
  - how to apply theory to practice

  → ….

Research in physics education (and other fields) suggests that:

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  - can inform students of isolated bits of factual knowledge
  - can (potentially) motivate and guide
- For deep understanding of
  - complex concepts
  - how to apply theory to practice

→ students have to "figure it out for them-selves" by grappling with problems and applying principles in varied practical contexts

Research in physics education suggests that:

- Problem-solving activities with rapid feedback yield improved learning gains

- Eliciting and addressing common conceptual difficulties improves learning and retention

What needs to go on in class?

- Clear and organized presentation by instructor is not *at all* sufficient
- Must find ways to guide students to synthesize concepts in their own minds
- Instructor's role becomes that of guiding students through problem-solving activities
  - aid students to work their way through complex chains of thought

What needs to go on in class?

- Clear and organized presentation by instructor is not *at all* sufficient

- Must find ways to guide students to synthesize concepts in their own minds

- Focus of classroom becomes *activities and thinking in which students are engaged*
  – and *not* what the instructor is presenting or how it is presented

Active-Learning Pedagogy

(“*Interactive Engagement*”)

- problem-solving activities during class time
  - student group work
  - frequent question-and-answer exchanges

- “*guided-inquiry*” methodology: guide students with leading questions, through structured series of research-based problems

Key Themes of Research-Based Instruction

- Emphasize qualitative, non-numerical questions to reduce unthoughtful "plug and chug."

- Make extensive use of multiple representations to deepen understanding.

  (Graphs, diagrams, words, simulations, animations, etc.)

- Require students to *explain their reasoning* (verbally or in writing) to more clearly expose their thought processes.

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- **Deliberately elicit and address common student ideas (which have been uncovered through subject-specific research).**

The Biggest Challenge: Large Lecture Classes

- Difficult to sustain active learning in large classroom environments
- Two-way communication between students and instructor is key obstacle
- Curriculum development must be matched to innovative instructional methods

Active Learning in Large Classes

- **De-emphasis of lecturing**; Instead, ask students to respond to questions and work problems that address known difficulties.

- Incorporate cooperative **group work** using both multiple-choice and free-response items

- Use whiteboards, clickers, and/or flashcards to obtain **rapid feedback** from entire class.

Goal: *Transform large-class learning environment into "office" learning environment (i.e., instructor + one or two students)*

Key Parameter: Room Format Influences Ability to Monitor Students Written Work

- Do students sit at tables?
  - If yes, whiteboards can probably be used.
  - If no, clickers or flashcards may be helpful.
- Can instructor walk close by most students?
  - If yes, easy to monitor most groups' work
  - If no, must monitor sample of students
- Number of students is a secondary factor, but potentially significant

Features of the Interactive Lecture

- High frequency of questioning
- Must often create unscripted questions
- Easy questions used to maintain flow
- Many question variants are possible
- Instructor must be prepared to use diverse questioning strategies

Curriculum Requirements for Research-Based Active-Learning Lectures

- Question sequences (short-answer and multiple-choice) and brief free-response problems
  - emphasizing qualitative questions
  - employing multiple representations
  - targeting known difficulties
  - covering wide range of topics
- Text reference (or “Lecture Notes”) with strong focus on conceptual and qualitative questions

e.g.: *Workbook for Introductory Physics*

(DEM and K. Manivannan, online at physicseducation.net)

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High frequency of questioning

- Time per question can be as little as 15 seconds, as much as several minutes.
  - similar to rhythm of one-on-one tutoring
- Maintain small conceptual “step size” between questions for high-precision feedback on student understanding.

Features of the Interactive Lecture

- High frequency of questioning
- **Must often create unscripted questions**
- Easy questions used to maintain flow
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Must often create unscripted questions

- Not possible to pre-determine all possible discussion paths
- Knowledge of probable conceptual sticking points is important
- Make use of standard question variants
- Write question and answer options on board
  (but can delay writing answers, give time for thought)

Features of the Interactive Lecture

- High frequency of questioning
- Must often create unscripted questions
- **Easy questions used to maintain flow**
- Many question variants are possible
- Instructor must be prepared to use diverse questioning strategies

Easy questions used to maintain flow

- Easy questions (> 90% correct responses) build confidence and encourage student participation.
- If discussion bogs down due to confusion, can jump start with easier questions.
- Goal is to maintain continuous and productive discussion with and among students.

Features of the Interactive Lecture

- High frequency of questioning
- Must often create unscripted questions
- Easy questions used to maintain flow
- **Many question variants are possible**
- Instructor must be prepared to use diverse questioning strategies

Many question variants are possible

- Minor alterations to question can generate provocative change in context.
  - add/subtract/change system elements (force, resistance, etc.)

- Use standard questioning paradigms:
  - greater than, less than, equal to
  - increase, decrease, remain the same
  - left, right, up, down, in, out

Features of the Interactive Lecture

- High frequency of questioning
- Must often create unscripted questions
- Easy questions used to maintain flow
- Many question variants are possible
- **Instructor must be prepared to use diverse questioning strategies**

Instructor must be prepared to use diverse questioning strategies

- If discussion dead-ends due to student confusion, might need to backtrack to material already covered.
- If one questioning sequence is not successful, an alternate sequence may be helpful.
- Instructor can solicit suggested answers from students and build discussion on those.

Interactive Question Sequence

- Set of closely related questions addressing diverse aspects of single concept
- Progression from easy to hard questions
- Use multiple representations (diagrams, words, equations, graphs, etc.)
- Emphasis on qualitative, not quantitative questions, to reduce “equation-matching” behavior and promote deeper thinking

"Fully Interactive" Physics Lecture

DEM and K. Manivannan, Am. J. Phys. ***70,*** *639 (2002)*

- Simulate one-on-one dialogue of instructor's office
- Use numerous structured question sequences, focused on specific concept: small conceptual "step size"
- Use student response system to obtain instantaneous responses from all students simultaneously (e.g., "flash cards")

[a variant of Mazur's "Peer Instruction"]

V

Transforming the lecture-hall environment: The fully interactive physics lecture

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Numerous reports suggest that learning gains in introductory university physics courses may be increased by "active-learning" instructional methods. These methods engender greater mental engagement and more extensive student–student and student–instructor interaction than does a typical lecture class. It is particularly challenging to transfer these methodologies to the large-enrollment lecture hall. We report on seven years of development and testing of a variant of Peer Instruction as pioneered by Mazur that aims at achieving virtually continuous instructor–student interaction through a "fully interactive" physics lecture. This method is most clearly distinguished by instructor–student dialogues that closely resemble one-on-one instruction. We present and analyze a detailed example of such classroom dialogues, and describe the format, procedures, and curricular materials required for creating the desired lecture-room environment. We also discuss a variety of assessment data that indicate strong gains in student learning, consistent with other researchers. We conclude that interactive-lecture methods in physics instruction are practical, effective, and amenable to widespread implementation.

