Analysis of Shifts in Students' Reasoning Regarding Electric Field and Potential Concepts

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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" (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)

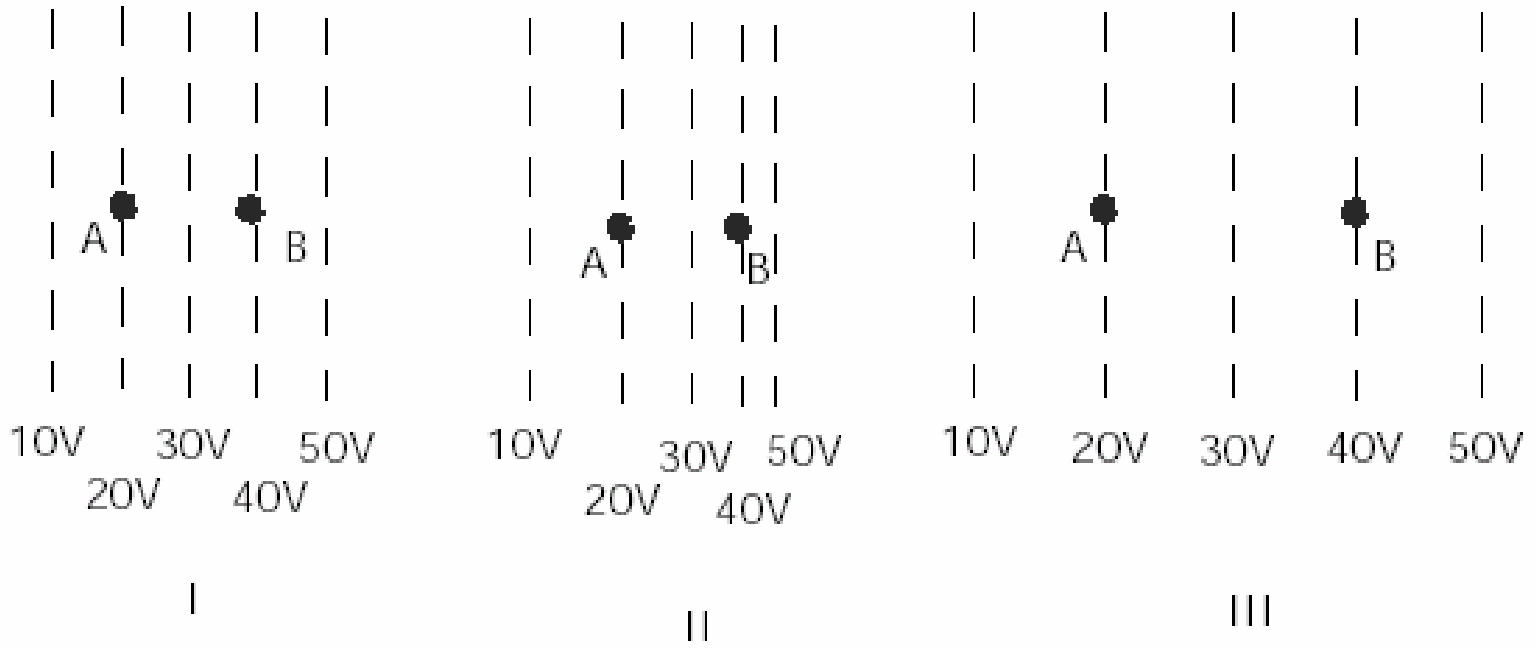
Characterization of Students' Background and Understanding

- 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).

#27

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?

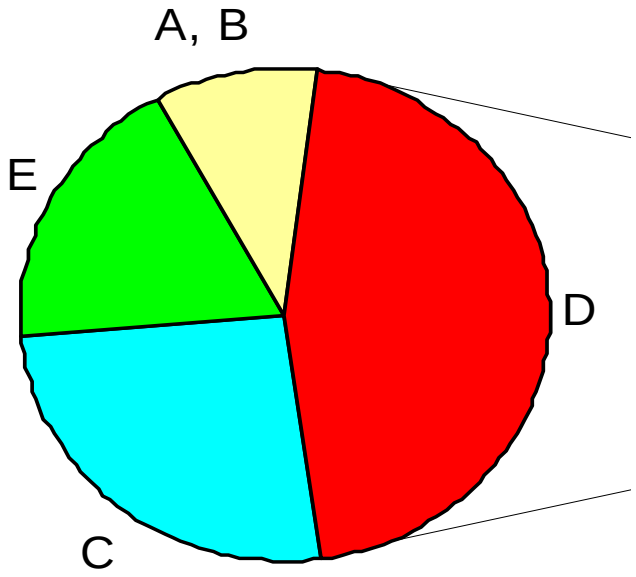
(a) I > III > II
(b) I > II > III
(c) III > I > II
(d) II > I > III **[correct]**
(e) I = II = III

closer spacing of equipotential lines ⇒ larger magnitude field

Pre-Instruction

#27 Pre-test

N = 299



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

[correct]

