Role of Diverse Representational Modes in the Learning of Physics

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Investigation of Diverse Representational Modes in the Learning of Physics and Chemistry

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- Probe students' reasoning with widely used "standard" representations
  - e.g., force-vector, free-body, *P-V*, and field-vector diagrams
  - Preliminary work: "*Initial understanding of vector concepts among students in introductory physics courses*" [N.-L. Nguyen and D. E. Meltzer, Am. J. Phys. **71**, 630 (2003).]
- Compare student reasoning with different forms of representation of same concept
  - e.g., verbal, diagrammatic, mathematical/symbolic, graphical

"Multiple-Representation" Quiz

- Same or similar question asked in more than one form of representation
  - e.g., verbal [words only], diagrammatic, mathematical, etc.
- Comparison of responses yields information on students' reasoning patterns with diverse representations

Must ensure that students have first had extensive practice with each form of representation

Investigation of Physics Students' Understanding of Representations

- Second-semester, algebra-based general physics course (PHYS 112)
- Five separate years (1998-2002) at Iowa State University
- Several "multi-representation" quizzes given in class

Example: Quiz on Gravitation

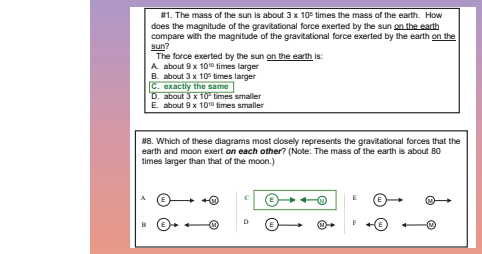
- 11-item quiz given on second day of class (all students have completed study of mechanics)
- Two questions on quiz relate to Newton's third law in astronomical context
  - verbal version and diagrammatic version

#1. The mass of the sun is about 3 x 10^5 times the mass of the earth. How does the magnitude of the gravitational force exerted by the sun on the earth compare with the magnitude of the gravitational force exerted by the earth on the sun?
The force exerted by the sun on the earth is:
A. about 9 x 10^{10} times larger
B. about 3 x 10^5 times larger
C. exactly the same
D. about 3 x 10^5 times smaller
E. about 9 x 10^{10} times smaller

"verbal"

#8. Which of these diagrams most closely represents the gravitational forces that the earth and moon exert ***on each other***? (Note: The mass of the earth is about 80 times larger than that of the moon.)

"diagrammatic"



Results of Quiz on Gravitation

	1998	1999	2000	2001	2002
	N= 78	*N* = 96	*N* = 83	*N* = 77	*N* = 74
#1. force by sun is:					
larger	81%	83%	76%	70%	84%
* the same	14%	10%	20%	23%	14%
smaller	5%	6%	4%	6%	3%
#8. earth/moon force					
⊕ ⟵ ⊕	54%	45%	45%	55%	43%
* ⊕ ⟶ ⊕	6%	6%	12%	12%	7%
⊕ ⟶ ⊕	38%	47%	41%	34%	46%
other	1%	2%	2%	0%	4%

Comparison of Responses: Diagrammatic vs. Verbal

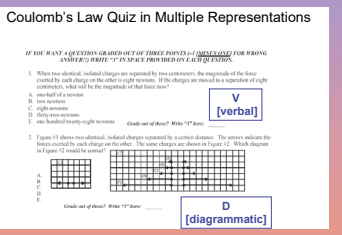
ratio of:	1998	1999	2000	2001	2002	Phys 222 (Calc) *N* = 240
correct on #8 (diagrammatic) / ***correct on #1 (verbal)***	0.45	0.60	0.59	0.50	0.50	0.61
"smaller" on #8 (diagrammatic) / ***"smaller" on #1 (verbal)***	8	8	11	5	18	26

Apparently many students have difficulty translating phrase "*exerted on*" into vector diagram form.

Comparison of Responses

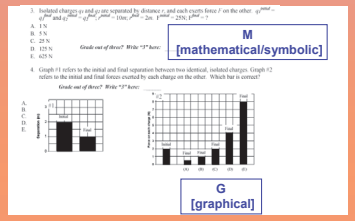
- Proportion of correct responses on diagrammatic version of question is consistently lower than on verbal version.
  - ratio of correct responses on one version compared to the other is *very* consistent from year to year
- Pattern of incorrect responses is dramatically different on two versions of question:
  - most common response on verbal version: *force exerted by more massive object has larger magnitude*
  - on diagrammatic version: *force exerted by more massive **or** less massive object has larger magnitude*

Coulomb's Law Quiz in Multiple Representations



V [verbal]

D [diagrammatic]



M [mathematical/symbolic]

G [graphical]

DC Circuits

1. In a parallel circuit, a three-ohm resistor and a six-ohm resistor are connected to a battery. In a series circuit, a four-ohm and an eight-ohm resistor are connected to a battery that has the *same* voltage as the battery in the parallel circuit. What will be the ratio of the current through the six-ohm resistor to the current through the four-ohm resistor? Current through six-ohm resistor divided by current through four-ohm resistor is:
A. greater than one
B. equal to one
C. less than one
D. equal to negative one
E. cannot determine without knowing the battery voltage
Grade out of 3? Write "3" here: _____