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I. INTRODUCTION

Numerous investigations in recent years have shown active-learning methods to be effective in increasing student learning of physics concepts. These methods aim at promoting substantially greater engagement of students during in-class activities than occurs, for instance, in a traditional physics lecture. A long-standing problem has been that of

The basic elements of an interactive lecture strategy have been described by Mazur.[1] In this paper we broaden and extend that discussion, explaining in detail how the lecture component in large-classroom instruction may be almost eliminated. Depending on the preferences of the instructor and the specific student population, this strategy may yield worthwhile learning outcomes. To carry out the rapid back-and-forth dialogue observed in one-on-one instruction in


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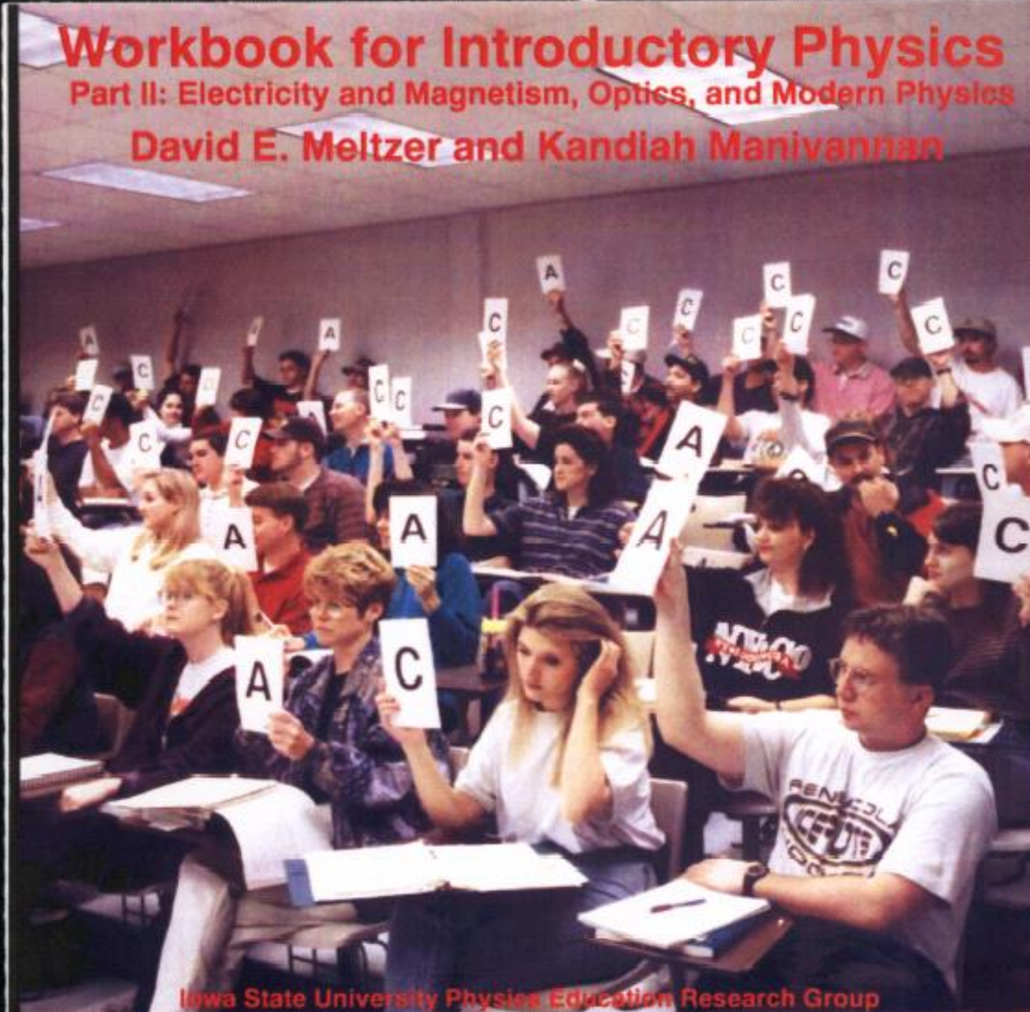
Sequence of Activities

- Very brief introductory lectures ($\approx$10 minutes)
- Students work through sequence of multiple-choice questions, signal responses using flash cards
- Some “lecture” time used for group work on worksheets
- Recitations run as “tutorials”: students use worksheets with instructor guidance
- Homework assigned out of workbook

