Variability in Student Learning Associated with Diverse Modes of Representation

David E. Meltzer

Department of Physics and Astronomy
Iowa State University
Ames, Iowa

Supported in part by National Science Foundation grants DUE #9981140 and REC #0206683

Collaborators

Tom Greenbowe (Department of Chemistry, ISU)
Leith Allen (Ohio State University)

Post-doc
Irene Grimberg

Graduate Student
Larry Engelhardt

Investigation of Physics Learning with Diverse Representations

- Probe student understanding of standard physics representations
- Compare student reasoning when using different forms of representation

“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

Context of Investigation

- Second-semester, algebra-based general physics course (mostly electricity and magnetism)
- Five separate years (1998-2002) at Iowa State University
- Several “multi-representation” quizzes given in class

Will present data analysis for Gravitation quiz, Coulomb’s law quiz, and DC Circuits quiz

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?

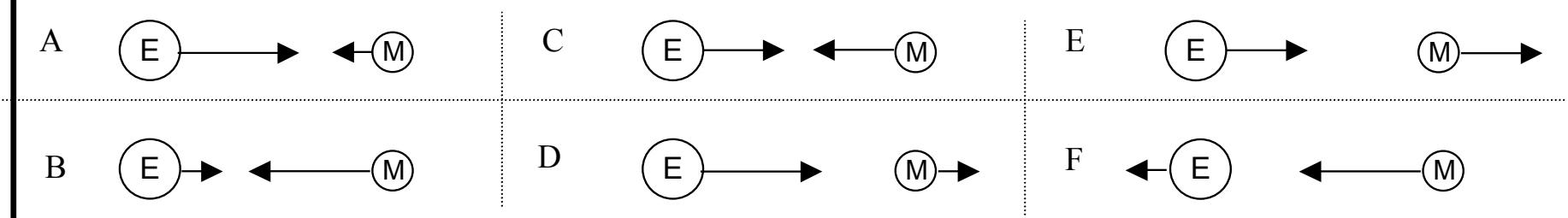
The force exerted by the sun on the earth is:

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"

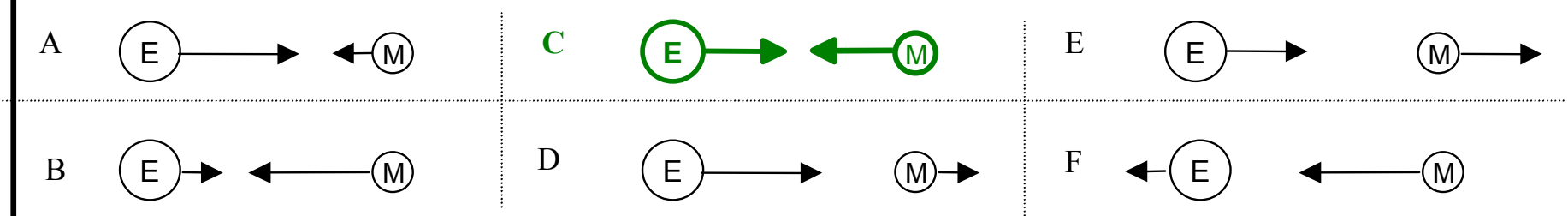


#1. The mass of the sun is about 3 x 10^5 times the mass of the earth. How does the magnitude of the gravitational force exerted by the sun <u>on the earth</u> compare with the magnitude of the gravitational force exerted by the earth <u>on the sun</u>?

The force exerted by the sun <u>on the earth</u> 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

#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.)



#1. The mass of the sun is about 3×10^5 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?

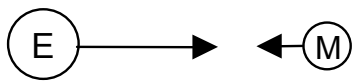
The force exerted by the sun on the earth is:

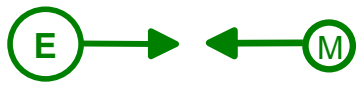
A. about 9×10^{10} times larger
B. about 3×10^5 times larger
C. exactly the same
D. about 3×10^5 times smaller
E. about 9×10^{10} times smaller

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					
*** the same**	**14%**	**10%**	**20%**	**23%**	**14%**
smaller					

#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.)