Correct Answer, Incorrect Reasoning

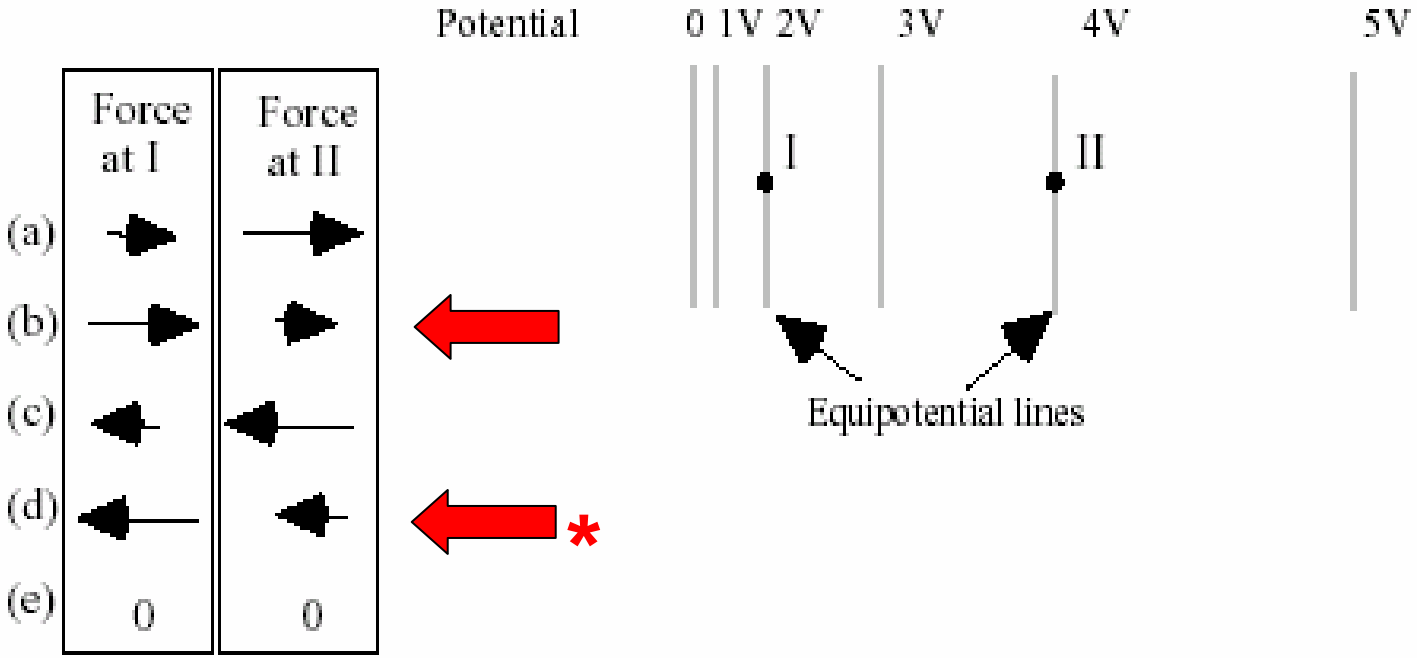
- Nearly half of pre-instruction responses are correct, despite the fact that most students say they have not studied this topic

- 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

#30

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?