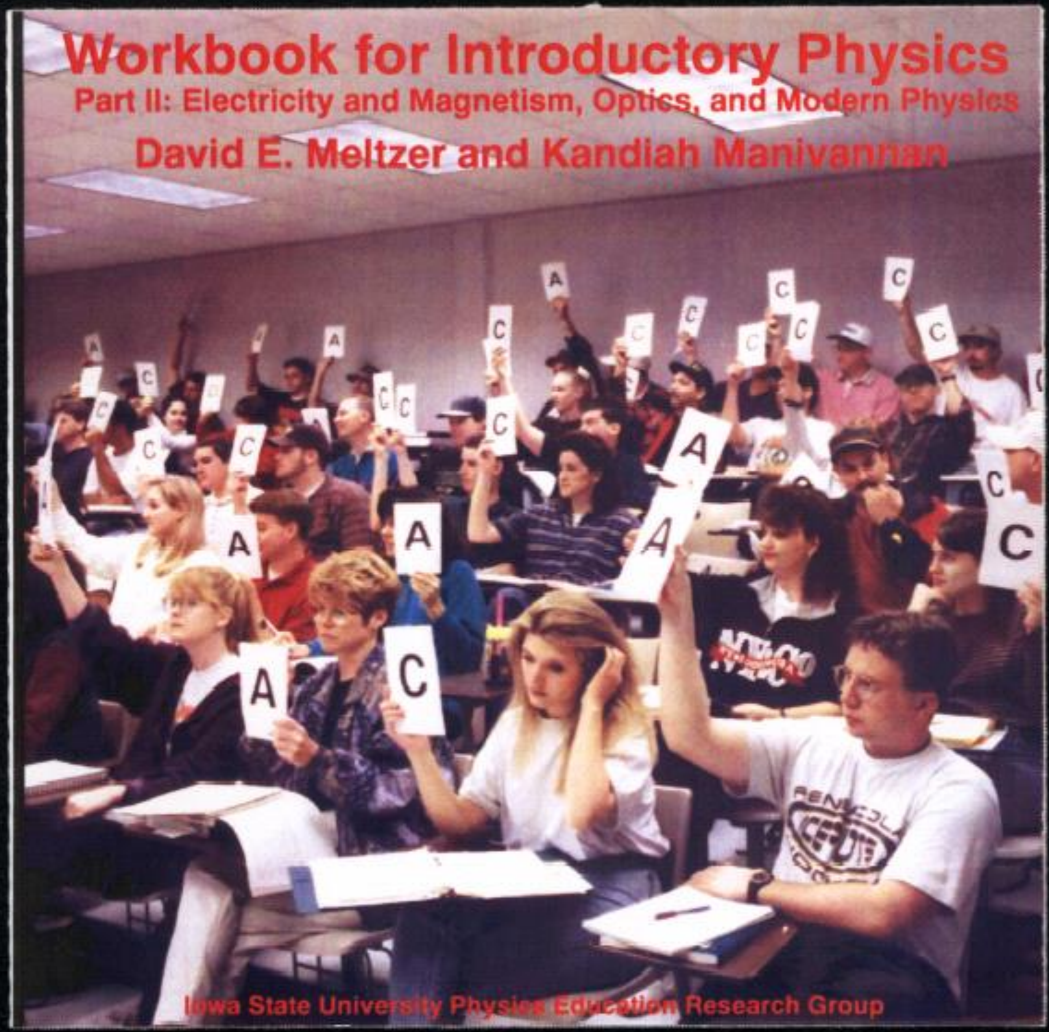
Workbook for Introductory Physics

Part II: Electricity and Magnetism, Optics, and Modern Physics

David E. Meltzer and Kandiah Manivannan



Iowa State University Physics Education Research Group



physicseducation.net

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Chapter 1 Electrical Forces

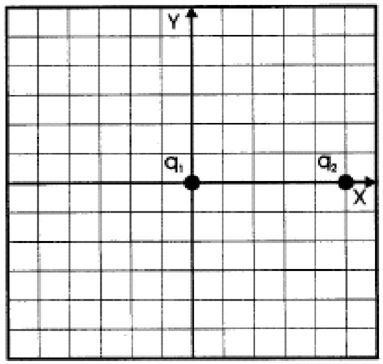
"Flash-Card" Questions

In-Class Questions

Prerequisite Concepts:

- **Positive and negative charges; Coulomb's law: $F = kq_1q_2/r^2$**
- **Protons (+) and electrons (–)**
- **Superposition principle: $F_{net}=F_1+F_2 + . . . + F_n$**
- **Vector addition: $F_{netx}=F_{1x} + F_{2x} + . . . F_{nx}$**
- **Newton's second law, $a = F/m$**

Questions #1–2 refer to the figure below. Charge q_1 is located at the origin, and charge q_2 is located on the positive x axis, five meters from the origin. There are no other charges anywhere nearby.



1. If q_1 is positive and q_2 is negative, what is the direction of the electrical force on q_1?

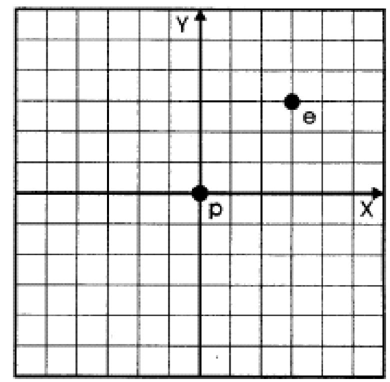
   A. in the positive x direction
   B. in the negative x direction
   C. in the positive y direction
   D. in the negative y direction
   E. the force is not directed precisely along any of the coordinate axes, but at some angle
   F. there is no force in this case

2. If q_1 is positive and q_2 is positive, what is the direction of the electrical force on q_1?

   A. in the positive x direction
   B. in the negative x direction
   C. in the positive y direction
   D. in the negative y direction
   E. the force is not directed precisely along any of the coordinate axes, but at some angle
   F. there is no force in this case

3. In this figure, a proton is located at the origin, and an electron is located at the point (3m, 3m). What is the direction of the electrical force on the proton?

"Flash-Card" Questions



A. 

B. 

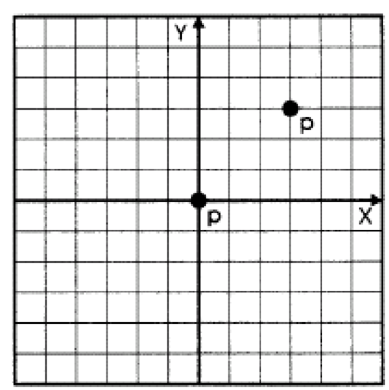
C. 

D. 

E. 

F. 

4. In this figure, a proton is located at the origin, and a proton is located at the point (3m, 3m). The vector representing the electrical force on the proton *at the origin* makes what angle with respect to the positive x axis?



A. 0°
B. 45°
C. 90°
D. 135°
E. 225°
F. 270°

Chapter 3 Electric Potential Energy

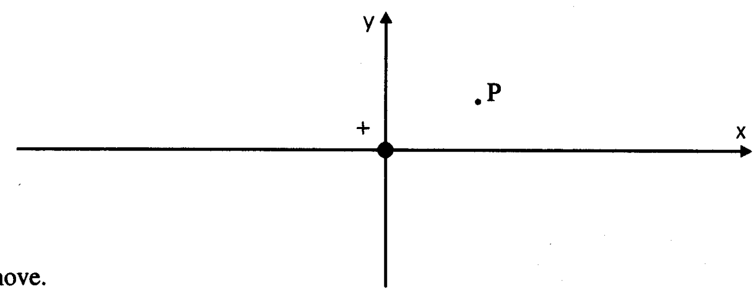
In-Class Questions

Prerequisite Concepts:

- **Positive and negative charge; Coulomb's law**
- **Definition of electric field**
- **Electric field of a parallel plate capacitor**
- **Kinetic energy and mechanical potential energy**
- **Definition of work; work/energy relationship**
- **Conservative forces/conservation of total energy**
- **Electrical force is conservative**

[Note: All gravitational forces may be ignored in this chapter]

1. *(Questions #1–6 refer to this figure.)* This figure shows a positive charge that is ***fixed in position*** at the origin. Suppose a positive charge q is placed at position P, and then released so that it (the charge q) is free to move. What will happen to this charge q?



A. It will not move.
B. It will move closer to the origin.
C. It will move farther away from the origin.
D. It will start moving closer to the origin, but then will reverse direction and start moving back out again.
E. It will start moving away from the origin, but then will reverse direction and start moving back in again.

2. As the charge q moves, what will happen to the magnitude of the electrical force acting on it?

A. The force will remain constant.
B. The force will increase in magnitude.
C. The force will decrease in magnitude, but never quite reach zero.
D. The force will decrease in magnitude, and at a certain point will reach zero.
E. The force will begin to decrease in magnitude, but then will start to increase again.

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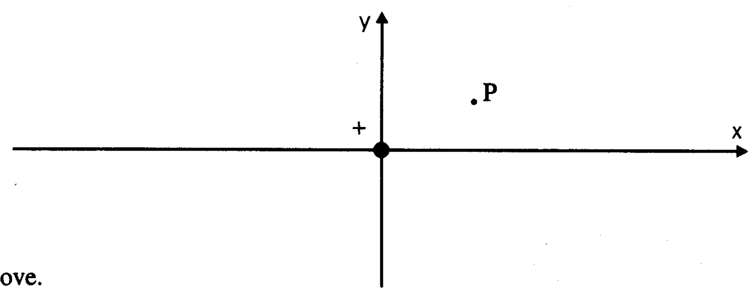
[Note: All gravitational forces may be ignored in this chapter]

#1:

A: 0%
B: 7%
C: 93%
D: 0%
E: 0%

1. *(Questions #1–6 refer to this figure.)* This figure shows a positive charge that is ***fixed in position*** at the origin. Suppose a positive charge q is placed at position P, and then released so that it (the charge q) is free to move. What will happen to this charge q?



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E. The force will begin to decrease in magnitude, but then will start to increase again.

