Research-Based Active-Learning Instructional Methods in Large-Enrollment Physics Classes

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Outline

- Motivation and description of active-engagement teaching strategy
- Watch video (18 minutes): pauses for comments and questions
- Describe details of questioning strategies
- Discussion of practical and implementation issues

Research in physics education and other scientific and technical fields suggests that:

- “Teaching by telling” has only limited effectiveness
  - can inform students of isolated bits of factual knowledge

- For understanding of
  - inter-relationships of diverse phenomena
  - deep theoretical explanation of concepts

→ **students have to “figure it out for them-selves” by struggling intensely with ideas**

Research in physics education and other scientific and technical fields suggests that:

- "Teaching by telling" has only limited effectiveness
  - listening and note-taking have relatively little impact
- Problem-solving activities with rapid feedback yield improved learning gains
  - student group work
  - frequent question-and-answer exchanges with instructor

Goal:* *Guide students to "figure things out for themselves" as much as possible

What Role for Instructors?

- Introductory students often don’t know what questions they need to ask
  - or what lines of thinking may be most productive
- Instructor’s role becomes that of guiding students to ask and answer useful questions

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 to ask and answer useful questions
  - 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

Keystones of Innovative Pedagogy

- problem-solving activities during class time
- deliberately elicit and address common learning difficulties
- guide students to “figure things out for themselves” as much as possible

The Biggest Challenge: Large Lecture Classes

- Very difficult to sustain active learning in large classroom environments
- Two-way communication between students and instructor becomes paramount obstacle
- Curriculum development must be matched to innovative instructional methods

Active Learning in Large Physics Classes

- **De-emphasis of lecturing**; Instead, ask students to respond to many questions.
- Use of classroom communication systems to obtain **instantaneous feedback** from entire class.
- Cooperative **group work** using carefully structured free-response worksheets

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

“Fully Interactive” Physics Lecture

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

- Very high levels of student-student and student-instructor interaction
- 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”)

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.
[DOI: 10.1119/1.1463739]

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 large-enrollment classes requires a variety of specific instruc-

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

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

Video (18 minutes)

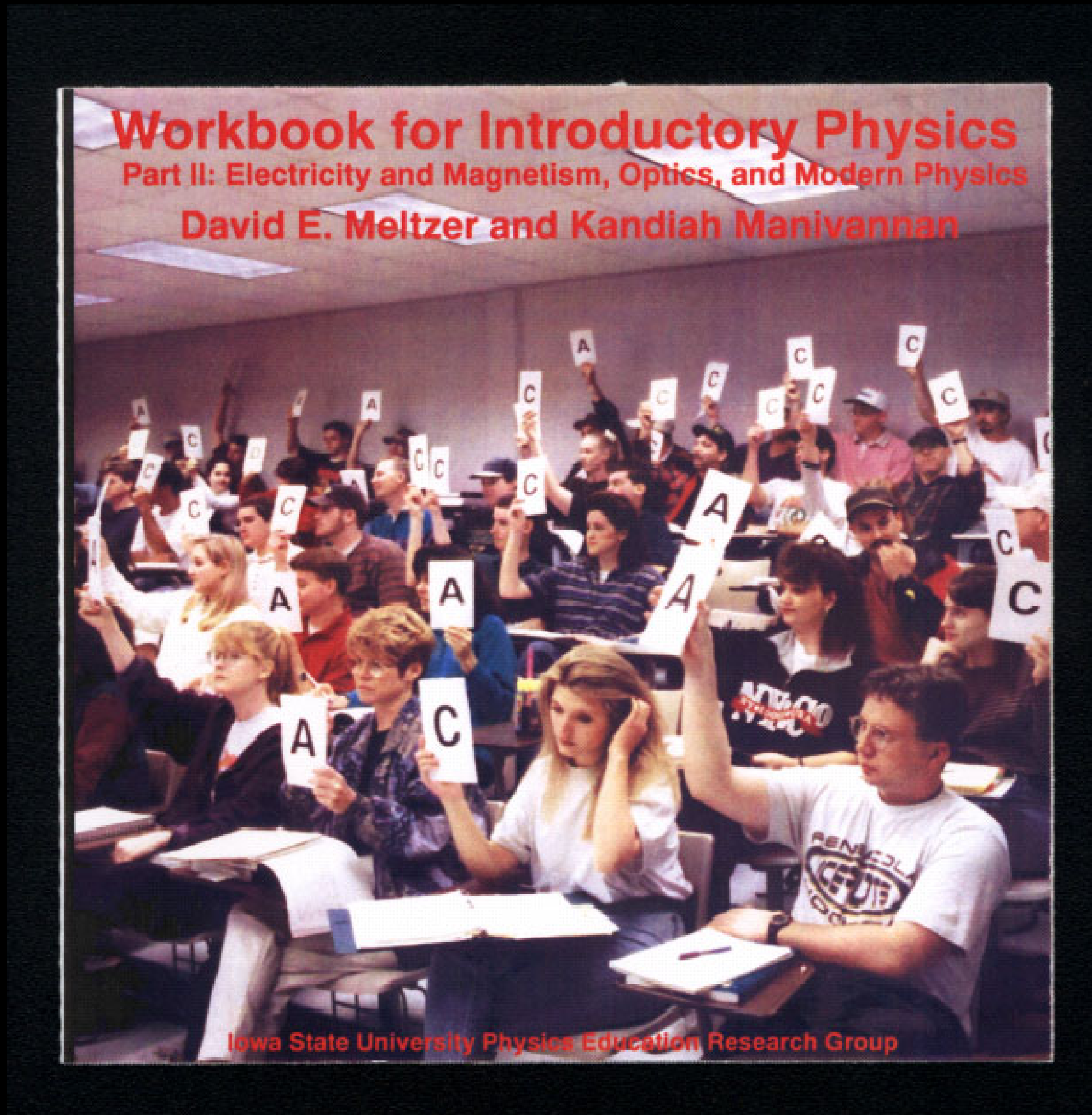
- Excerpt from class taught at Southeastern Louisiana University in 1997
- Algebra-based general physics course
- *First Part:* Students respond to questions written on blackboard.
- *Second Part:* Students respond to questions printed in their workbook.