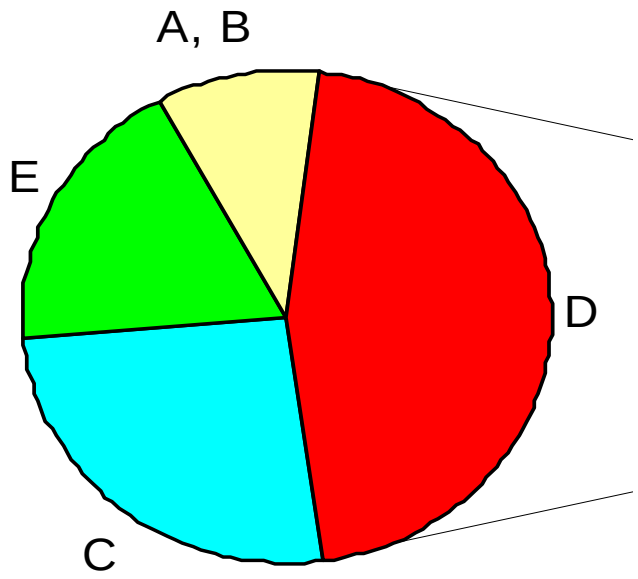


(b) or (d) consistent with correct answer on #27

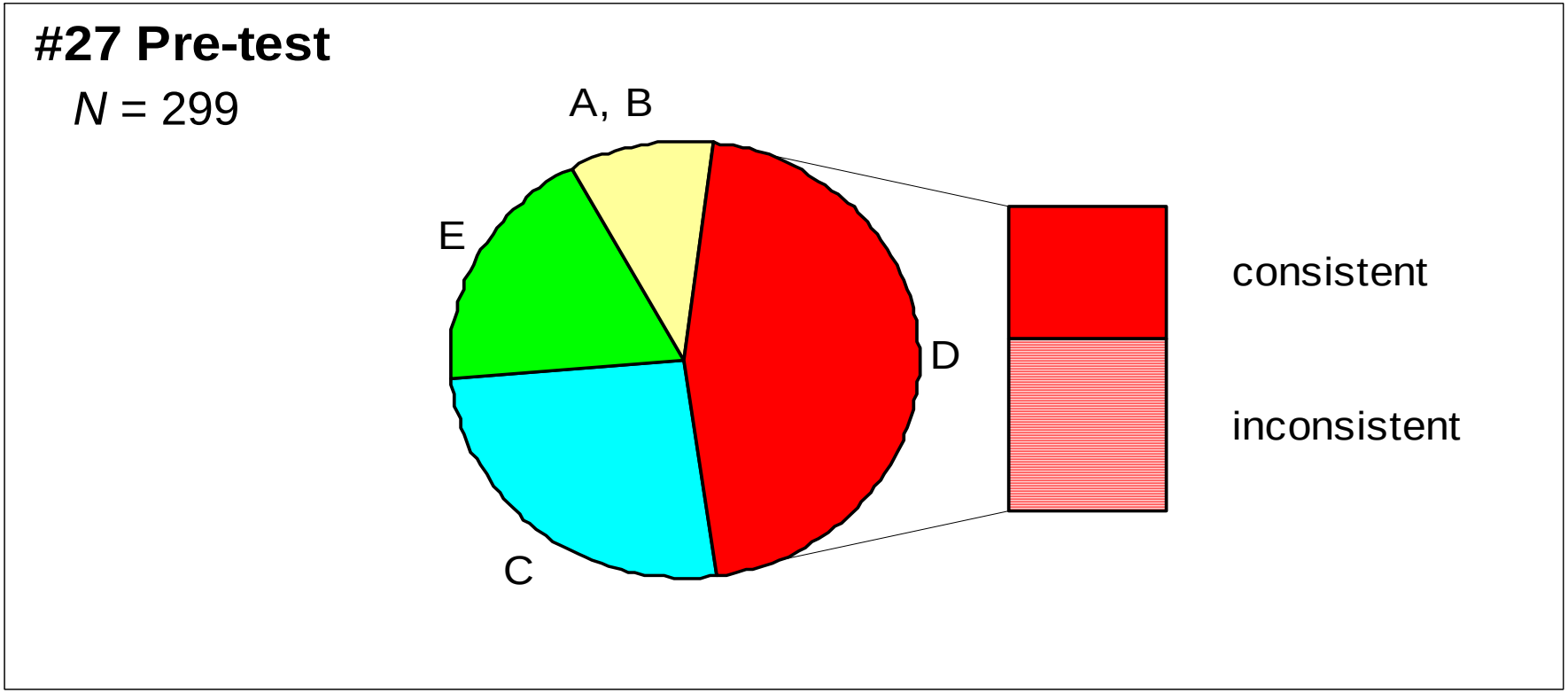
Pre-Instruction

#27 Pre-test

N = 299



Pre-Instruction

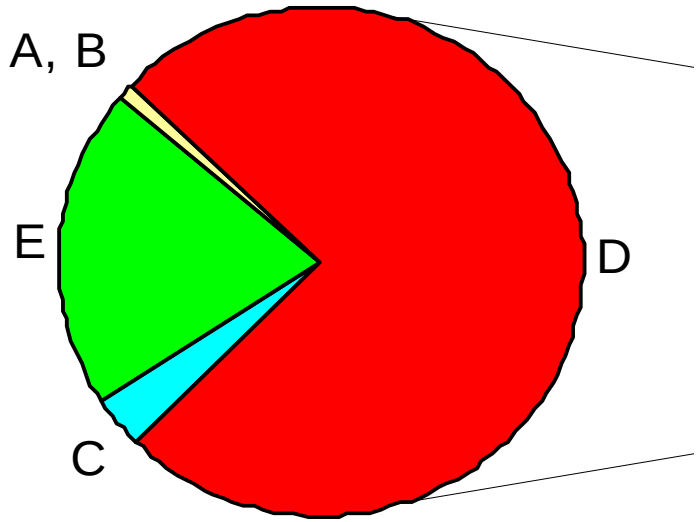


“consistent”: *consistent with answer on #30* *(but some guesses)*