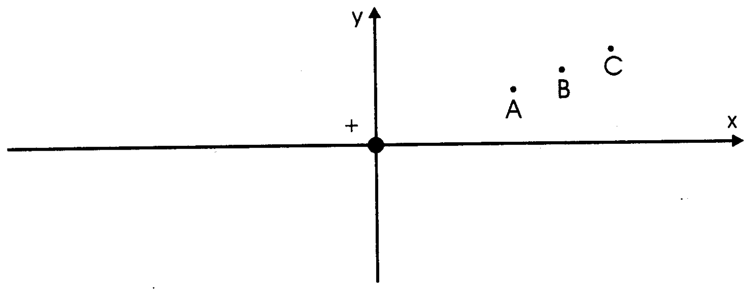
#2:

A: 10%
B: 8%
C: 77%
D: 2%
E: 5%

#7:

A: 2%
B: 3%
C: 3%
D: 83%
E: 9%

7. *(Questions #7–10 refer to this figure.)* In this figure (as in the previous one) a positive charge is fixed in position at the origin. Suppose a positive charge q is held at rest at position A, and then released and allowed to move freely. It passes through position B, and then moves on toward position C. Which of the following statements about charge q is true?



A. Its kinetic energy is the same at B and A, and its electric potential energy is the same at B and A.

B. Its kinetic energy is larger at B than at A, and its electric potential energy is larger at B than at A.

C. Its kinetic energy is smaller at B than at A, and its electric potential energy is smaller at B than at A.

D. Its kinetic energy is larger at B than at A, but its electric potential energy is smaller at B than at A.

E. Its kinetic energy is smaller at B than at A, but its electric potential energy is higher at B than at A.

#8:

A: 0%
B: 2%
C: 8%
D: 87%
E: 3%

8. This question again refers to the situation in Question #7. In comparing the energy of the charge q at positions C and B, which of the following statements is true?

A. Its kinetic energy is the same at C and B, and its electric potential energy is the same at C and B.

B. Its kinetic energy is larger at C than at B, and its electric potential energy is larger at C than at B.

C. Its kinetic energy is smaller at C than at B, and its electric potential energy is smaller at C than at B.

D. Its kinetic energy is larger at C than at B, but its electric potential energy is smaller at C than at B.

E. Its kinetic energy is smaller at C than at B, but its electric potential energy is higher at C than at B.

#9:

A: 0%
B: 13%
C: 7%
D: 53%
E: 22%

9. Again consider the setup shown in Question #7. Suppose now that a positively charged particle is shot from a gun that is located far away from the positive charge at the origin, but which is aimed directly at it. After leaving the gun the particle heads toward the origin, passing first through position C, then position B, and then position A. In comparing its energy at positions C and B, which of the following statements is true?

A. Its kinetic energy and electric potential energy are both the same at C and B.

B. Its kinetic energy and electric potential energy are both larger at C than at B.

C. Its kinetic energy and electric potential energy are both smaller at C than at B.

D. Its kinetic energy is larger at C than at B, but its electric potential energy is smaller at C than at B.

E. Its kinetic energy is smaller at C than at B, but its electric potential energy is higher at C than at B.

#10:

A: 67%
B: 20%
C: 9%
D: 2%
E: 0%

10. Consider the situation described in #9. Let us call the ***magnitude*** of the change in kinetic energy $|\Delta KE|$, and the ***magnitude*** of the change in electric potential energy $|\Delta PE|$. Which of these is true about the energy of the particle shot from the gun, as it travels from position C to position B?

A. $|\Delta KE| = |\Delta PE|$

B. $|\Delta KE| > |\Delta PE|$

C. $|\Delta KE| < |\Delta PE|$

D. Not enough information to answer.

Problem “Dissection” Technique

- Decompose complicated problem into conceptual elements
- Work through problem step by step, with continual feedback from and interaction with the students
- May be applied to both qualitative and quantitative problems

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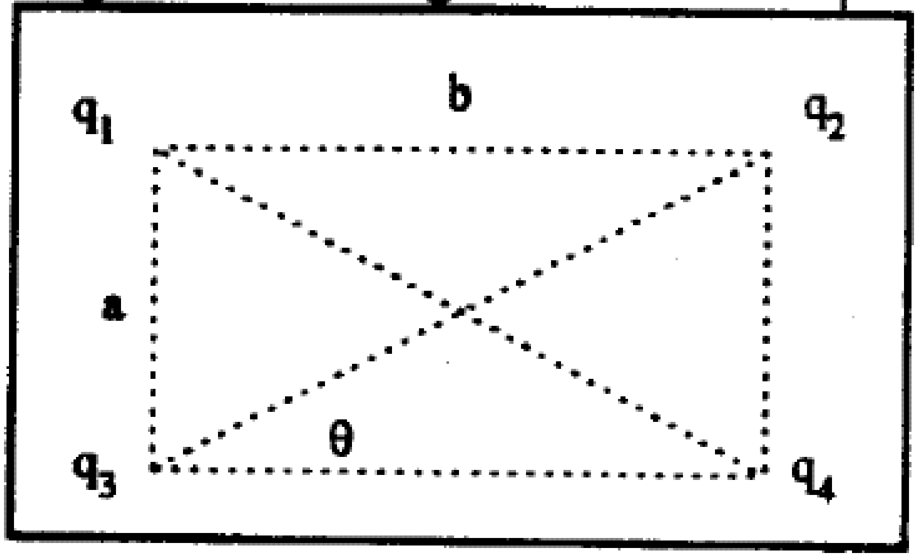
Example: Electrostatic Forces

Figure 1. Diagram used for problem dissection



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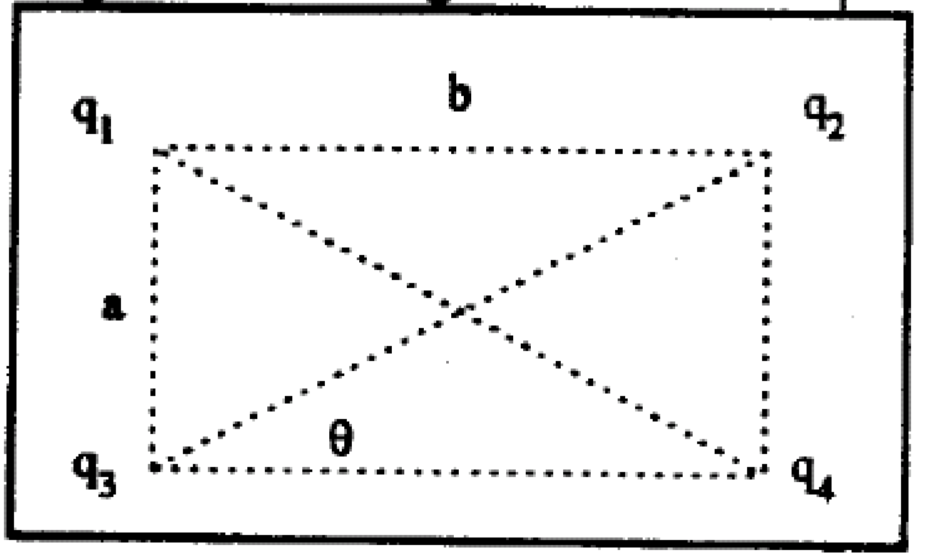

Four charges are arranged on a rectangle as shown in Fig. 1. ($q_1 = q_3 = +10.0\ \mu C$ and $q_2 = q_4 = -15.0\ \mu C$; a = 30 cm and b = 40 cm.) Find the magnitude and direction of the resultant electrostatic force on q_1.