Curriculum Requirements for Fully Interactive Lecture

- Many question sequences employing multiple representations, covering full range of topics
- Free-response worksheets adaptable for use in lecture hall
- Text reference ("Lecture Notes") with strong focus on conceptual and qualitative questions

→ *Workbook for Introductory Physics (DEM and K. Manivannan, CD-ROM, 2002)*

Supported by NSF under "Assessment of Student Achievement" program



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Promoting Interactivity in Lecture Classes
Enhancing Active Learning
The Fully Interactive Physics Lecture

Part 9: Flash-Card Masters

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Curriculum Development on the Fast Track

- Need curricular materials for complete course $\Rightarrow$ must create, test, and revise “on the fly”
- Daily feedback through in-class use aids assessment
- Pre- and post-testing with standardized diagnostics helps monitor progress

Curricular Material for Large Classes

"Workbook for Introductory Physics"

- Multiple-choice "Flash-Card" Questions
  - Conceptual questions for whole-class interaction
- Worksheets for Student Group Work
  - Sequenced sets of questions requiring written explanations
- Lecture Notes
  - Expository text for reference
- Quizzes and Exams
  - some with worked-out solutions

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.

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)*

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.

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

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

Chapter 1 Electrical Forces

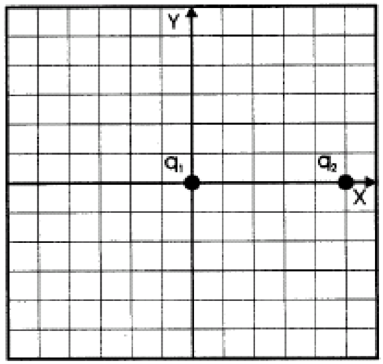
"Flash-Card" Questions

In-Class Questions

Prerequisite Concepts:

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

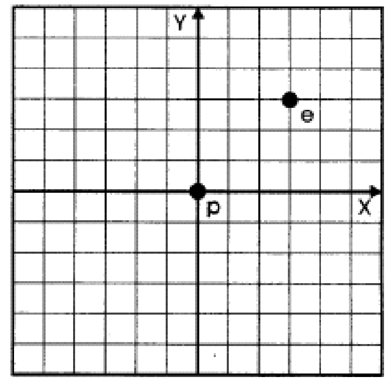
   A. in the positive x direction
   B. in the negative x direction
   C. in the positive y direction
   D. in the negative y direction
   E. the force is not directed precisely along any of the coordinate axes, but at some angle
   F. there is no force in this case

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

"Flash-Card" Questions

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?



A. 

B. 

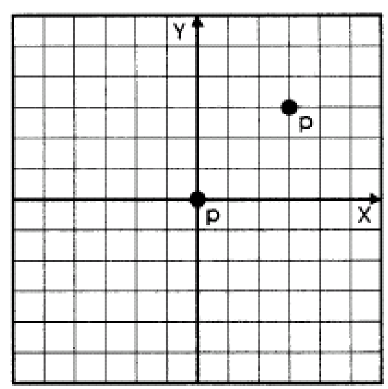
C. 

D. 

E. 

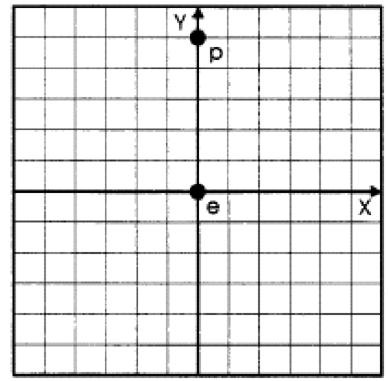
F. 