Post-Instruction

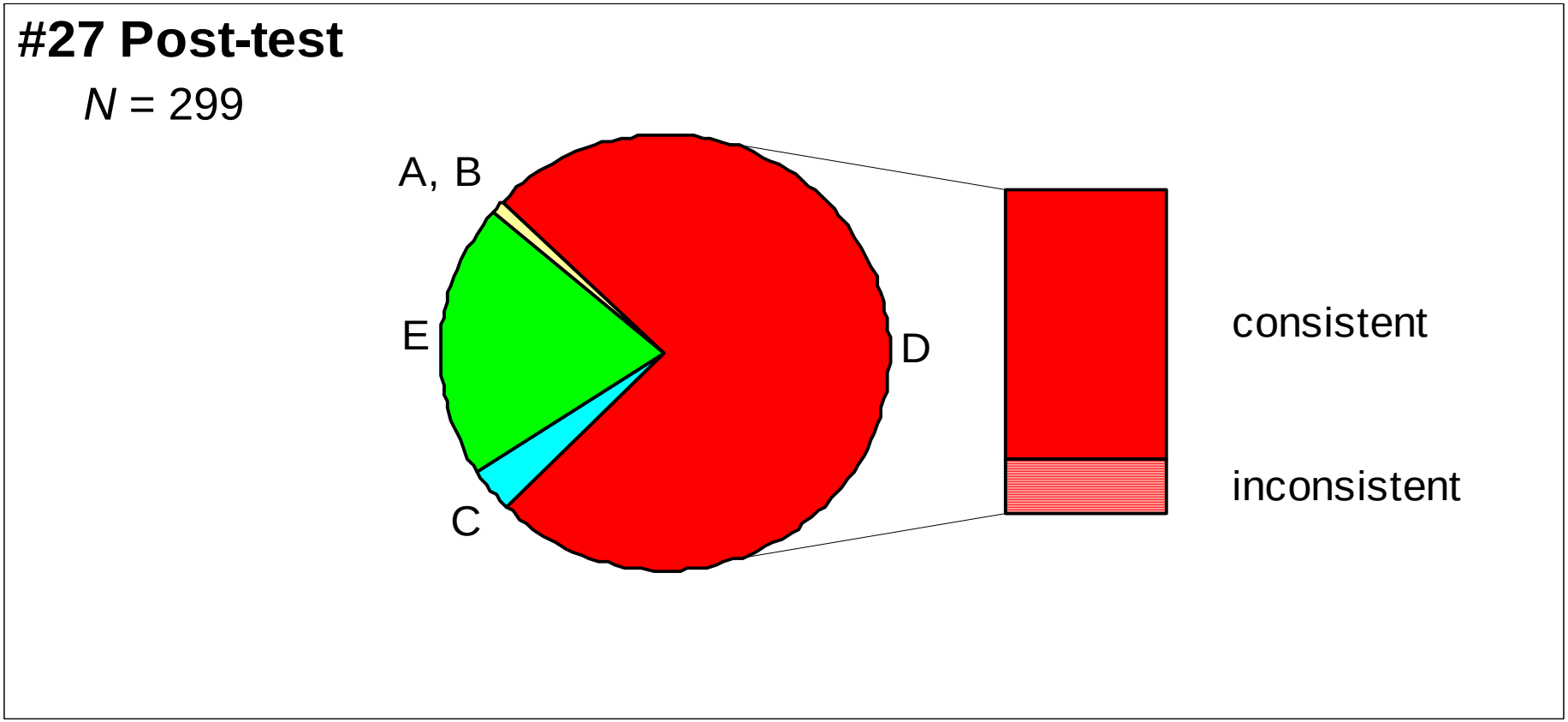
#27 Post-test

N = 299



- **Sharp increase in correct responses**

Post-Instruction

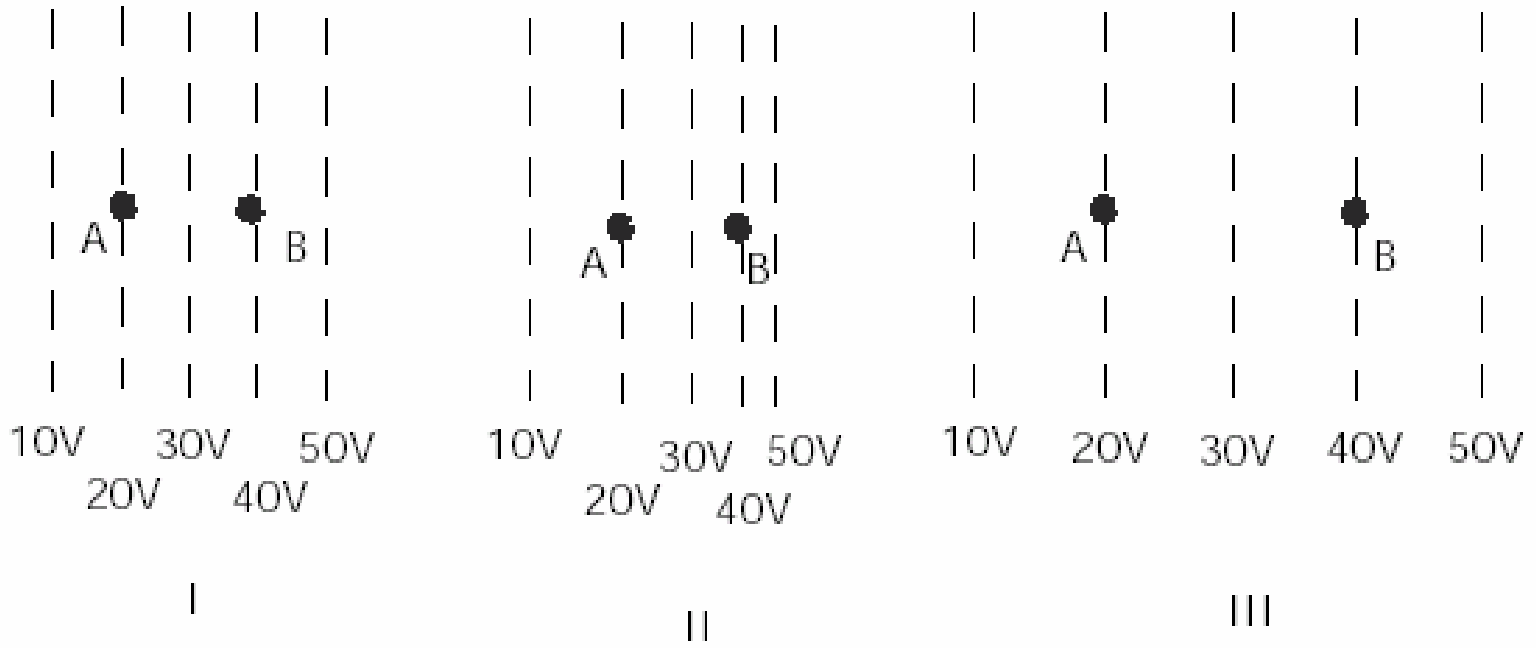


- **Correct responses *more consistent* with other answers**

(and most explanations actually* are *consistent)

#27

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.



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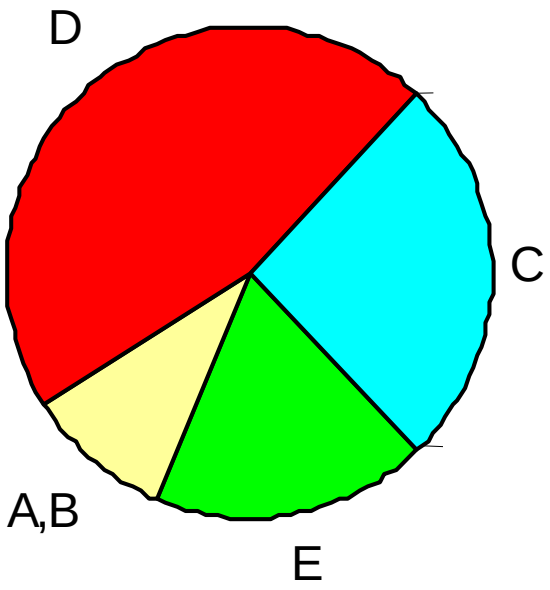
(a) I > III > II
(b) I > II > III
(c) III > I > II
(d) II > I > III
(e) I = II = III