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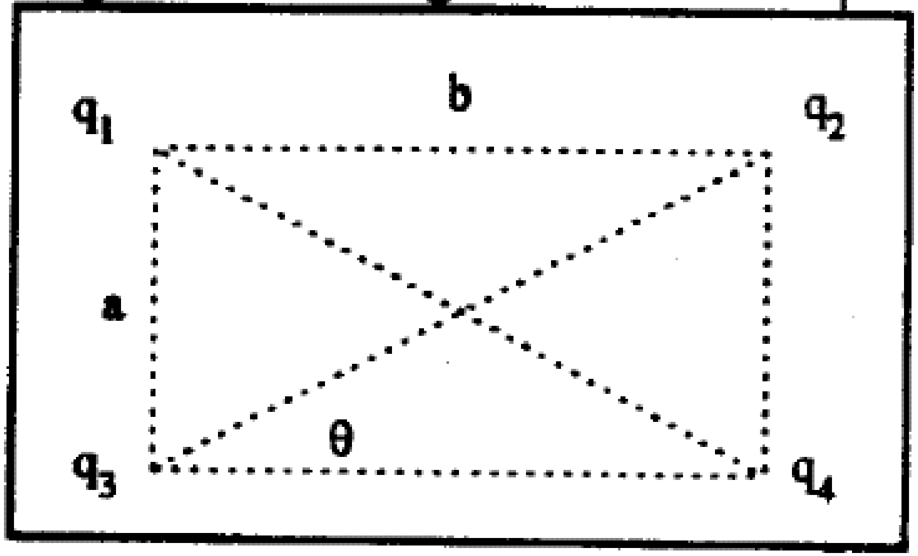

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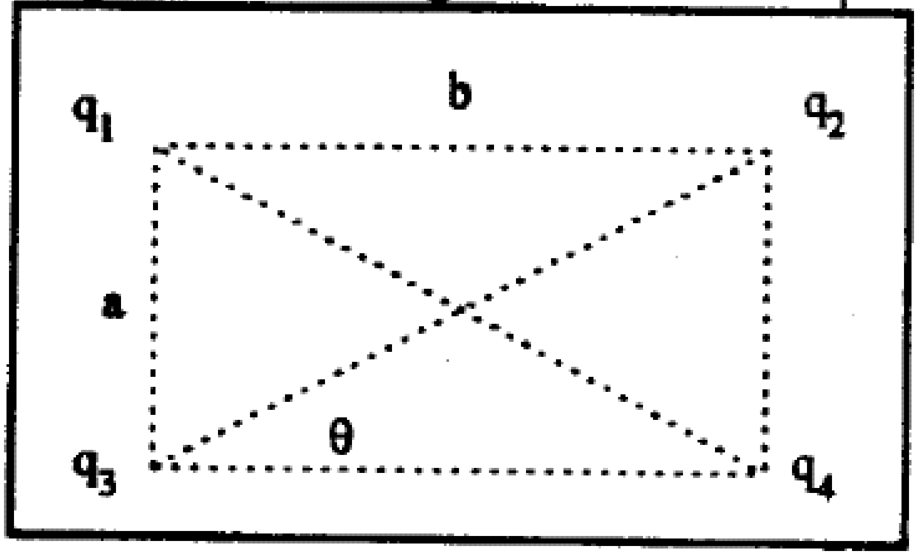

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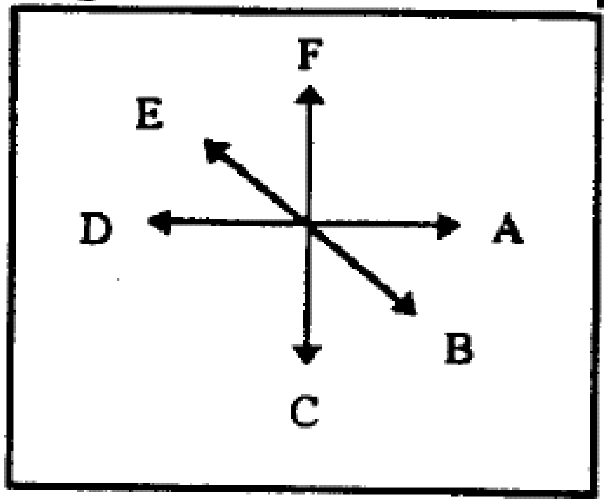
Question #1: How many forces (due to electrical interactions) are acting on charge q_1?

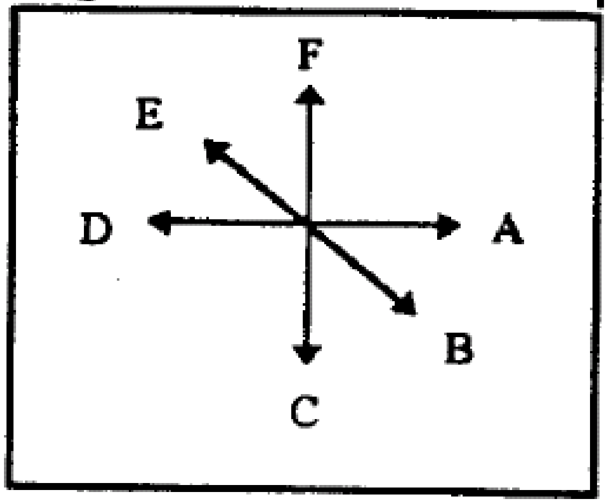
(A) 0 (B) 1 (C) 2 (D) 3 (E) 4 (F) Not sure/don't know

Figure 2. Direction options



For questions #2-4 refer to Fig. 2 and pick a direction from the choices A, B, C, D, E, and F.

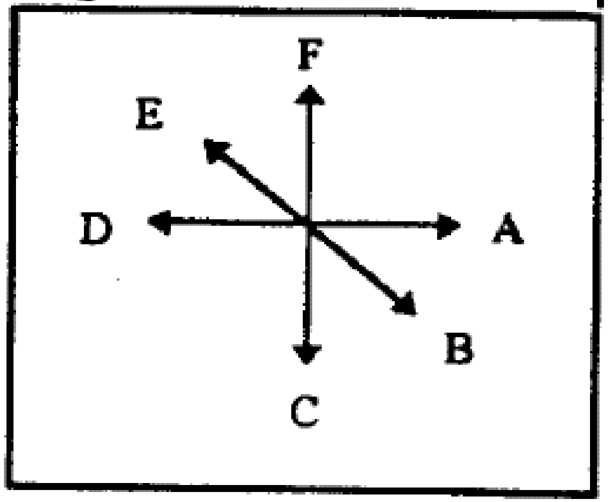
Figure 2. Direction options



For questions #2-4 refer to Fig. 2 and pick a direction from the choices A, B, C, D, E, and F.

