Time-dependent Interpretation of Correct Responses to Multiple-Choice Questions

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Q: What can a correct multiple-choice response tell us about a student's thinking?

- A: It depends.
  - Answers can be right for wrong reasons. They can also be right for no reason, i.e., just a lucky guess. How can one judge?
- ***General answer:*** Responses to related questions can help reveal the significance of a particular question-response.
- ***Specific answer:*** Analysis of students' explanations can shed light on *probable* implications of particular answers on specific instruments in particular instructional contexts.

Investigating Students' Reasoning Through Detailed Analysis of Response Patterns

- Pattern of multiple-choice responses may offer evidence about students' mental models.
  - R. J. Dufresne, W. J. Leonard, and W. J. Gerace, 2002.
  - L. Bao, K. Hogg, and D. Zollman, "Model Analysis," 2002.

- Time-dependence of response pattern may give insight into evolution of students' thinking.
  - R. Thornton, "Conceptual Dynamics," 1997
  - D. Dykstra, "Essentialist Kinematics," 2001
  - L. Bao and E. F. Redish, "Concentration Analysis," 2001

Students' Understanding of Representations in Electricity and Magnetism

- Analysis of responses to multiple-choice diagnostic test "Conceptual Survey in Electricity and Magnetism" (Maloney, O'Kuma, Hieggelke, and Van Heuvelen, 2001)
- Administered 1998-2001 in algebra-based physics course at Iowa State [interactive-engagement instruction] (*N* = 299; matched sample)
- Additional data from students' written explanations of their reasoning (2002, unmatched sample: pre-instruction, *N* = 72; post-instruction, *N* = 66)

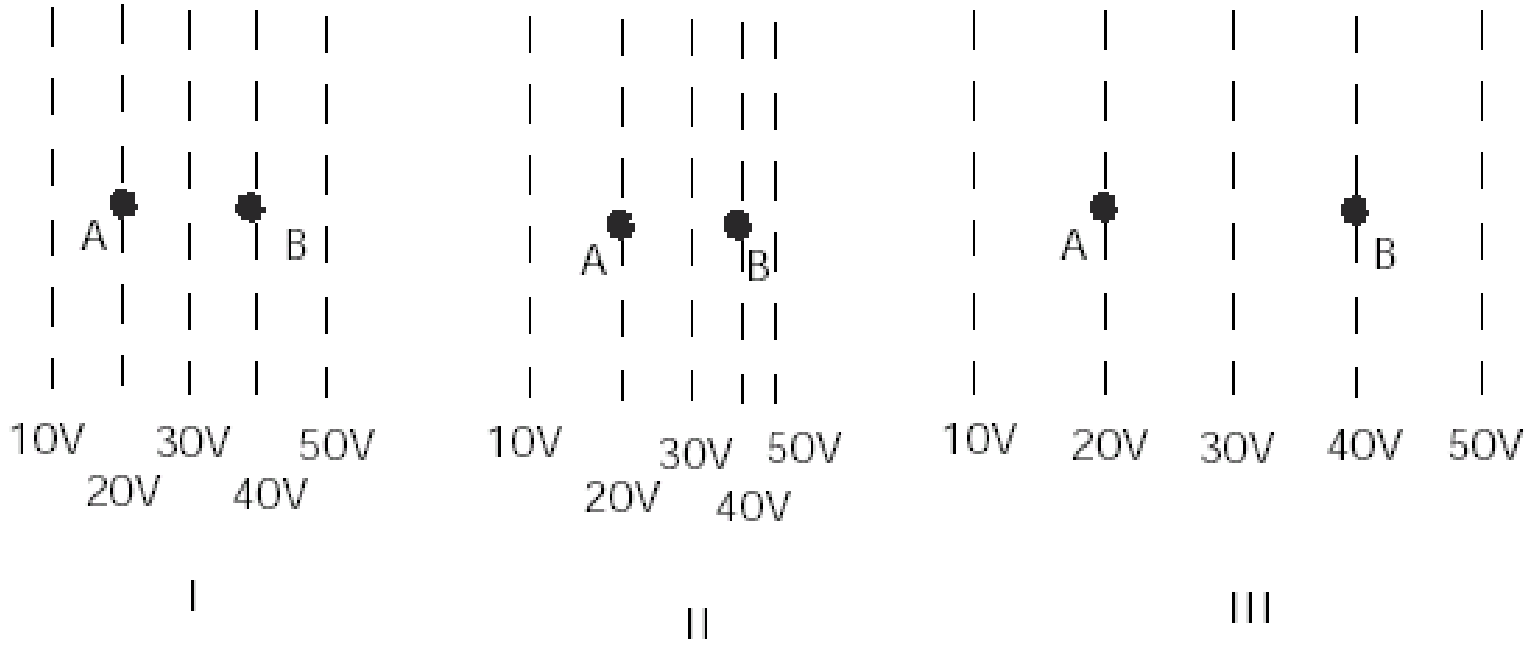
Characterization of Students' Background and Understanding