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°

5. In this figure, a proton is located at (0m, 5m) and an electron is located at the origin.



The electrical force on the electron is:

A. directed toward the positive-y direction, and has greater magnitude than the electrical force acting on the proton
B. directed toward the positive-y direction, and has smaller magnitude than the electrical force acting on the proton
C. directed toward the positive-y direction, and has magnitude equal to the electrical force acting on the proton
D. directed toward the negative-y direction, and has greater magnitude than the electrical force acting on the proton
E. directed toward the negative-y direction, and has smaller magnitude than the electrical force acting on the proton
F. directed toward the negative-y direction, and has magnitude equal to the electrical force acting on the proton

6. Two charged particles are separated by a certain distance, and exert an electrical force on each other. What will happen to the magnitude of this electrical force if the separation between the particles is *decreased*?

A. The force will decrease in magnitude.
B. The force will increase in magnitude.
C. The magnitude of the force will not change.
D. The magnitude of the force may decrease or increase, depending on whether the charges are like or unlike.
E. The magnitude of the force on one particle will increase, while that on the other particle will decrease.

7. Two particles with charges q_1 and q_2 are separated by a distance r. There are no other charges nearby. Consider the following actions:

   I. increase q_1

   II. increase q_2

   III. increase r

   IV. decrease r

   Which of the above actions will cause the magnitude of the force between the charges to *increase*?

   A. I and III only

   B. I and IV only

   C. II and III only

   D. II and IV only

   E. I and II and III

   F. I and II and IV

8. When two charged particles are separated by 2 meters, the magnitude of the electrical force between them is F. What will be the magnitude of this force if their separation is increased to 4 meters?

   A. 1/4 F

   B. 1/2 F

   C. F

   D. 2F

   E. 4F

   F. not enough information given to determine magnitude of force

9. Which of these will result in the repulsive force between two identical charged particles *increasing* by a factor of 8:

   A. double one of the charges

   B. double both of the charges

   C. double one of the charges and cut the particle separation in half

   D. triple one of the charges and cut the particle separation in half

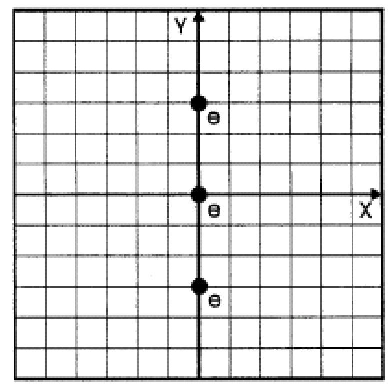
   E. triple both of the charges

   F. double both of the charges and double the particle separation

10. A 6-C charge and a 12-C charge are separated by 2 m; there are no other charges present. Compared to the electrical force on the 6-C charge, the electrical force on the 12-C charge is:

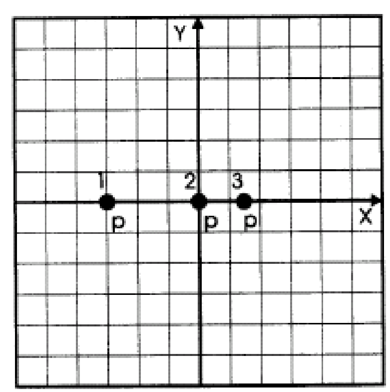
A. one-fourth as strong
B. one-half as strong
C. the same magnitude
D. two times as strong
E. four times as strong

11. In this figure, electrons are located on the y axis at y = 3 m, y = 0 m, and y = – 3 m. The direction of the net electrical force on the electron at the origin is:



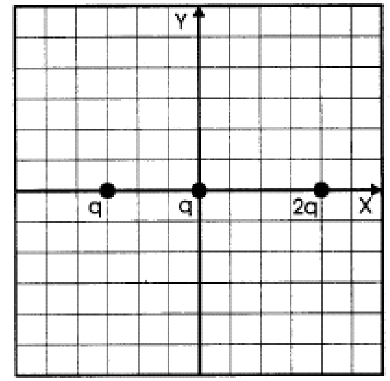
A. towards positive x
B. towards positive y
C. towards negative x
D. towards negative y
E. nowhere, since there is no net force on this electron

12. In this figure, protons are located on the x axis at x = – 3 m, x = 0 m, and x = 1.5 m. The direction of the net electrical force on the proton at the origin is:



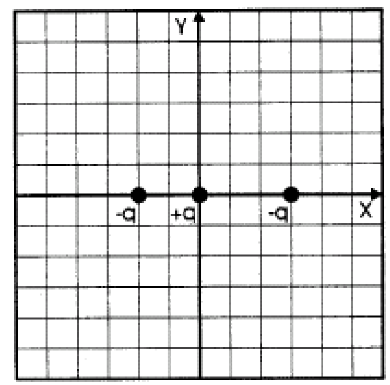
A. towards positive x
B. towards positive y
C. towards negative x
D. towards negative y
E. nowhere, since there is no net force on this proton