closer spacing of equipotential lines ⇒ <u>smaller</u> magnitude field

Pre-Instruction

#27 Pre-test

N = 299

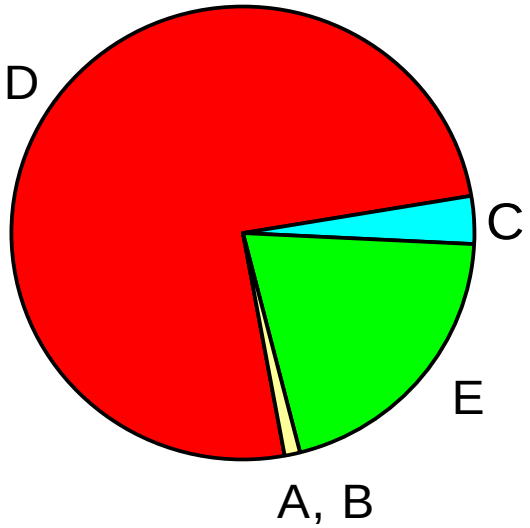


"C": wider spacing of equipotential lines ⇒ stronger field

Post-Instruction

#27 Post-test

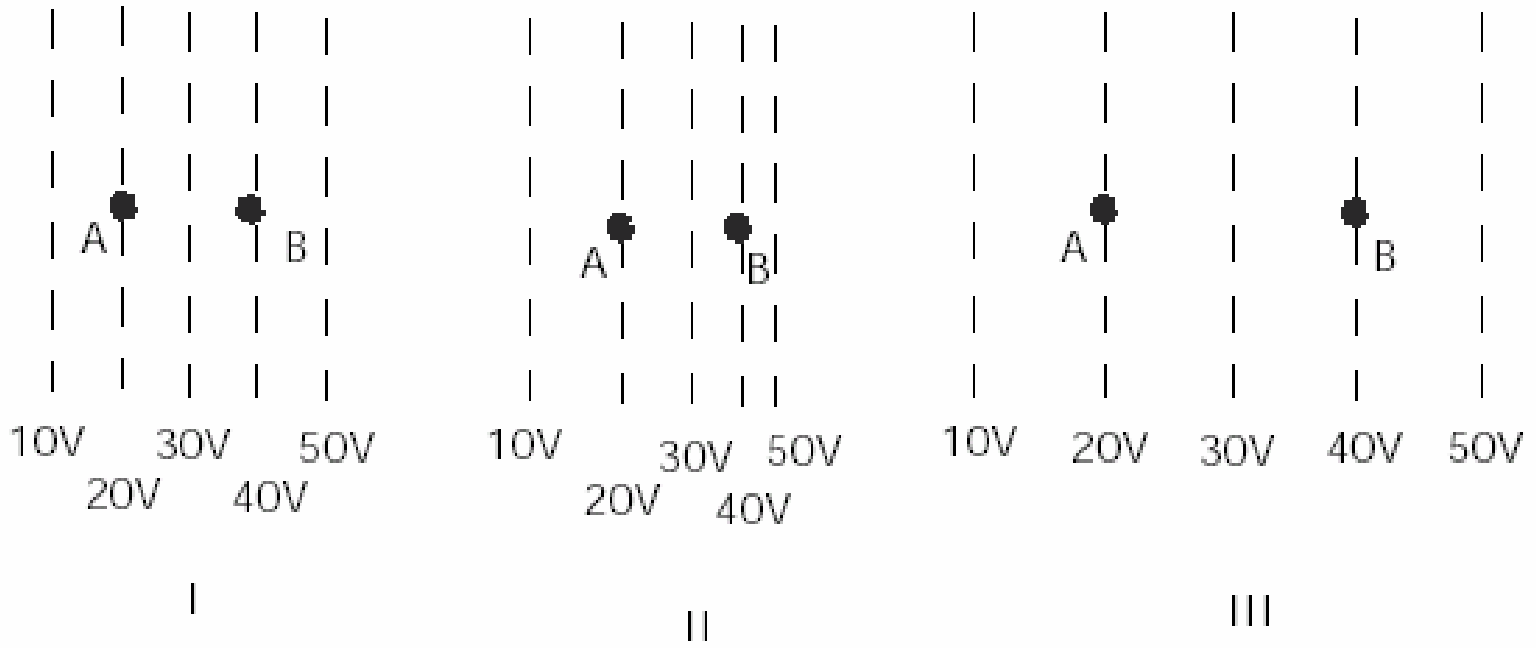
N = 299



- **Proportion of responses in this category drastically reduced**

#27

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.



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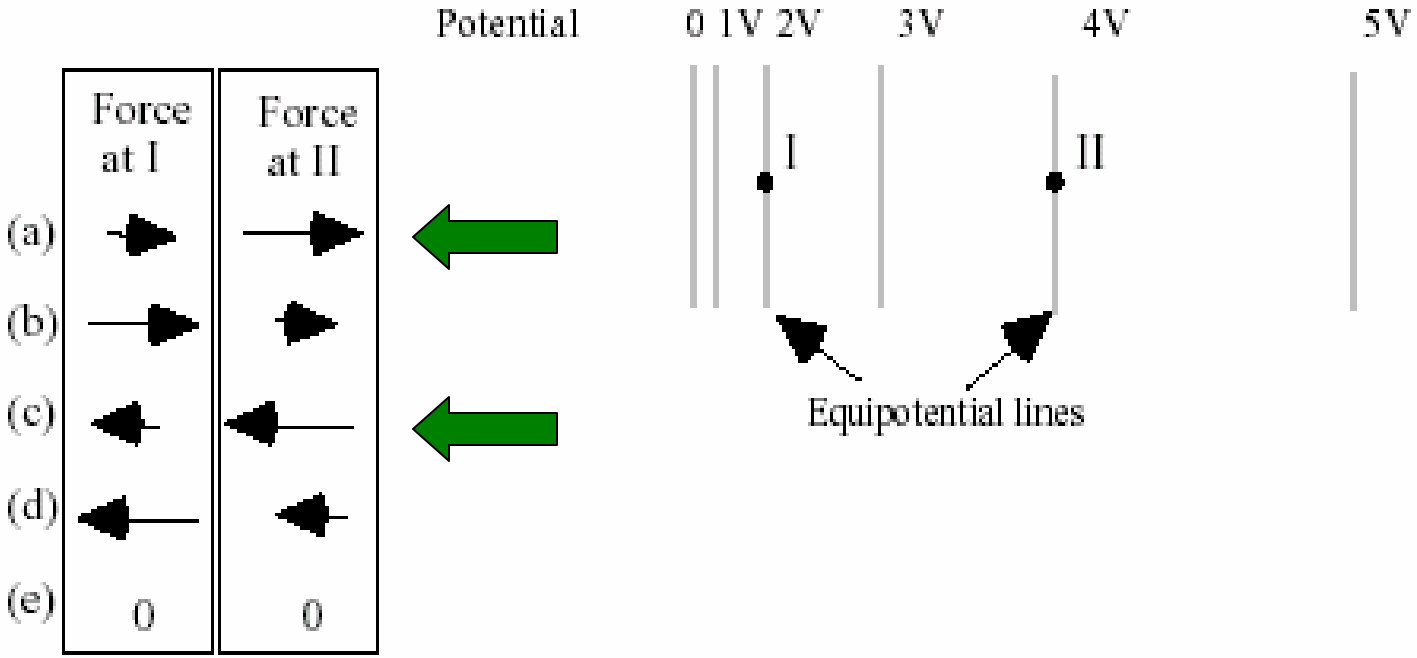
(a) I > III > II
(b) I > II > III
(c) III > I > II
(d) II > I > III
(e) I = II = III