- Only about one third of students have had any previous exposure to electricity and/or magnetism concepts.
- *Pre-Instruction*: Responses to questions range from clear and acceptable explanations to uncategorizable outright guesses.
- *Post-Instruction*: Most explanations fall into fairly well-defined categories.

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

#18

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.



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

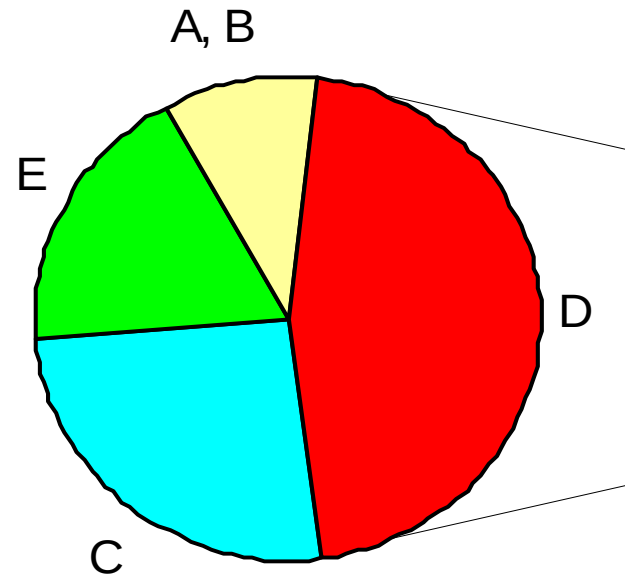
(a) I > III > II
(b) I > II > III
(c) III > I > II
(d) II > I > III **[correct]**
(e) I = II = III

closer spacing of equipotential lines ⇒ larger magnitude field

Pre-Instruction

#18 Pre-test

N = 299



"D": *closer spacing of equipotential lines ⇒ stronger field*

[correct]

Correct Answer, Incorrect Reasoning

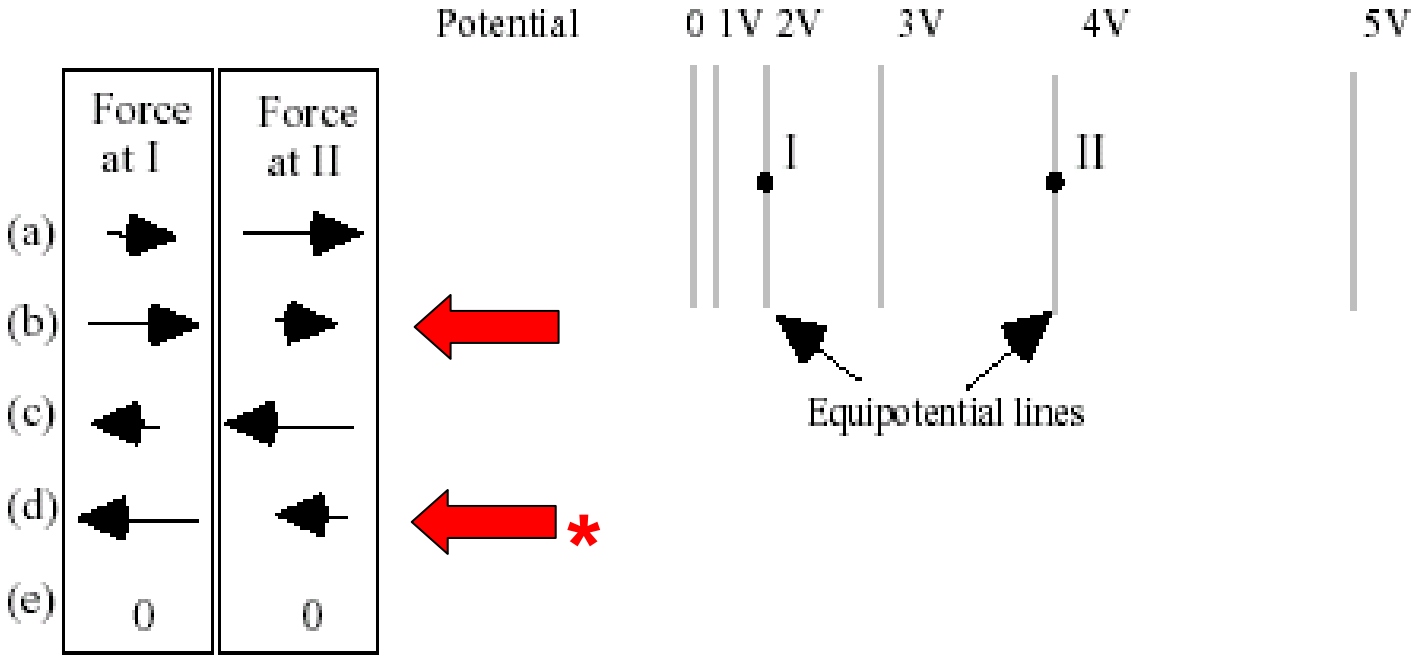
- Nearly half of pre-instruction responses are correct, despite the fact that most students say they have not studied this topic