13. In this figure, positive charges of magnitude q, q, and 2q are located on the x axis as shown. The direction of the net electrical force on the positive charge at the origin is:



A. towards positive x
B. towards positive y
C. towards negative x
D. towards negative y
E. nowhere, since there is no net force on this proton

14. In this figure, particles with charges –q, +q, and –q are located on the x axis as shown. The direction of the net electrical force on the positive charge at the origin is:



A. towards positive x
B. towards positive y
C. towards negative x
D. towards negative y
E. nowhere, since there is no net force on this proton

15. A electron is fixed at the origin; there are no other charges present. If a negative charge is brought in and released at a nearby point, and allowed to move freely, then as it moves the magnitude of the force acting on this negative charge will:

A. always be zero
B. remain constant, but nonzero
C. always increase
D. always decrease, but never reach zero
E. sometimes increase and sometimes decrease
F. not enough information to decide

16. A electron is fixed at the origin; there are no other charges present. If a negative charge is brought in and released at a nearby point, and allowed to move freely, then as it moves the magnitude of the acceleration of this negative charge will:

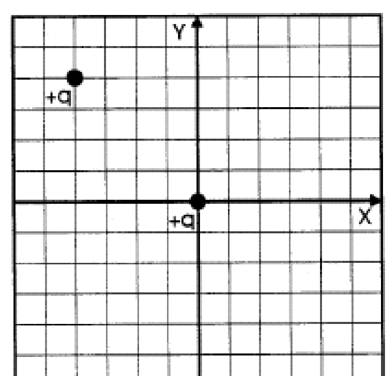
    A. always be zero
    B. remain constant, but nonzero
    C. always increase
    D. always decrease, but never reach zero
    E. sometimes increase and sometimes decrease
    F. not enough information to decide

17. A electron is fixed at the origin; there are no other charges present. If a negative charge is brought in and released at a nearby point, and allowed to move freely, then as it moves the speed of this negative charge will:

    A. always be zero
    B. remain constant, but nonzero
    C. always increase
    D. always decrease, but never reach zero
    E. sometimes increase and sometimes decrease
    F. not enough information to decide

18. In this figure, a positive charge is located at the origin, and another positive charge is located at the point (–4m, 4m). The x component of the electrical force on the charge at the origin is:

    A. greater than zero
    B. equal to zero
    C. less than zero
    D. may be equal to, less than, or greater than zero, depending on the precise magnitude of the two charges.