Question #2: Direction of force on q_1 due to q_2

Figure 2. Direction options



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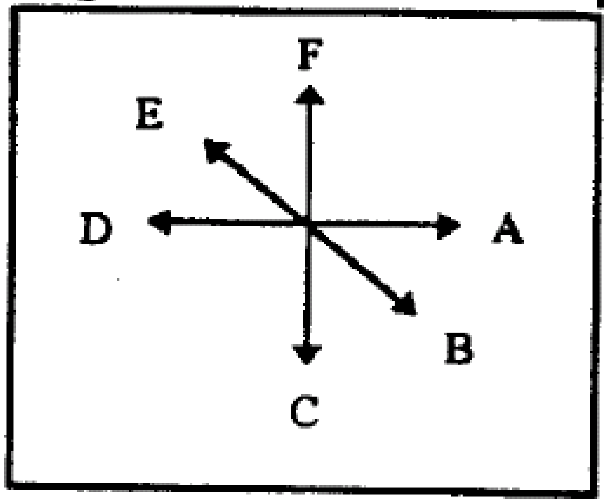
Question #2: Direction of force on q_1 due to q_2

Question #3: Direction of force on q_1 due to q_3

Figure 2. Direction options



For questions #2-4 refer to Fig. 2 and pick a direction from the choices A, B, C, D, E, and F.

Question #2: Direction of force on q_1 due to q_2

Question #3: Direction of force on q_1 due to q_3

Question #4: Direction of force on q_1 due to q_4

Let F_2, F_3, and F_4 be the *magnitudes* of the force on q_1 due to q_2, due to q_3, and due to q_4 respectively.

Let F_2, F_3, and F_4 be the *magnitudes* of the force on q_1 due to q_2, due to q_3, and due to q_4 respectively.

Question #5. F_2 is given by

(A) kq_1q_2/a^2

(B) kq_1q_2/b^2

(C) $kq_1q_2/(a^2 + b^2)$

(D) $kq_1q_2/\sqrt{(a^2 + b^2)}$

(E) None of the above

(F) Not sure/Don't know

Let F_2, F_3, and F_4 be the *magnitudes* of the force on q_1 due to q_2, due to q_3, and due to q_4 respectively.

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(A) kq_1q_2/a^2

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(D) $kq_1q_2/\sqrt{(a^2 + b^2)}$

(E) None of the above

(F) Not sure/Don't know

Question #6. F_3 is given by

(A) kq_1q_3/a^2

(B) kq_1q_3/b^2

(C) $kq_1q_3/(a^2 + b^2)$

(D) $kq_1q_3/\sqrt{(a^2 + b^2)}$

(E) None of the above

(F) Not sure/Don't know

Let F_2, F_3, and F_4 be the *magnitudes* of the force on q_1 due to q_2, due to q_3, and due to q_4 respectively.

Question #5. F_2 is given by

(A) kq_1q_2/a^2

(B) kq_1q_2/b^2

(C) $kq_1q_2/(a^2 + b^2)$

(D) $kq_1q_2/\sqrt{(a^2 + b^2)}$

(E) None of the above

(F) Not sure/Don't know

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(A) kq_1q_3/a^2

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(C) $kq_1q_3/(a^2 + b^2)$

(D) $kq_1q_3/\sqrt{(a^2 + b^2)}$

(E) None of the above

(F) Not sure/Don't know

(etc.)

More Flexible Approach: Whiteboards

- Provide small whiteboards (~0.5 m^2 if possible) and markers to each student group
- Optimal group size: 3±1 students
- Provide mix of brief algebraic, graphical, and conceptual problems for students to work during class (may include multiple-choice questions)
- Walk around room, viewing student work as best as possible given room layout

Assess, Support, Guide

- Rapidly assess and address needs of individual groups, constrained by available time [imagine a coach roaming a football field]:

1. Thumbs up
2. *Minor technical assist:* “Watch your units”; “you’ve got a sign error”
3. *Minor conceptual assist:* “Is the force in the same direction as the displacement, or not?”
4. *Guide back on track:* “This question is about angular acceleration, not centripetal acceleration”

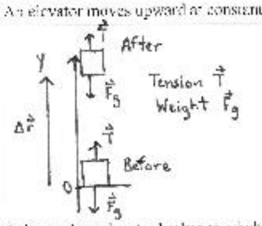
Sources of Materials

- Randall Knight, *Student Workbook* for *Physics for Scientists and Engineers: A Strategic Approach*
- McDermott, Shaffer, and the PEG at UW: *Tutorials in Introductory Physics*
- Meltzer and Manivannan, *Workbook for Introductory Physics*
- *See* Meltzer and Thornton*, Resource Letter ALIP-1*
- Make your own

Knight, *Student Workbook*

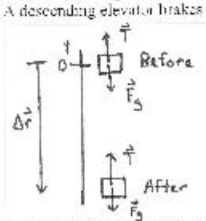
Exercises 3–10: For each situation
- Draw a before-and-after pictorial diagram.
- Draw and label the displacement vector $\Delta\vec{r}$ on your diagram.
- Draw a free-body diagram showing *all* forces acting on the object.
- Make a table beside your diagrams showing the sign (+, −, or 0) of (i) the work done by each force seen in your free-body diagram, (ii) the net work W_{net}, and (iii) ΔK, the object's change in kinetic energy.

3. An elevator moves upward at constant speed.



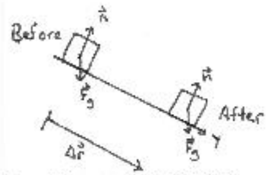
Force	Work	Sign
Tension	W_T	+
Weight	W_g	−
	W_{net}	0
	ΔK	0

4. A descending elevator brakes to a halt.



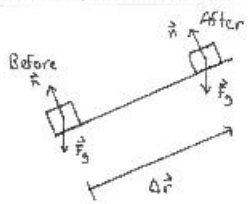
Force	Work	Sign
Tension	W_T	−
Weight	W_g	+
	W_{net}	−
	ΔK	−

5. A box slides down a frictionless slope.



Force	Work	Sign
F_g	W_g	+
Normal	W_n	0
	W_{net}	+
	ΔK	+

6. A box slides up a frictionless slope.



Force	Work	Sign
F_g	W_g	−
Normal	W_n	0
	W_{net}	−
	ΔK	−

Exercises 3–10: For each situation:

- Draw a before-and-after pictorial diagram.
- Draw and label the displacement vector $\Delta\vec{r}$ on your diagram.
- Draw a free-body diagram showing *all* forces acting on the object.
- Make a table beside your diagrams showing the sign (+, −, or 0) of (i) the work done by each force seen in your free-body diagram, (ii) the net work W_{net}, and (iii) ΔK, the object's change in kinetic energy.