- Explanations offered include:
  - "chose them in the order of closest lines"
  - "magnitude decreases with increasing distance"
  - "greatest because 50 [V] is so close"
  - "more force where fields are closest"
  - "because charges are closer together"
  - "guessed"

students' initial "intuitions" may influence their learning

#20

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?

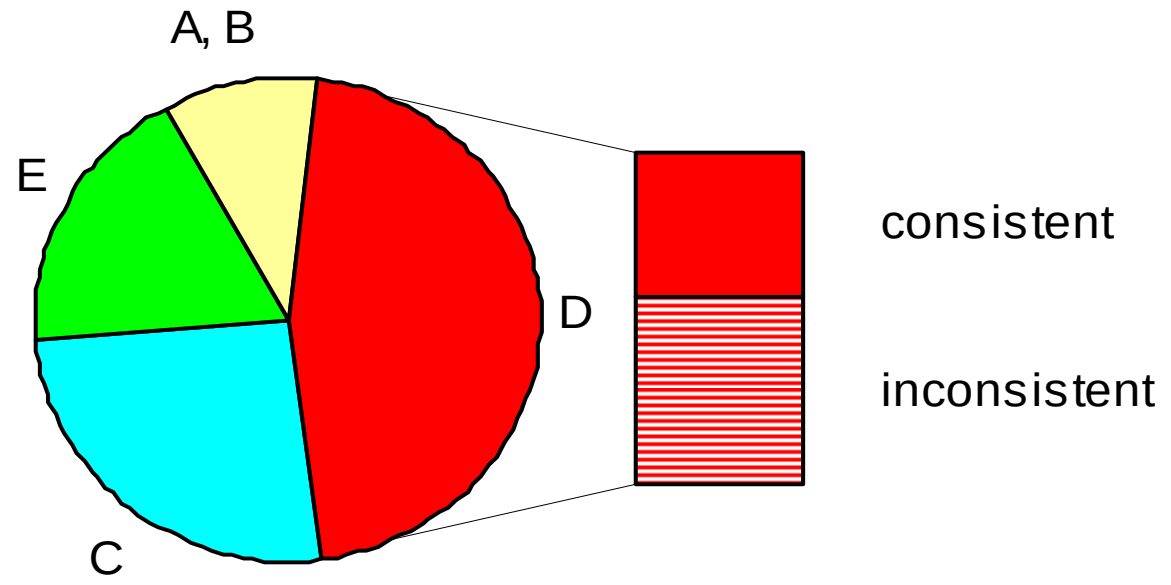


(b) or (d) consistent with correct answer on #18

Pre-Instruction

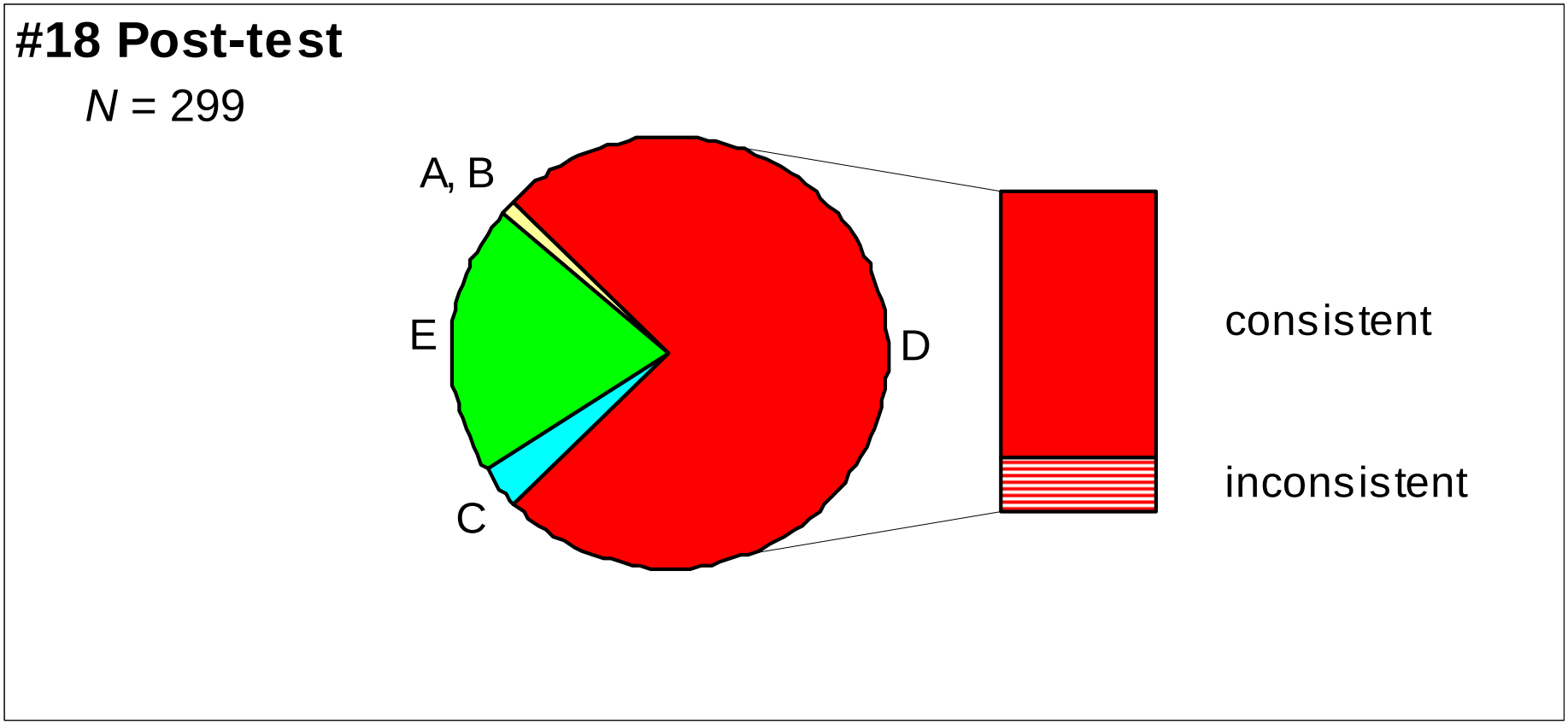
#18 Pre-test

N = 299



“consistent”: *consistent with answer on #20* *(but some guesses)*

Post-Instruction



- **Correct responses *more consistent* with other answers**

(and most explanations actually* are *consistent)

Analysis of Correct Responses on #18

- ***Pre-Instruction:* 46% correct (*D*) responses**
  - Fewer than 20% of students who gave *correct* answers claimed that they had previously studied this material.
  - Of those students giving correct answers, only 45% give a *consistent* (*B* or *D*) response on #20 (almost the same as random guessing).
  - Most explanations were based on “intuition” or simply guessing.