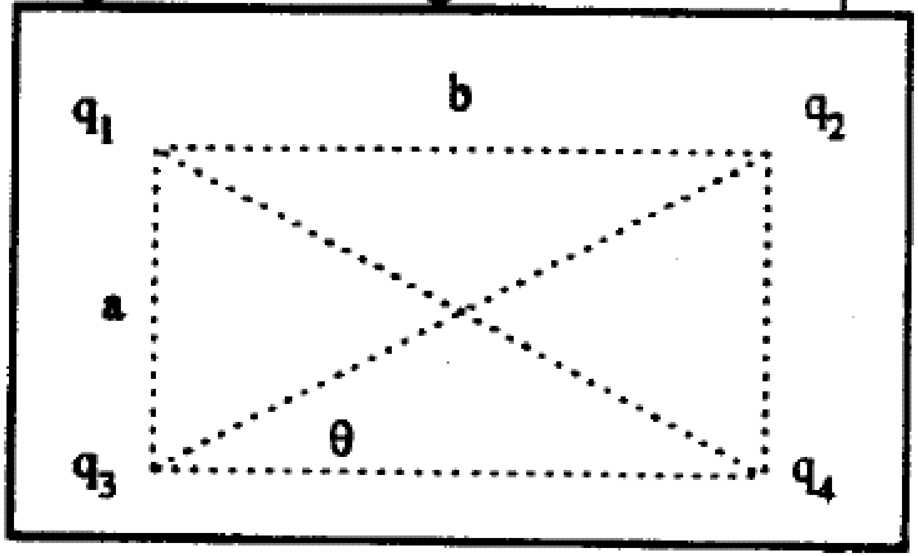


Problem “Dissection” Technique

- 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

Example: Electrostatic Forces

Figure 1. Diagram used for problem dissection



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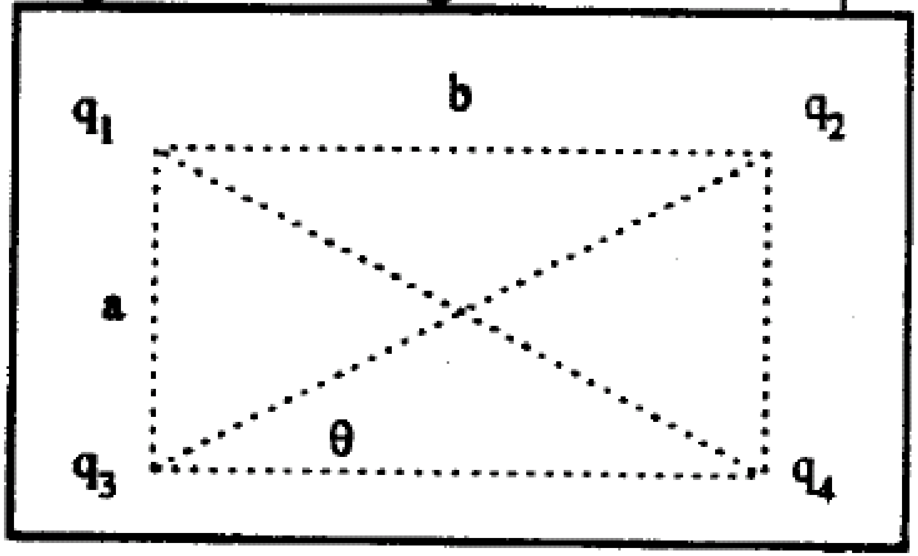

Four charges are arranged on a rectangle as shown in Fig. 1. ($q_1 = q_3 = +10.0\ \mu C$ and $q_2 = q_4 = -15.0\ \mu C$; a = 30 cm and b = 40 cm.) Find the magnitude and direction of the resultant electrostatic force on q_1.

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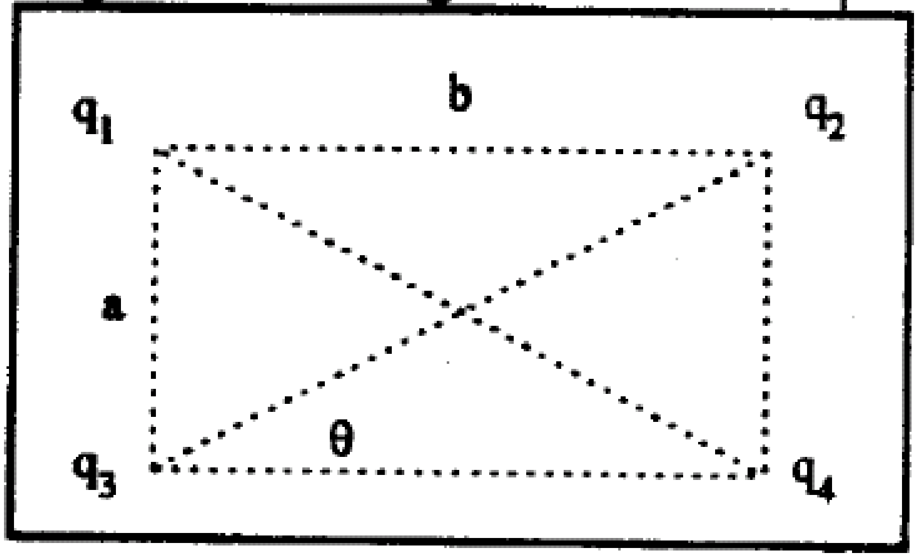

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Question #1: How many forces (due to electrical interactions) are acting on charge q_1?

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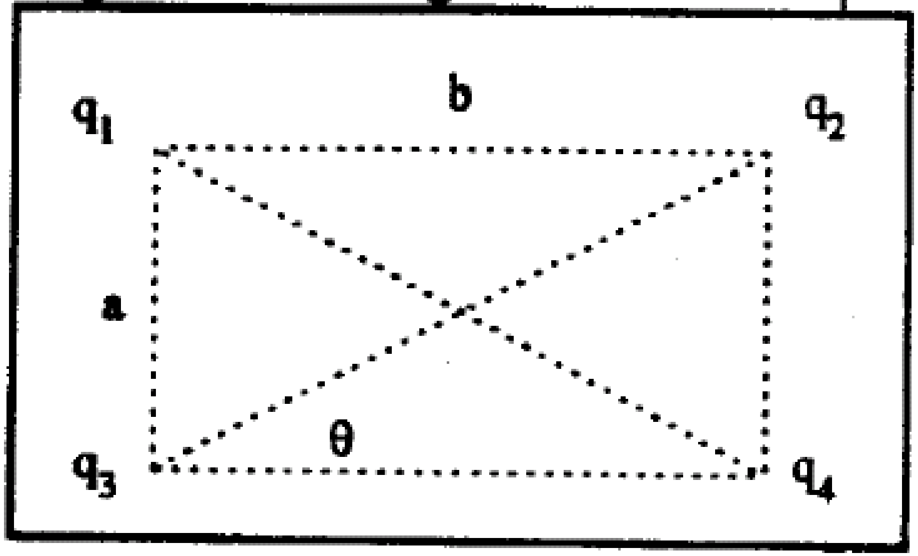