Field magnitude at point B equal in all cases

#30

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?

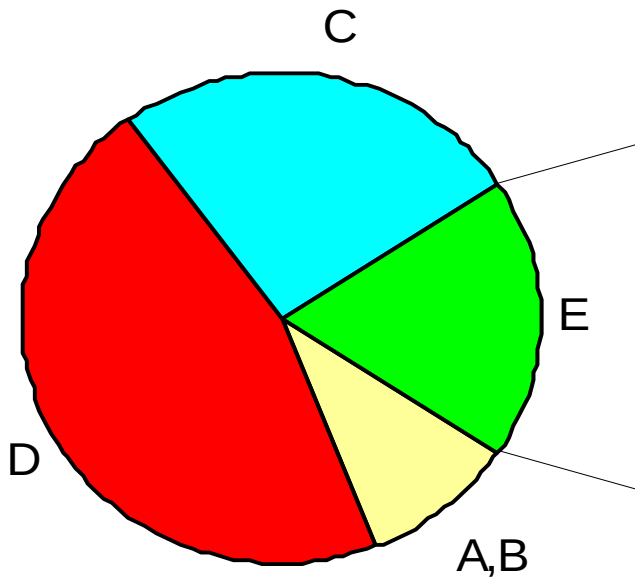


(a) or (c) consistent with “E” response on #27

Pre-Instruction

#27 Pre-test

N = 299

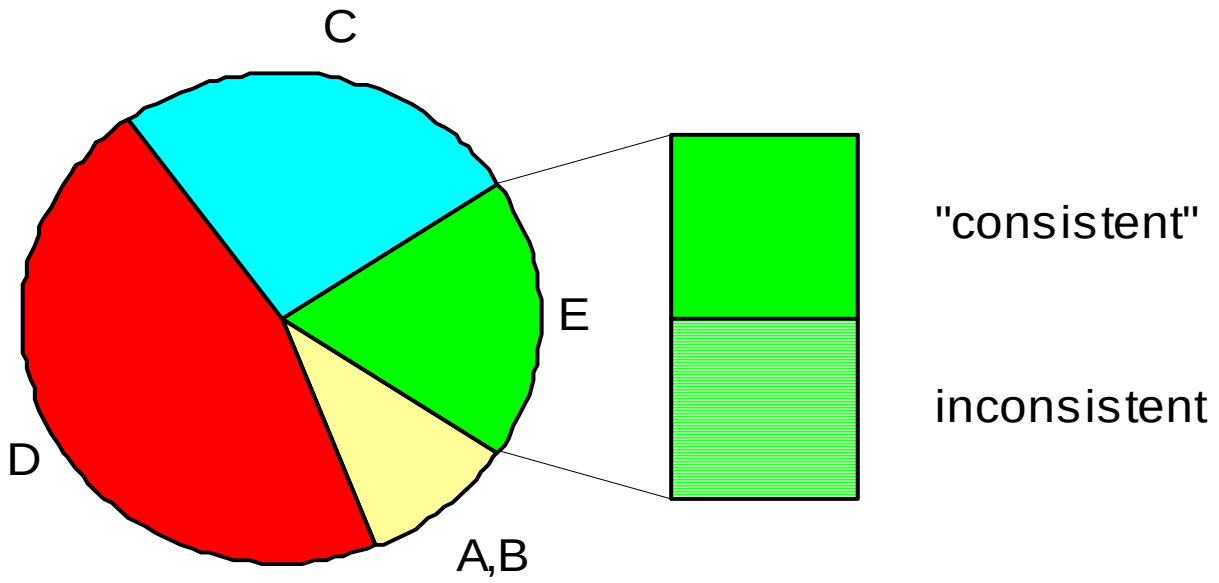


“E”: ***magnitude of field scales with value of potential at point***

Pre-Instruction

#27 Pre-test

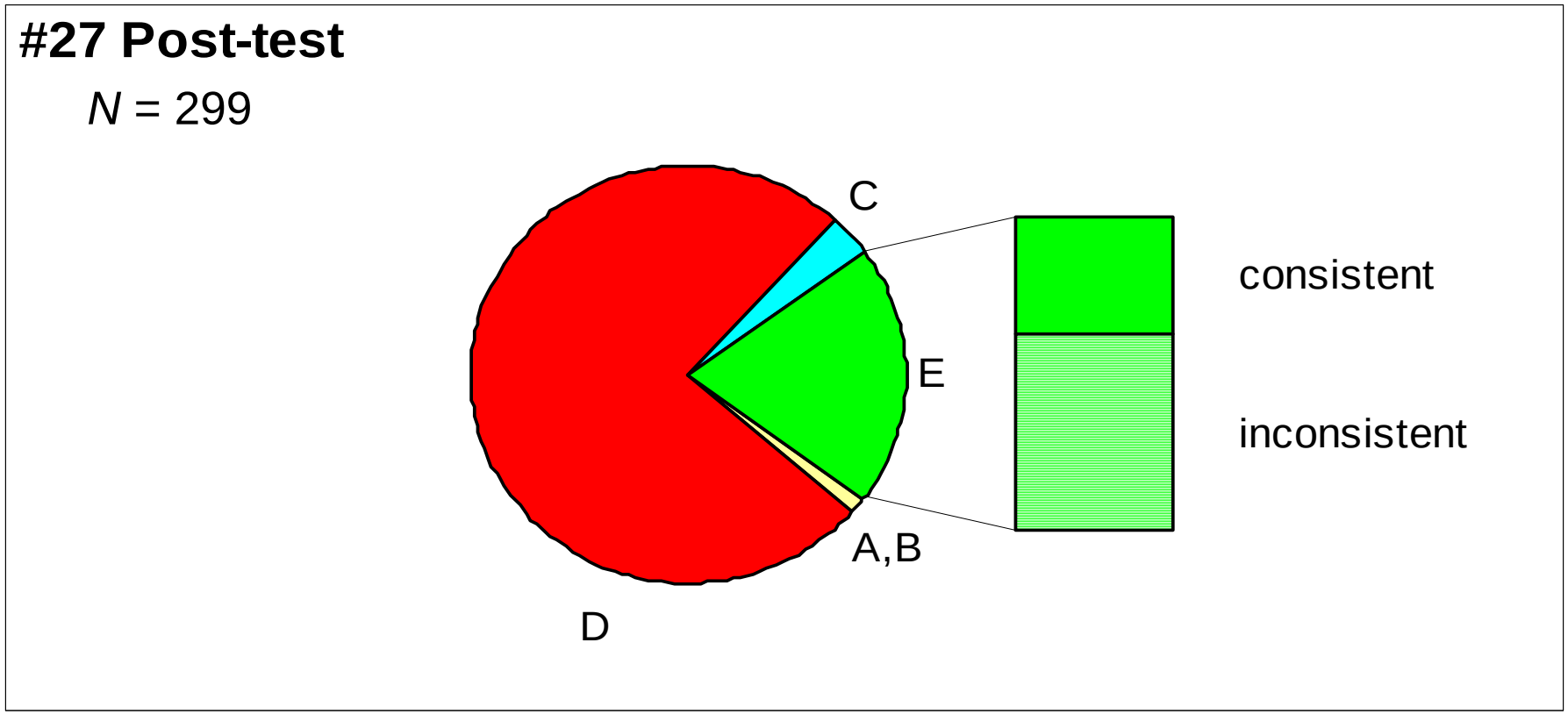
N = 299



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

“consistent”: ***consistent with answer on #30*** ***(but many guesses)***

Post-Instruction



- **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"

Some Student Conceptions Persist, Others Fade

- Initial association of wider spacing with larger field magnitude effectively resolved through instruction
  - Proportion of “C” responses drops to near zero
- Initial tendency to associate field magnitude with magnitude of potential at a given point persists even after instruction
  - Proportion of “E” responses remains ≈ 20%
    - *But less consistently applied after instruction: for students with “E” on #27, more discrepancies between responses to #27 and #30* ***after*** *instruction*

Summary

- Even in the absence of previous instruction, students' responses manifest reproducible patterns that may influence learning trajectories.
- Analysis of pre- and post-instruction responses discloses consistent patterns of change in student reasoning that may assist in design of improved instructional materials.