➢ Conclusion: Most pre-instruction correct responses did not correspond to adequate conceptual understanding

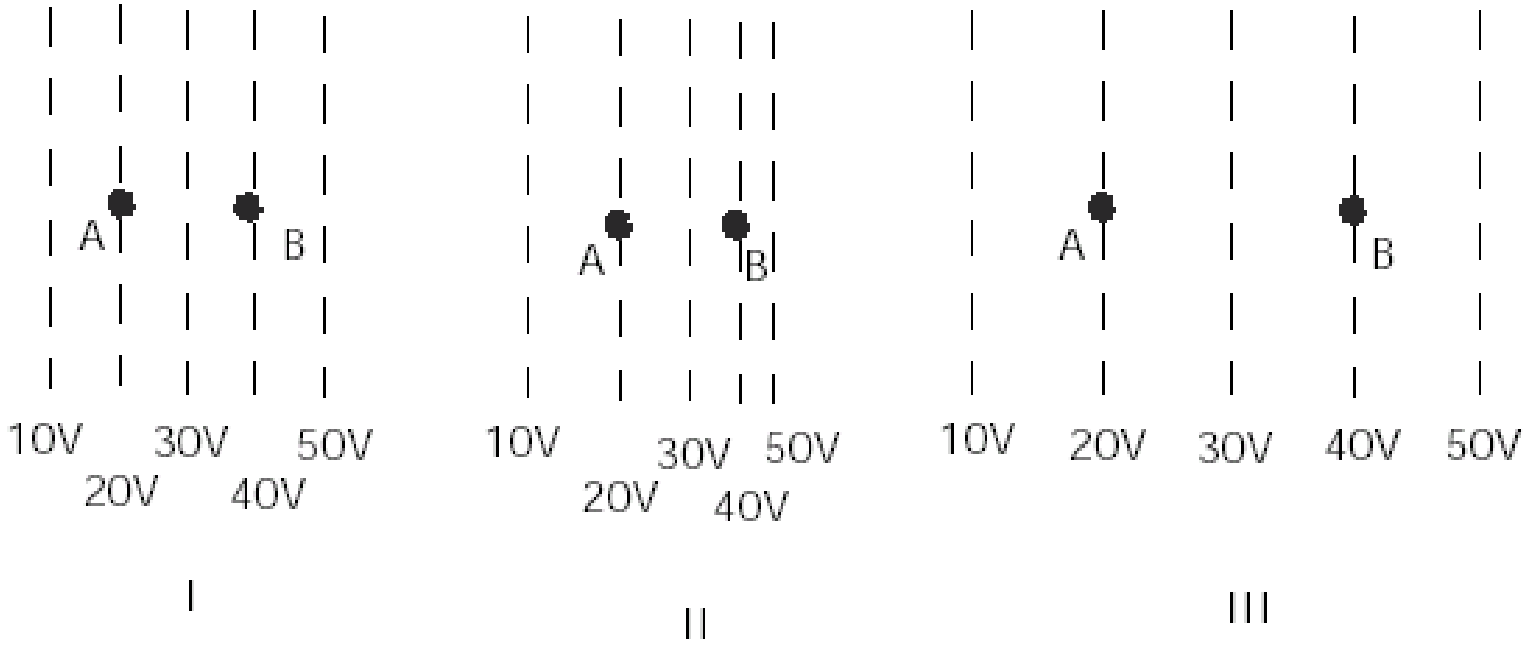
Analysis of Correct Responses on #18

- ***Post-Instruction:* 75% correct (*D*) responses**
  - Of students giving correct responses, 83% now gave a *consistent* (*B* or *D*) response on #20.
  - Students who had correct responses on #18 were far more likely (83% vs. 57%) to give *B* or *D* responses on #20 than those who were incorrect.
  - Most (63%) of the students who were correct on #18 and consistent on #20 gave adequate explanations for *both* items.

➢ Conclusion: Most post-instruction correct responses ***did*** correspond to adequate conceptual understanding

#18

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.