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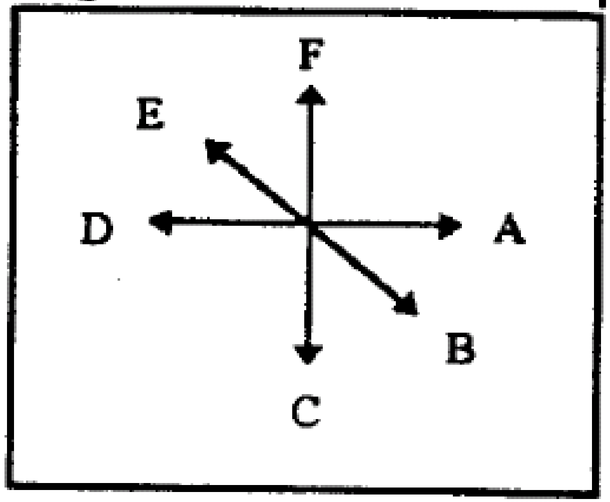
Question #1: How many forces (due to electrical interactions) are acting on charge q_1?

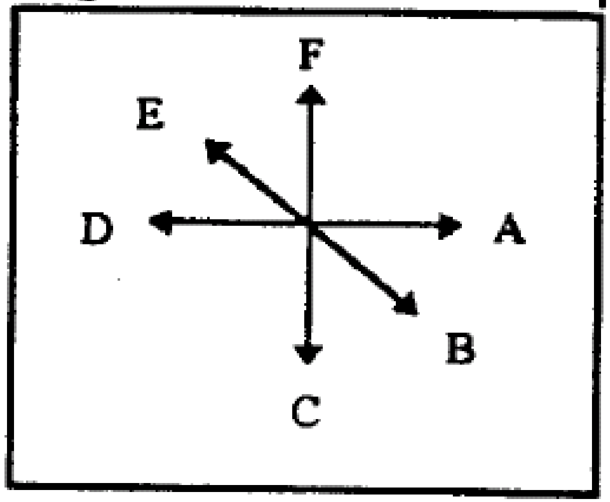
(A) 0 (B) 1 (C) 2 (D) 3 (E) 4 (F) Not sure/don't know

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



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

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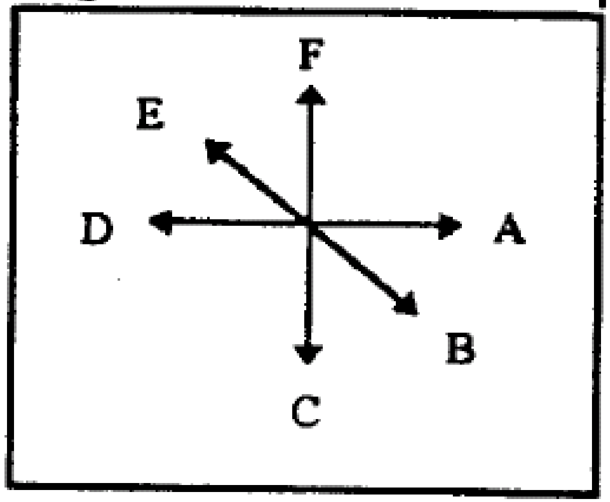

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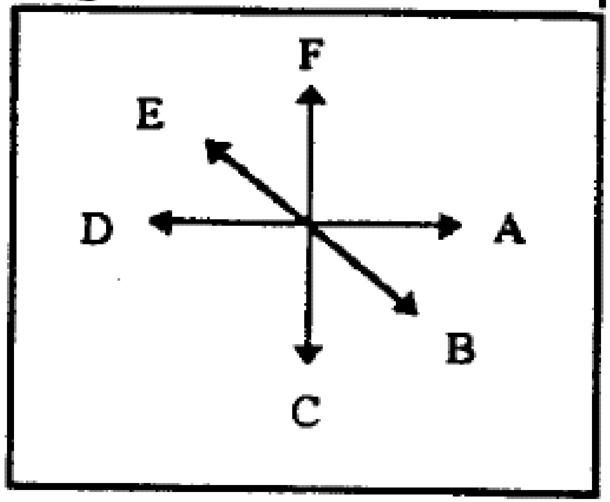
Question #2: Direction of force on q_1 due to q_2

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

Figure 2. Direction options



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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

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.