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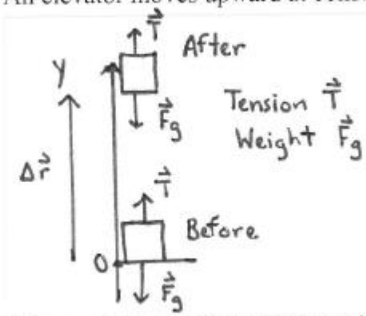
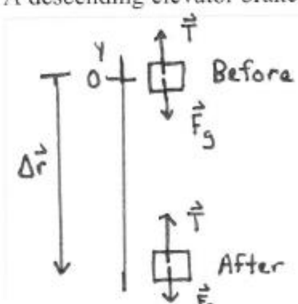


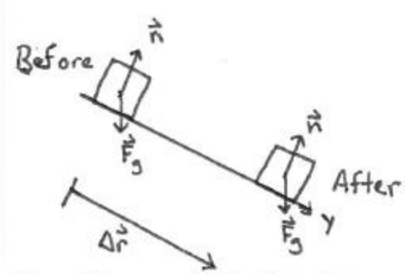
Force	Work	Sign
Tension	W_T	+
Weight	W_g	−
	W_{net}	0
	ΔK	0

4. A descending elevator brakes to a halt.



Force	Work	Sign
Tension	W_T	−
Weight	W_g	+
	W_{net}	−
	ΔK	−

5. A box slides down a frictionless slope.



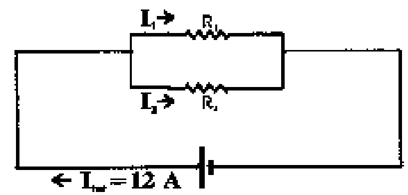
Force	Work	Sign
F_g	W_g	+
Normal	W_n	0
	W_{net}	+
	ΔK	+

6. A box slides up a frictionless slope.

Meltzer and Manivannan, *Workbook for Introductory Physics*

In-Class Exercises

Questions #1–4 refer to this figure:



Let I_1 and I_2 represent the current flowing through resistors R_1 and R_2, respectively. I_{tot} = 12 A, as indicated.

1. What is the value of $(I_1 + I_2)$?

   $(I_1 + I_2)$ = ____________

2. If $R_2 = R_1$, find the following values:

   $\frac{I_1}{I_2}$ = ____________

   I_1 = ____________

   I_2 = ____________

3. If $R_2 = 2R_1$, find the following values:

   $\frac{I_1}{I_2}$ = ____________

   I_1 = ____________

   I_2 = ____________

4. If $R_2 = 3R_1$, find the following values:

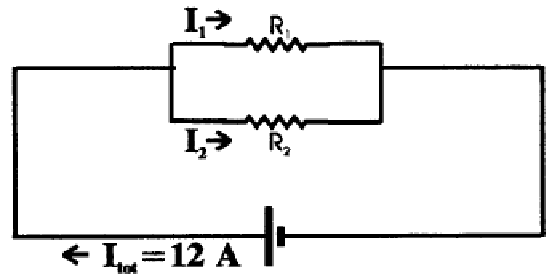
   $\frac{I_1}{I_2}$ = ____________

   I_1 = ____________

   I_2 = ____________

In-Class Exercises

Questions #1–4 refer to this figure:



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   $I_1 =$ ________

   $I_2 =$ ________

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   $\frac{I_1}{I_2} =$ ________

   $I_1 =$ ________

   $I_2 =$ ________

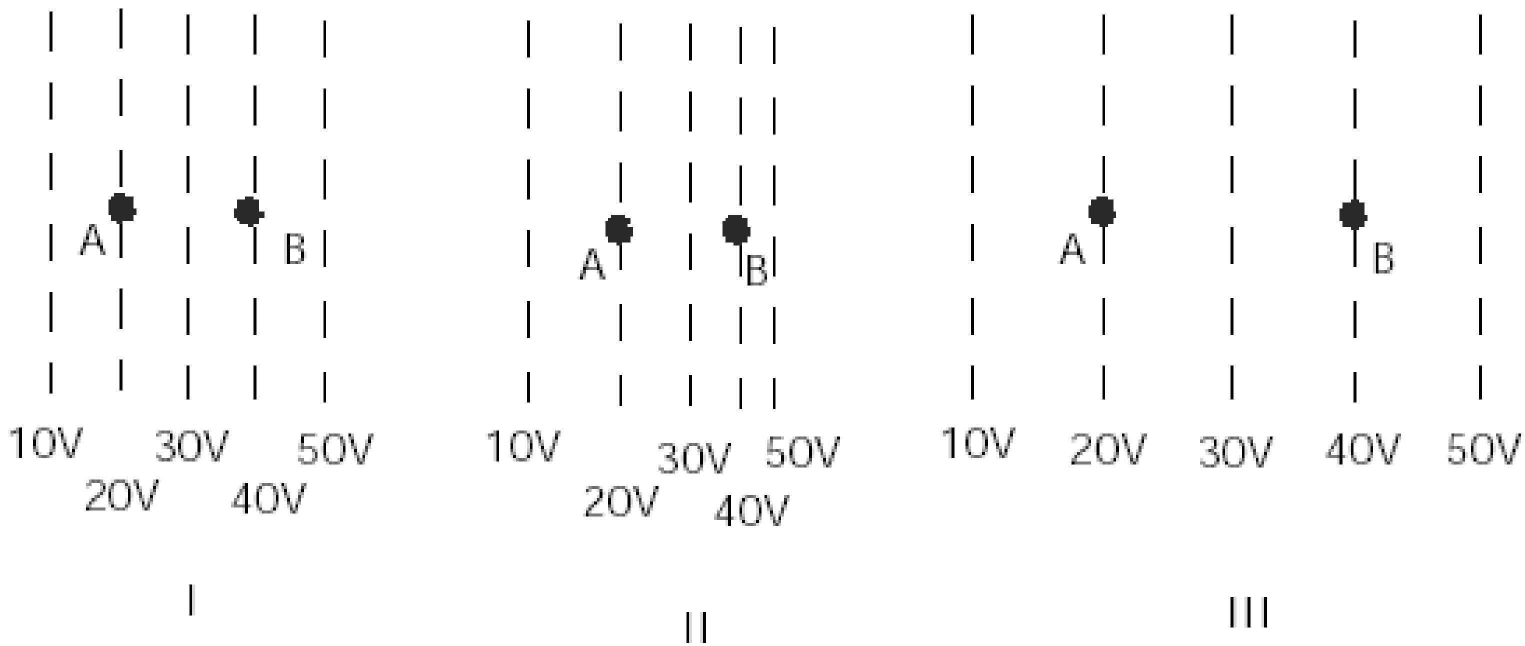
4. If $R_2 = 3R_1$, find the following values:

Assessment Data

Scores on Conceptual Survey of Electricity and Magnetism, 14-item electricity subset

Sample	*N*
National sample (algebra-based)	402
National sample (calculus-based)	1496

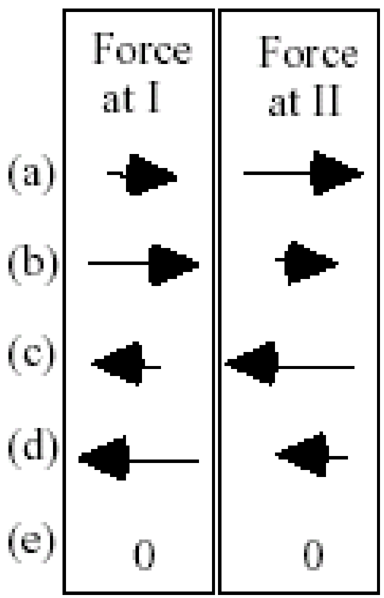
In the figures below, the dotted lines show the equipotential lines of electric fields. (A charge moving along a line of equal potential would have a constant electric potential energy.) A charged object is moved directly from point A to point B. The charge on the object is +1 μC.