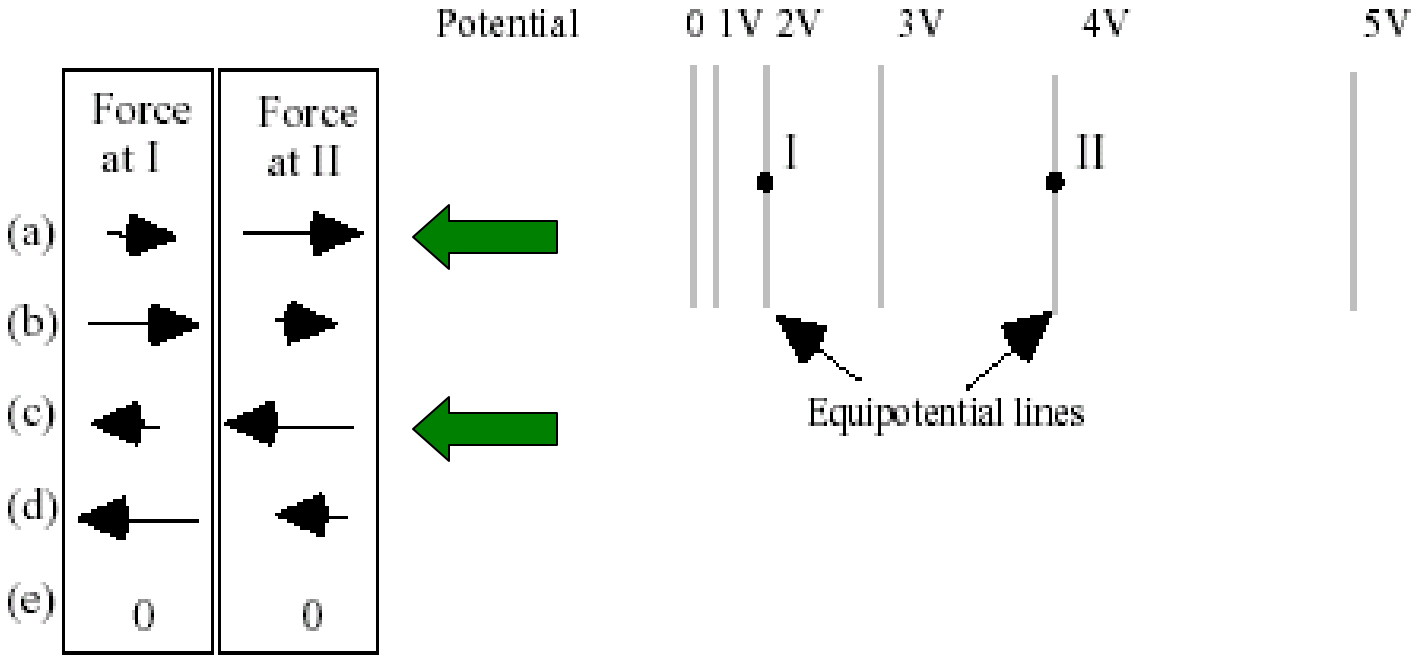
How does the magnitude of the electric field at B compare for these three cases?

(a) I > III > II
(b) I > II > III
(c) III > I > II
(d) II > I > III
(e) I = II = III

Field magnitude at point B equal in all cases

#20

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?