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

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

Question #6. F_3 is given by

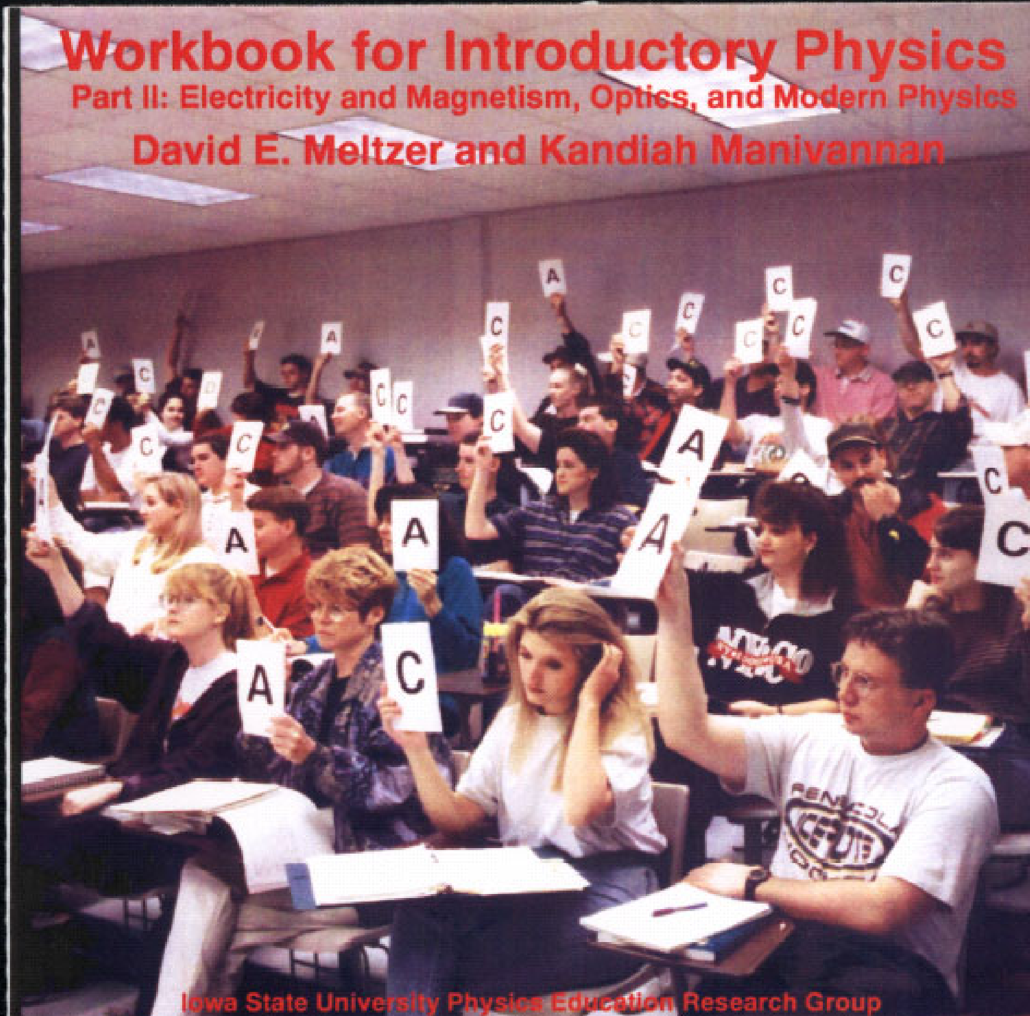
(A) kq_1q_3/a^2
(B) kq_1q_3/b^2
(C) $kq_1q_3/(a^2 + b^2)$
(D) $kq_1q_3/\sqrt{(a^2 + b^2)}$
(E) None of the above
(F) Not sure/Don't know

(etc.)

Workbook for Introductory Physics

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

David E. Meltzer and Kandiah Manivannan



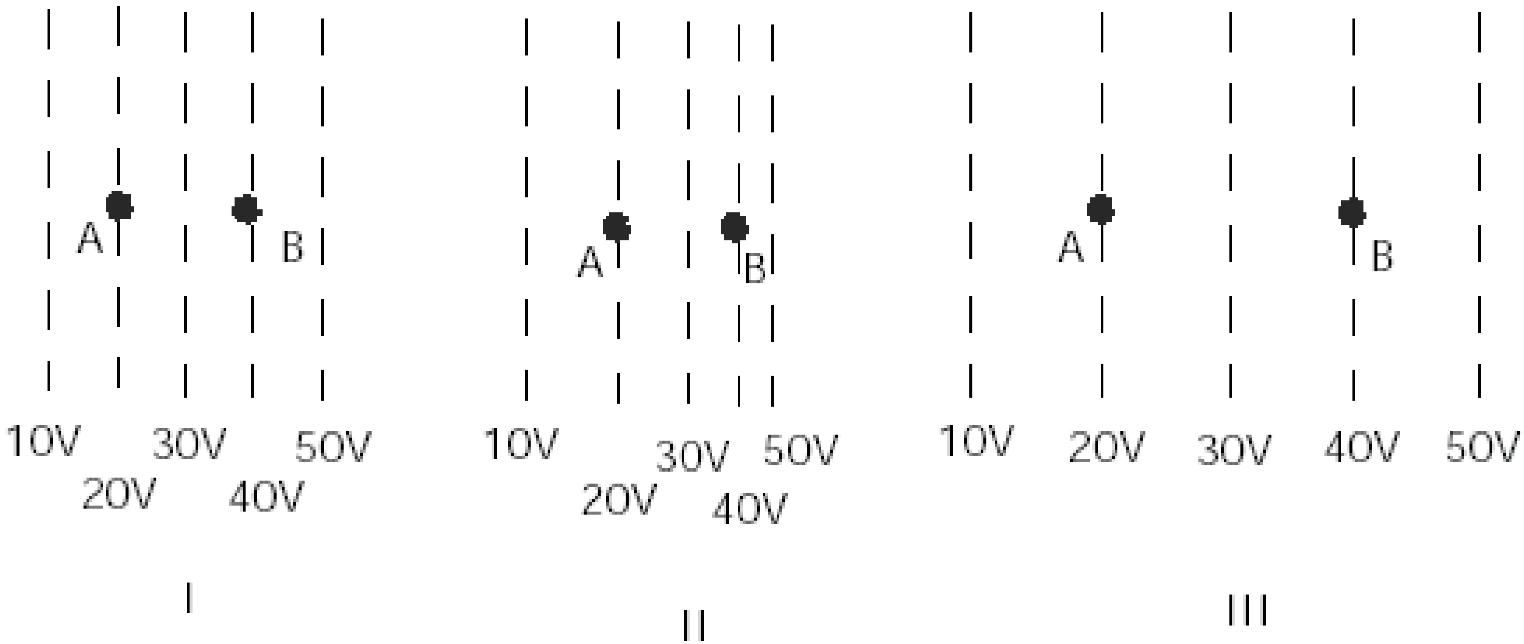
Iowa State University Physics Education Research Group