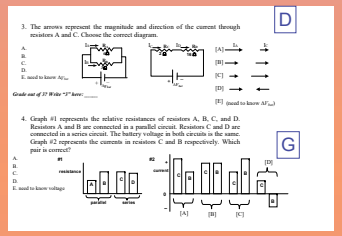
V

2. Parallel circuit: $R_A = 6\ \Omega$, $R_B = 9\ \Omega$.
Series circuit: $R_C = 7\ \Omega$, $R_D = 3\ \Omega$.
$\Delta V_{AB}(series) = \Delta V_{AB}(parallel)$

A. $\frac{I_C}{I_D} > 1$ B. $\frac{I_C}{I_D} = 1$ C. $\frac{I_C}{I_D} < 1$ D. $\frac{I_C}{I_D} = -1$ E. need ΔV_{bat}

Grade out of 3? Write "3" here: _____

M



D

G

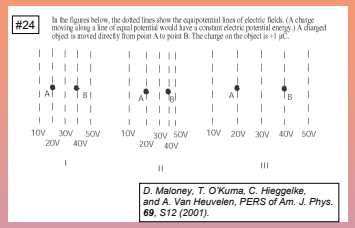
Students' Problem-Solving Performance and Representational Mode

[D. E. Meltzer, submitted to Am. J. Phys. *(2003)]*

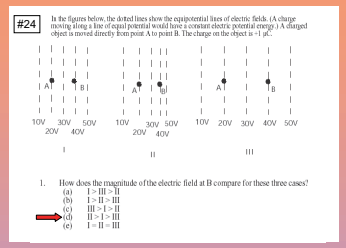
- Significant discrepancy between student responses on Newton's third-law questions in "verbal" and "diagrammatic" representations
  - *diagrams often evoke "larger mass ⇒ larger force" misconception*
  - *strong tendency to confuse "force exerted **on**" and "force exerted **by**" when using diagrams*
- Even after identical instruction, consistent discrepancy between female and male performance on circuit-diagram questions
  - *50% higher error rates for female students in PHYS 112*

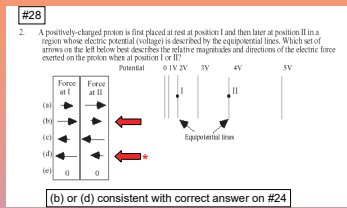
Current Work: Students' Understanding of Representations in Electricity and Magnetism

- Analysis of responses to multiple-choice diagnostic test "Conceptual Survey in Electricity"
- Administered 1998-2002 in algebra-based physics course at ISU (PHYS 112)
- Additional data from students' written explanations of their reasoning (2002)



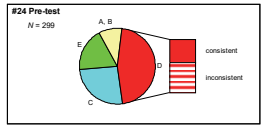
D. Maloney, T. O'Kuma, C. Hieggelke, and A. Van Heuvelen, PERS of Am. J. Phys. **69**, S12 (2001).





(b) or (d) consistent with correct answer on #24

Pre-Instruction



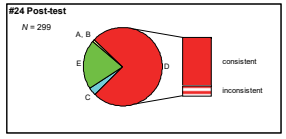
"D": closer spacing of equipotential lines ⇒ stronger field
"consistent": consistent with answer on #28

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"

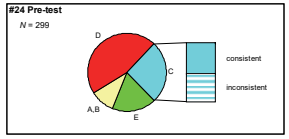
students' initial "intuitions" may influence their learning

Post-Instruction



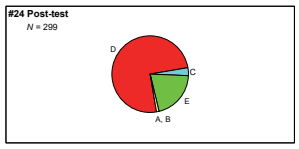
- **Sharp increase in correct responses**
- **Correct responses *more consistent* with other answers**

Pre-Instruction



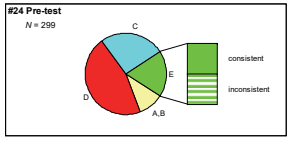
"C": wider spacing of equipotential lines ⇒ stronger field
"consistent": consistent with answer on #28

Post-Instruction



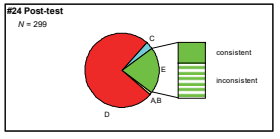
- **Proportion of responses in this category drastically reduced**

Pre-Instruction



"E": field magnitude independent of equipotential line spacing **"consistent": *consistent with answer on #28***

Post-Instruction



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

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 #24, more discrepancies between responses to #24 and #28 **after** instruction*

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

- 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"

Summary

- We have uncovered a consistent pattern of student learning difficulties with some standard physics representations.
- Preliminary results suggest some gender-related performance disparities with certain types of representations.
- Analysis of pre- and post-instruction responses discloses consistent patterns of change in student reasoning with particular forms of representation.