A 

C 

E 

B 

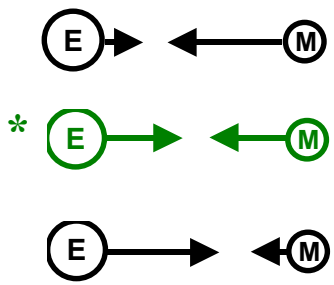
D 

F 

Results of Quiz on Gravitation

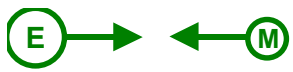
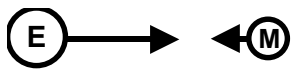
	1998	1999	2000	2001	2002
#1. force by sun is:	*N= 78*	*N = 96*	*N = 83*	*N = 77*	*N = 74*
larger					
* **the same**	**14%**	**10%**	**20%**	**23%**	**14%**
smaller					

#8. earth/moon force



6%	**6%**	**12%**	**12%**	**7%**

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%**	**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%**
[wrong direction]	1%	2%	2%	0%	4%

Comparison of Responses

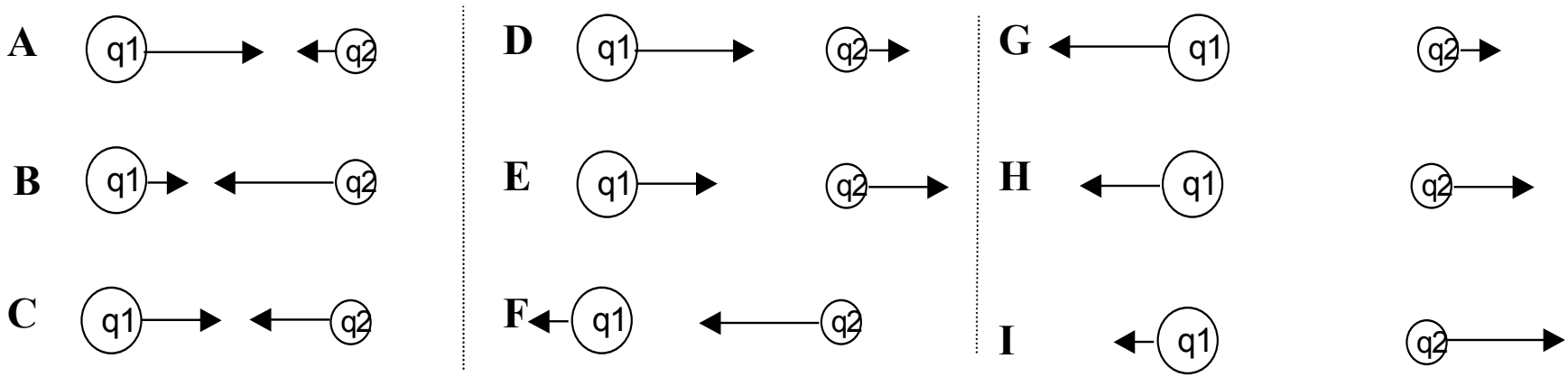
- Proportion of correct responses on diagrammatic version of question is consistently lower than on verbal version.
- Pattern of incorrect responses is dramatically different on two versions of question:
  - most common response on verbal version: *force exerted by more massive object has larger magnitude*
  - on diagrammatic version: *force exerted by more massive **or** less massive object has larger magnitude*

Comparison of Responses: Diagrammatic vs. Verbal

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

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

In the figure below, particle q1 has a charge of +10 C, and particle q2 has a charge of –2 C.



Question on 2002 Final Exam

(A) *[3 points]* Which of these diagrams most closely represents the electrical forces that the two charges exert ***on each other?***

(B) *[2 points]* Explain your answer to part (A).

Students' explanations confirm hypothesis regarding "arrow" error

Coulomb's Law Quiz in Multiple Representations

IF YOU WANT A QUESTION GRADED OUT OF THREE POINTS (–1 [MINUS ONE] FOR WRONG ANSWER!!) WRITE "3" IN SPACE PROVIDED ON EACH QUESTION.

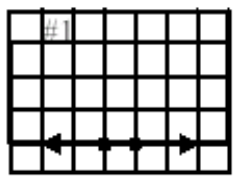
1. When two identical, isolated charges are separated by two centimeters, the magnitude of the force exerted by each charge on the other is eight newtons. If the charges are moved to a separation of eight centimeters, what will be the magnitude of that force now?

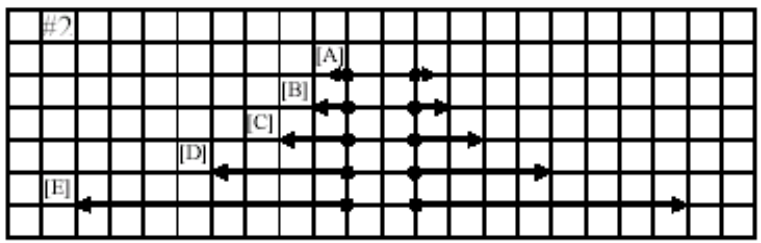
A. one-half of a newton
B. two newtons
C. eight newtons
D. thirty-two newtons
E. one hundred twenty-eight newtons

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

V [verbal]

2. Figure #1 shows two identical, isolated charges separated by a certain distance. The arrows indicate the forces exerted by each charge on the other. The same charges are shown in Figure #2. Which diagram in Figure #2 would be correct?