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

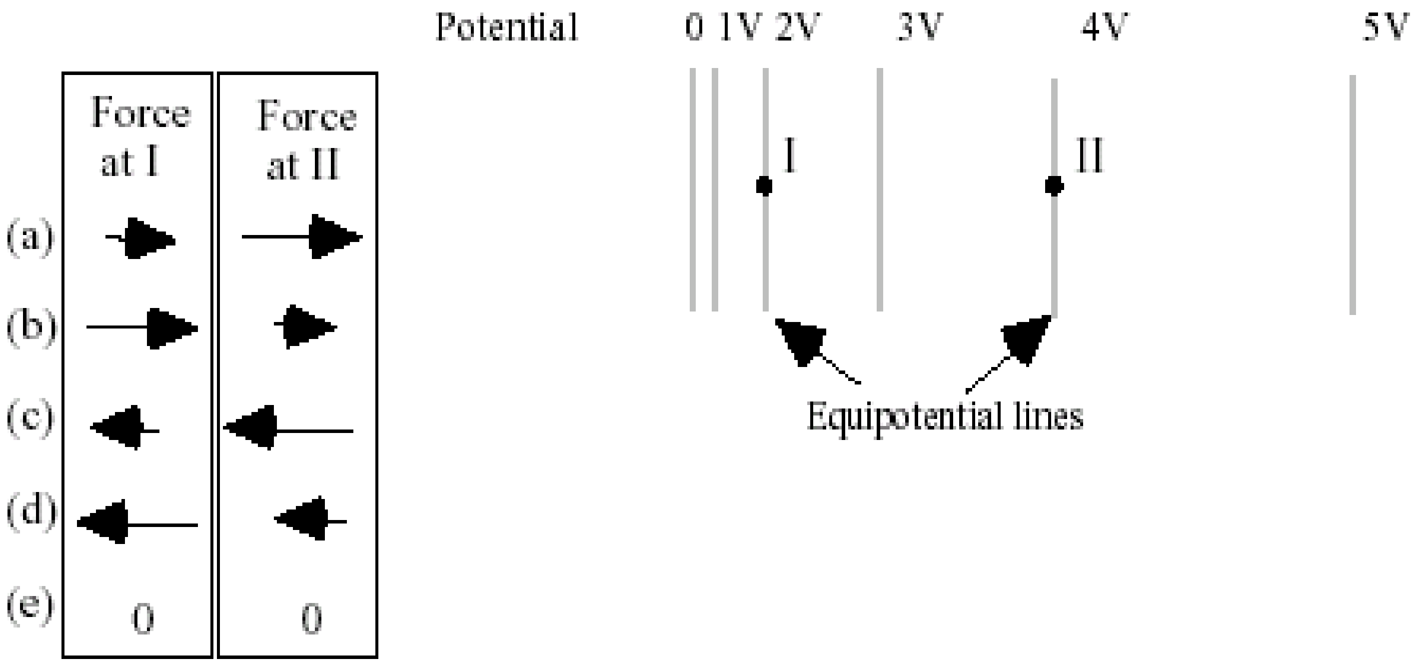
In the figures below, the dotted lines show the equipotential lines of electric fields. (A charge moving along a line of equal potential would have a constant electric potential energy.) A charged object is moved directly from point A to point B. The charge on the object is +1 μC.



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*	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

	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%

Ongoing Curricular Development

(Projects starting 2003)

- "Formative Assessment Materials for Large-Enrollment Physics Lecture Classes"

  Funded through NSF's "Assessment of Student Achievement" program

- "Active-Learning Curricular Materials for Fully Interactive Physics Lectures"

  Funded through NSF's "Course, Curriculum, and Laboratory Improvement – Adaptation and Implementation" program

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)***