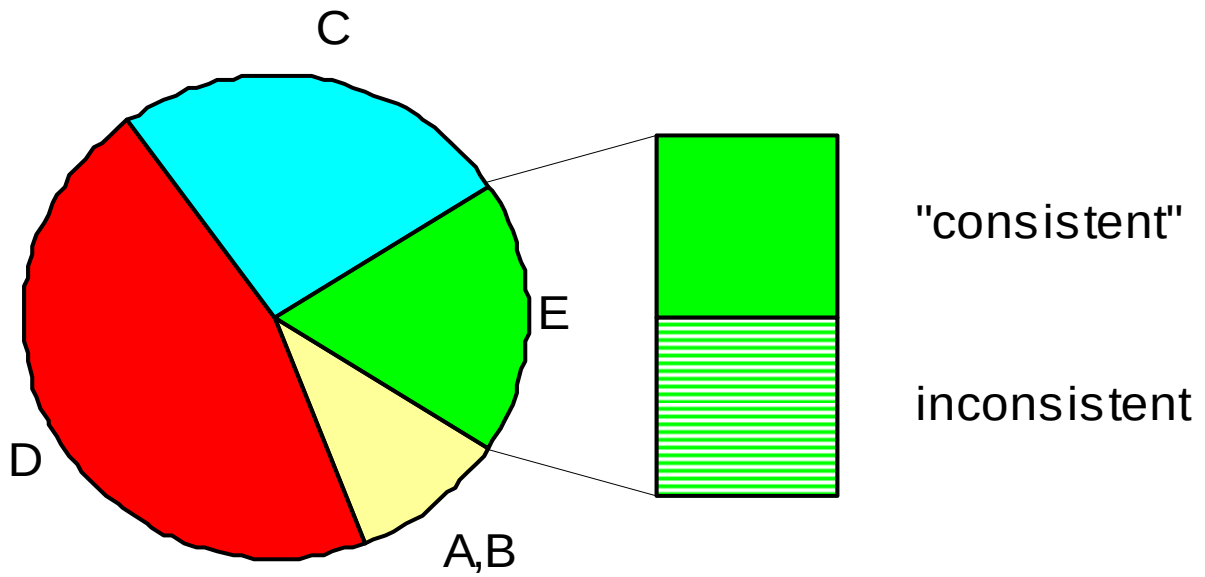


(a) or (c) consistent with “E” response on #18

Pre-Instruction

#18 Pre-test

N = 299



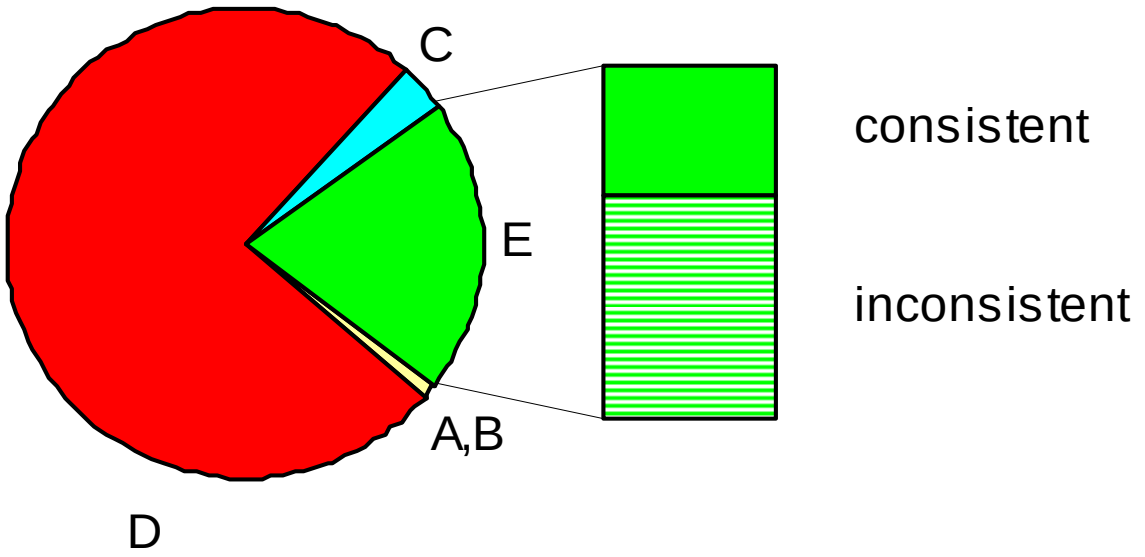
“E”: ***magnitude of field scales with value of potential at point***

“consistent”: ***consistent with answer on #20*** ***(but many guesses)***

Post-Instruction

#18 Post-test

N = 299



- **Proportion of responses in this category virtually unchanged**
- **Incorrect responses *less consistent* with other answers**

Students' Explanations Consistent Pre- and Post-Instruction [i.e., for $E_{B,\mathrm{I}} = E_{B,\mathrm{II}} = E_{B,\mathrm{III}}$]:

- Examples of pre-instruction explanations:
  - "they are all at the same voltage"
  - "the magnitude is 40 V on all three examples"
  - "the voltage is the same for all 3 at *B*"
  - "the change in voltage is equal in all three cases"
- Examples of post-instruction explanations:
  - "the potential at *B* is the same for all three cases"
  - "they are all from 20 V – 40 V"
  - "the equipotential lines all give 40 V"
  - "they all have the same potential"

Analysis of Incorrect Responses on #18

- ***Post-Instruction:* 20% incorrect *E* responses**
  - Incorrect response rate on *E* was (disappointingly) almost unchanged from pretest (18%).
  - However, only 38% of students who gave posttest *E* responses gave consistent (*A* or *C*) responses on #20, *significantly* less than the 51% on the pretest.
  - Although consistency of *correct* responses increased sharply, consistency of *incorrect E* responses fell.

➢ Conclusion: Post-instruction incorrect *E* responses were less likely to correspond to ***consistent*** incorrect thinking than they had before instruction.

Summary

- With regard to student understanding, the implications of correct or incorrect multiple-choice responses can only be fully revealed when additional evidence is taken into consideration.

- When responses (correct or incorrect) are *consistent* with responses to related questions or with written explanations, they are far more likely to provide an accurate reflection of students' thinking than when they are not so consistent.