A.
B.
C.
D.
E.

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

D [diagrammatic]

3. Isolated charges q_1 and q_2 are separated by distance r, and each exerts force F on the other. $q_1^{initial} = q_1^{final}$ and $q_2^{initial} = q_2^{final}$; $r^{initial} = 10m$; $r^{final} = 2m$. $F^{initial} = 25N$; $F^{final} = ?$

A. 1 N
B. 5 N
C. 25 N
D. 125 N
E. 625 N

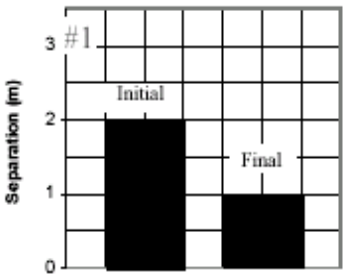
Grade out of three? Write "3" here: _____

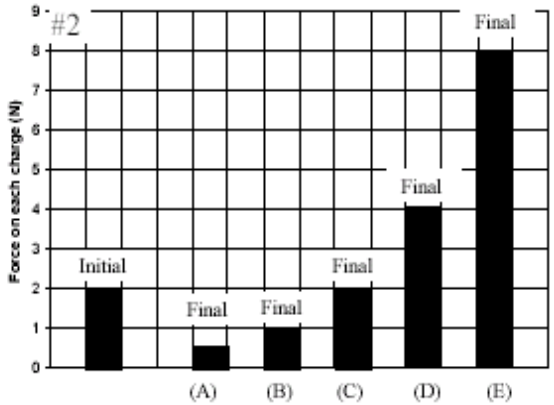
M
[mathematical/symbolic]

4. Graph #1 refers to the initial and final separation between two identical, isolated charges. Graph #2 refers to the initial and final forces exerted by each charge on the other. Which bar is correct?

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

A.
B.
C.
D.
E.





G
[graphical]

DC Circuits Quiz

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: $R_C = 7\ \Omega$; $R_D = 3\ \Omega$.
   $\Delta V_{bat}(series) = \Delta V_{bat}(parallel)$

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

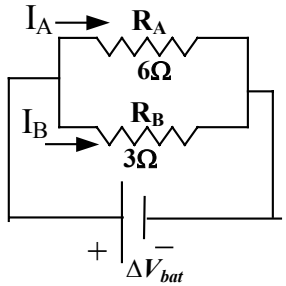
   Grade out of 3? Write "3" here: _____

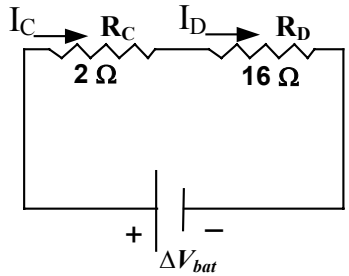
M

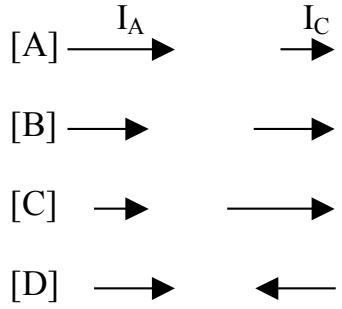
D

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

A.
B.
C.
D.
E. need to know ΔV_{bat}







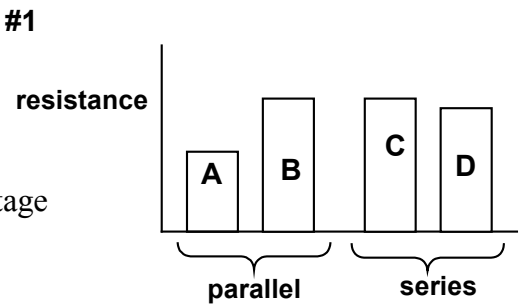
[E] (need to know ΔV_{bat})

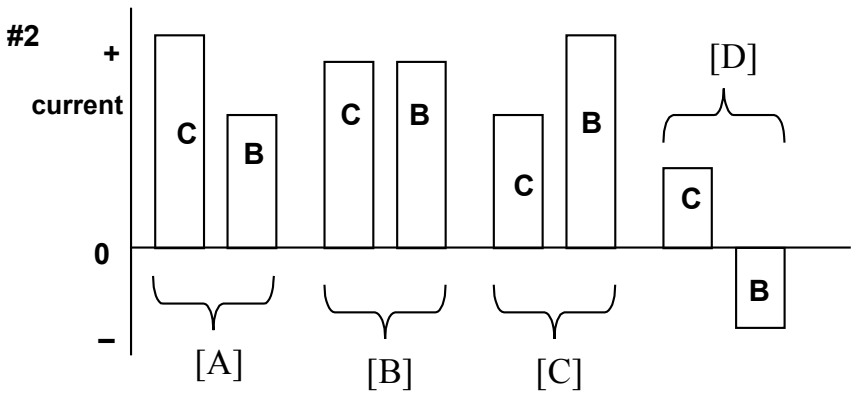
Grade out of 3? Write "3" here: _____

G

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 in both circuits is the same. Graph #2 represents the currents in resistors C and B respectively. Which pair is correct?

