Students Improve More on Graph Questions!

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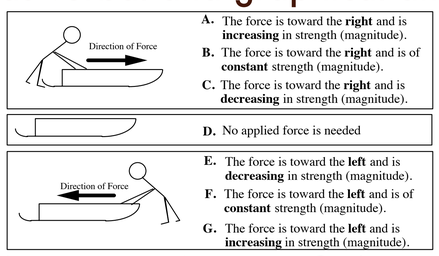
The FMCE[1] has verbal and graphical answers. Four questions have exact pairs.

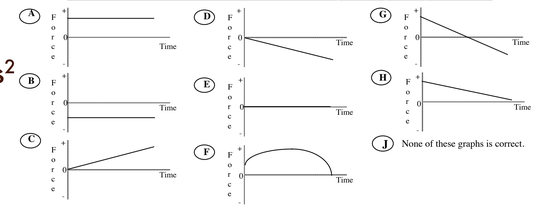
Question:
Do students answer isomorphic questions with coherent responses?

Answer:
NO!

Force Sled[2] (FS)



Force Graphs[2] (FG)



Motion	Questions (FS, FG)	Correct ($F \propto \Delta v/\Delta t$)	Common Incorrect ($F \propto v$)
Moving right, Speeding up	1, 16	B, A	A, C
Moving right, Steady speed	2, 14	D, E	B, A
Moving right, Slowing down	3, 18	F, B	C, H
Moving left, Speeding up	4, 19	F, B	G, D

Response Tables

- Show percentage of students who gave each response pair
  - Data from an algebra-based intro physics course at a 2-yr college, $N = 194$
- Diagonal responses indicate coherent responses on FS and FG questions

	Correct	Common	Other
Correct			
Common			
Other			

- Statistical results from χ^2 analyses with Cramér's correlation coefficient, ϕ_c, and Cohen's effect size, w.[3,4]

Consistency Plots[5]

Show how student responses change over time

- Start in Circles
- End in Triangles

- Stay in Squares (same over time)

Case 1
Moving Right, Speeding Up

Before Instruction

Force Sled \ Force Graphs	$F \propto \Delta v/\Delta t$	$F \propto v$	Other
$F \propto \Delta v/\Delta t$	4%	8%	1%
$F \propto v$	5%	77%	4%
Other	0%	1%	0%

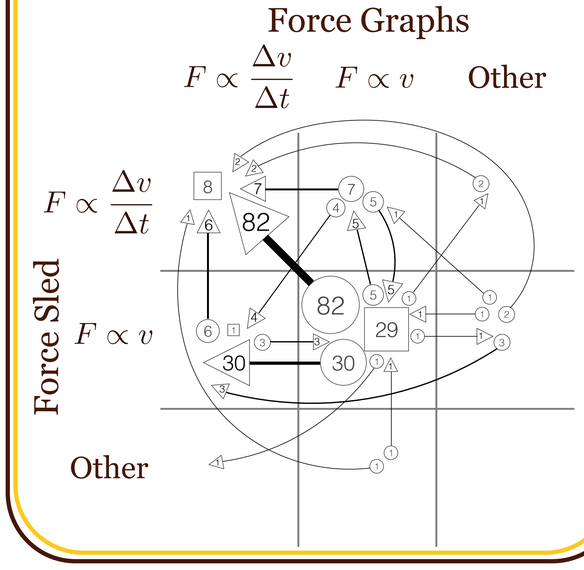
$\chi^2(4,\ N = 194) = 17.83,\ p = 0.001,\ \phi_c = 0.21,\ w = 0.30$

After Instruction

Force Sled \ Force Graphs	$F \propto \Delta v/\Delta t$	$F \propto v$	Other
$F \propto \Delta v/\Delta t$	56%	3%	1%
$F \propto v$	20%	20%	1%
Other	1%	0%	0%

$\chi^2(4,\ N = 194) = 53.11,\ p < 0.001,\ \phi_c = 0.37,\ w = 0.52$

Force Graphs



Case 2
Moving Right, Steady Speed

Before Instruction

Force Sled \ Force Graphs	$F \propto \Delta v/\Delta t$	$F \propto v$	Other
$F \propto \Delta v/\Delta t$	3%	3%	2%
$F \propto v$	3%	71%	13%
Other	1%	4%	2%