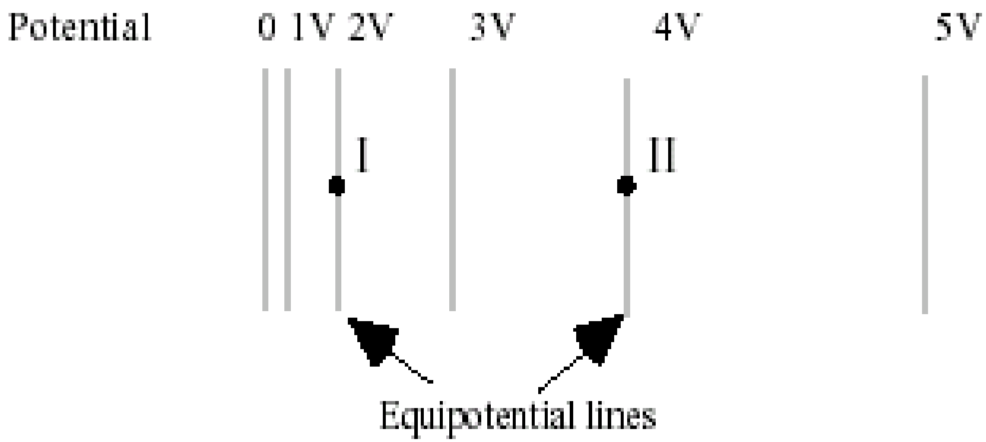


1. How does the magnitude of the electric field at B compare for these three cases?
   - (a) I > III > II
   - (b) I > II > III
   - (c) III > I > II
   - (d) II > I > III
   - (e) I = II = III

D. Maloney, T. O'Kuma, C. Hieggelke, and A. Van Heuvelen, PERS of Am. J. Phys. ***69****, S12 (2001).*

2. A positively-charged proton is first placed at rest at position I and then later at position II in a region whose electric potential (voltage) is described by the equipotential lines. Which set of arrows on the left below best describes the relative magnitudes and directions of the electric force exerted on the proton when at position I or II?





Assessment Data

Scores on Conceptual Survey of Electricity and Magnetism, 14-item electricity subset

Sample	***N***
National sample (algebra-based)	402
National sample (calculus-based)	1496

Assessment Data

Scores on Conceptual Survey of Electricity and Magnetism, 14-item electricity subset

Sample	*N*	Mean pre-test score
National sample (algebra-based)	402	**27%**
National sample (calculus-based)	1496	

Assessment Data

Scores on Conceptual Survey of Electricity and Magnetism, 14-item electricity subset

Sample	*N*	Mean pre-test score
National sample (algebra-based)	402	**27%**
National sample (calculus-based)	1496	**37%**

Assessment Data

Scores on Conceptual Survey of Electricity and Magnetism, 14-item electricity subset

Sample	*N*	Mean pre-test score	Mean post-test score
National sample (algebra-based)	402	**27%**	**43%**
National sample (calculus-based)	1496	**37%**	**51%**

Assessment Data

Scores on Conceptual Survey of Electricity and Magnetism, 14-item electricity subset

Sample	*N*	Mean pre-test score	Mean post-test score	<g>
National sample (algebra-based)	402	**27%**	**43%**	**0.22**
National sample (calculus-based)	1496	**37%**	**51%**	**0.22**

Assessment Data

Scores on Conceptual Survey of Electricity and Magnetism, 14-item electricity subset

Sample	*N*	Mean pre-test score	Mean post-test score	<g>
National sample (algebra-based)	402	**27%**	**43%**	**0.22**
National sample (calculus-based)	1496	**37%**	**51%**	**0.22**
ISU 1998	70	**30%**		
ISU 1999	87	**26%**		
ISU 2000	66	**29%**		

Assessment Data

Scores on Conceptual Survey of Electricity and Magnetism, 14-item electricity subset

Sample	*N*	Mean pre-test score	Mean post-test score	<g>
National sample (algebra-based)	402	**27%**	**43%**	**0.22**
National sample (calculus-based)	1496	**37%**	**51%**	**0.22**
ISU 1998	70	**30%**	**75%**	
ISU 1999	87	**26%**	**79%**	
ISU 2000	66	**29%**	**79%**	

Assessment Data

Scores on Conceptual Survey of Electricity and Magnetism, 14-item electricity subset

Sample	*N*	Mean pre-test score	Mean post-test score	<g>
National sample (algebra-based)	402	27%	43%	0.22
National sample (calculus-based)	1496	37%	51%	0.22
ISU 1998	70	30%	75%	0.64
ISU 1999	87	26%	79%	0.71
ISU 2000	66	29%	79%	0.70

Quantitative Problem Solving: Are skills being sacrificed?

ISU Physics 112 compared to ISU Physics 221 (calculus-based), numerical final exam questions on electricity

Quantitative Problem Solving: Are skills being sacrificed?

ISU Physics 112 compared to ISU Physics 221 (calculus-based), numerical final exam questions on electricity

	N	Mean Score
Physics 221: F97 & F98 ***Six final exam questions***	*320*	
Physics 221: F97 & F98 **Subset of three questions**	*372*	

Quantitative Problem Solving: Are skills being sacrificed?

ISU Physics 112 compared to ISU Physics 221 (calculus-based), numerical final exam questions on electricity

	N	**Mean Score**
Physics 221: F97 & F98 ***Six final exam questions***	*320*	56%
Physics 221: F97 & F98 **Subset of three questions**	*372*	59%

Quantitative Problem Solving: Are skills being sacrificed?

ISU Physics 112 compared to ISU Physics 221 (calculus-based), numerical final exam questions on electricity

	N	**Mean Score**
Physics 221: F97 & F98 ***Six final exam questions***	*320*	56%
Physics 112: F98 **Six final exam questions**	*76*	
Physics 221: F97 & F98 **Subset of three questions**	*372*	59%
Physics 112: F98, F99, F00 **Subset of three questions**	*241*	

Quantitative Problem Solving: Are skills being sacrificed?

ISU Physics 112 compared to ISU Physics 221 (calculus-based), numerical final exam questions on electricity

	N	**Mean Score**
Physics 221: F97 & F98 ***Six final exam questions***	*320*	56%
Physics 112: F98 **Six final exam questions**	*76*	77%
Physics 221: F97 & F98 **Subset of three questions**	*372*	59%
Physics 112: F98, F99, F00 **Subset of three questions**	*241*	78%

Summary

- Focus on ***what the students are doing in class,*** not on what the instructor is doing
- Guide students to answer questions and solve problems during class
- Maximize interaction between students and instructor ***(use communication system)*** and among students themselves ***(use group work)***