

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, 1638 (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 3×10^3 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 9×10^3 times larger
B. about 3×10^3 times larger
C. exactly the same
D. about 3×10^3 times smaller
E. about 9×10^3 times smaller

[verbal]

#6. 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]

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[mathematical/symbolic]

#6. 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]

3. In which circuit is the total resistance between points A and B the greatest?

A. 1 Ω
B. 2 Ω
C. 3 Ω
D. 4 Ω
E. 5 Ω

4. Graph 1 refers to the initial and final capacitor between two identical, isolated charges. Graph 2 refers to the initial and final electric field between two identical, isolated charges.

[graphical]

Results of Quiz on Gravitation

	1998	1999	2000	2001	2002
#1. force by sun is:	N=78	N=96	N=83	N=77	N=74
larger	81%	83%	78%	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
correct on #8 (diagrammatic)	0.45	0.60	0.59	0.50	0.50
correct on #1 (verbal)					
"smaller" on #8 (diagrammatic)	8	8	11	5	18
"smaller" on #1 (verbal)					

Phys 222 (Calc) N=246

➔ 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

IF YOU WANT A QUESTION GRADUATED FROM THREE POINTS TO ONE POINT FOR WRONG ANSWERS WRITE "3" IN SPACE PROVIDED ON EACH QUESTION.

1. Which object exerts the largest magnitude of electric force on the other? (Note: The mass of the earth is about 80 times larger than that of the moon.)

A. moon exerts a force
B. earth exerts a force
C. equal forces
D. neither exerts a force
E. both exert equally strong forces

2. Figure 1 shows two identical, isolated, parallel-plate capacitors. The plates between the capacitors are charged by each charge on the other. The same charge is shown in Figure 2. Which diagram best represents the electric field between the plates?

[diagrammatic]

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 three-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

2. Parallel circuit: $R_1 = 6 \Omega$, $R_2 = 9 \Omega$. Series circuit: $R_1 = 7 \Omega$, $R_2 = 3 \Omega$. $\Delta V_{\text{parallel}} = \Delta V_{\text{series}}$

A. $\frac{I_1}{I_2} > 1$ B. $\frac{I_1}{I_2} = 1$ C. $\frac{I_1}{I_2} < 1$ D. $\frac{I_1}{I_2} = 1$ E. need ΔV_{series}

[mathematical/symbolic]

3. The arrows represent the magnitude and direction of the current through resistors A and C. Choose the correct diagram.

4. Graph #1 represents the relative resistances of resistors A, B, C, and D. Resistors A and B are connected in a parallel circuit. Resistors C and D are connected in a series circuit. The battery voltage is the same in both circuits. Graph #2 represents the currents in resistors C and B, respectively. Which pair is correct?

[graphical]

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 \Rightarrow 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)

#24. In the figures below, the dotted lines show the equipotential lines of electric fields. (A charge moving along a line of equipotential 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 $+1 \mu\text{C}$.

I
II
III

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

#24. In the figures below, the dotted lines show the equipotential lines of electric fields. (A charge moving along a line of equipotential 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 $+1 \mu\text{C}$.

I
II
III

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

[mathematical/symbolic]

#28. 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)

(b)

(c)

(d)

(e)

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

Pre-Instruction

#24 Pre-test N = 299

"D": closer spacing of equipotential lines \Rightarrow 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:
 - "choose 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

#24 Post-test N = 299

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

Pre-Instruction

#24 Pre-test N = 299

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

Post-Instruction

#24 Post-test N = 299

Proportion of responses in this category drastically reduced

Pre-Instruction

#24 Pre-test N = 299

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

Post-Instruction

#24 Post-test N = 299

- 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 \approx 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.