A.
B.
C.
D.
E. need to know voltage





General Research Questions on Multiple Representations

- Are students' error rates different for the different representations?
- Is student confidence different for the different representations?
- Do individual students have consistent difficulties with a particular form of representation?
- Are there any gender-related differences in representational "preferences"?

Are Students' Error Rates Different for the Different Representations?

Cumulative Rate of Incorrect Responses: 1998-2002

1998-2002	*N*	Verbal	Diagrammatic	Mathematical	Graphical
Coulomb Quiz	*383*	11%	13%	15%	18%
Circuits Quiz	*362*	20%	19%	20%	25%

V, D, and M error rates very similar;
G slightly higher? More analysis later . . .

Is Student Confidence Different for the Different Representations?

Rate of Correct but "Low-Confidence" Responses

(defined as proportion of students having correct answers who did **not** *choose extra-credit option)*

1998-2002	***N*** ***(verbal correct)***	**Verbal**	**Diagrammatic + Mathematical**	**Statistical Significance (one-tailed test)**
Coulomb Quiz	*340*	18%	24%	$p = 0.02$
Circuits Quiz	*289*	32%	38%	$p = 0.07$

Confidence on "verbal" representation is slightly higher

[G omitted from analysis since its year-to-year fluctuations are significantly greater]

Do Individual Students Have Consistent Difficulties with Particular Forms of Representation?

Students who made representation errors
(defined as those with 1-3 correct responses)

	N	**Errors on one quiz only (*no* repeat errors)**	**Errors on *both* quizzes but *no* repeat errors**	**Errors on both quizzes, but ≤ 50% repeat errors**
2001	*44*	73%	11%	11%
2002	*26*	77%	8%	12%

Most students do not repeat same representation error on the two quizzes

Are there any Gender-related Differences in Representational "Preferences"?

Cumulative Rate of Incorrect Responses: 1998-2002

Males	***N***	**V**	**D**	**M**	**G**	***Any* error**
Coulomb Quiz	*154*	10%	11%	14%	13%	24%
Circuits Quiz	*147*	16%	14%	19%	22%	41%

Are there any Gender-related Differences in Representational "Preferences"?

Cumulative Rate of Incorrect Responses: 1998-2002

Males	*N*	V	D	M	G	*Any* error
Coulomb Quiz	*154*	10%	11%	14%	13%	24%
Circuits Quiz	*147*	16%	14%	19%	22%	41%

Females	***N***	**V**	**D**	**M**	**G**	***Any* error**
Coulomb Quiz	*229*	12%	14%	16%	21%	32%
Circuits Quiz	*215*	23%	21%	21%	27%	45%

Are there any Gender-related Differences in Representational "Preferences"?

Cumulative Rate of Incorrect Responses: 1998-2002

Males	*N*	V	D	M	G	*Any* error
Coulomb Quiz	*154*	10%	11%	14%	13%	24%
Circuits Quiz	*147*	16%	14%	19%	22%	41%

Females	***N***	**V**	**D**	**M**	**G**	***Any* error**
Coulomb Quiz	*229*	12%	14%	16%	**21%**	32%
Circuits Quiz	*215*	23%	21%	21%	**27%**	45%

Are there any Gender-related Differences in Representational "Preferences"?

Cumulative Rate of Incorrect Responses: 1998-2002

Males	***N***	**V**	**D**	**M**	**G**	***Any* error**
Coulomb Quiz	*154*	10%	11%	14%	13%	24%
Circuits Quiz	*147*	16%	14%	19%	22%	41%

Females	***N***	**V**	**D**	**M**	**G**	***Any* error**
Coulomb Quiz	*229*	12%	14%	16%	**21%**	32%
Circuits Quiz	*215*	23%	21%	21%	**27%**	45%

marginally significant?

Higher Error Rate on *G* for Females?

1998-2002	*N*	Combined error rate, V+D+M	Error rate, G
Coulomb Quiz			
Females	*229*	**14%**	**21%**
Males	*154*	**12%**	**13%**
Circuits Quiz			
Females	*215*	**22%**	**27%**
Males	*147*	**16%**	**22%**

For females, *G* vs. *V*, *G* vs. *D*, and *G* vs. *M* error rates are all significantly different (or marginally significant)

Summary

- Multi-representation quizzes can help diagnose representation-related conceptual difficulties *(e.g., gravitation quiz)*
- Present data suggest few consistent patterns of inter-representational learning differences *(possible exception: graphical representation among females)*
- Much additional investigation is warranted (and planned)