SAME

$\chi^2(4,\ N = 194) = 25.92,\ p < 0.001,\ \phi_c = 0.26,\ w = 0.37$

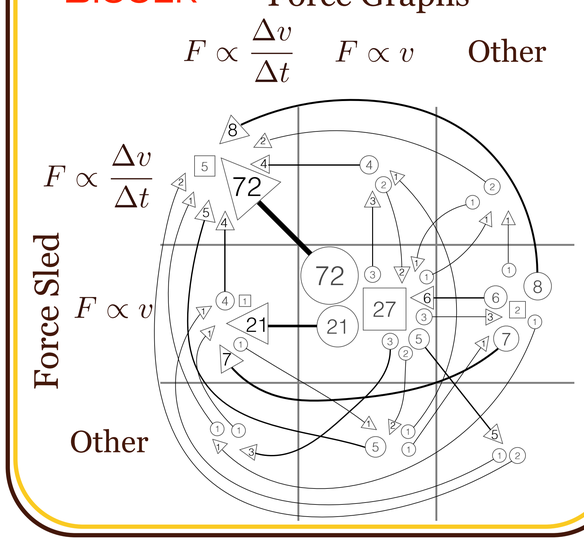
After Instruction

Force Sled \ Force Graphs	$F \propto \Delta v/\Delta t$	$F \propto v$	Other
$F \propto \Delta v/\Delta t$	53%	2%	1%
$F \propto v$	16%	19%	3%
Other	2%	2%	3%

SMALLER
BIGGER

$\chi^2(4,\ N = 194) = 86.35,\ p < 0.001,\ \phi_c = 0.47,\ w = 0.67$

Force Graphs



Case 3
Moving Right, Slowing Down

Before Instruction

Force Sled \ Force Graphs	$F \propto \Delta v/\Delta t$	$F \propto v$	Other
$F \propto \Delta v/\Delta t$	3%	10%	3%
$F \propto v$	2%	46%	25%
Other	1%	7%	5%

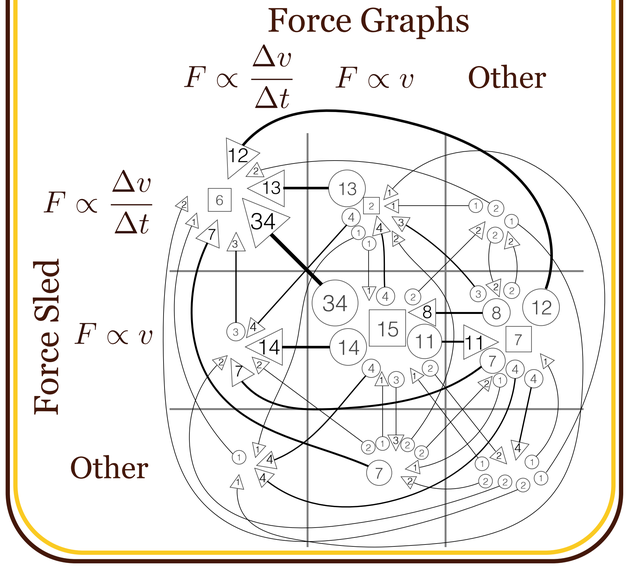
$\chi^2(4,\ N = 194) = 18.09,\ p = 0.001,\ \phi_c = 0.22,\ w = 0.31$

After Instruction

Force Sled \ Force Graphs	$F \propto \Delta v/\Delta t$	$F \propto v$	Other
$F \propto \Delta v/\Delta t$	41%	7%	2%
$F \propto v$	14%	13%	12%
Other	5%	3%	3%

$\chi^2(4,\ N = 194) = 43.32,\ p < 0.001,\ \phi_c = 0.33,\ w = 0.47$

Force Graphs



Case 4
Moving Left, Speeding Up

Before Instruction

Force Sled \ Force Graphs	$F \propto \Delta v/\Delta t$	$F \propto v$	Other
$F \propto \Delta v/\Delta t$	3%	4%	6%
$F \propto v$	4%	49%	34%
Other	0%	2%	0%

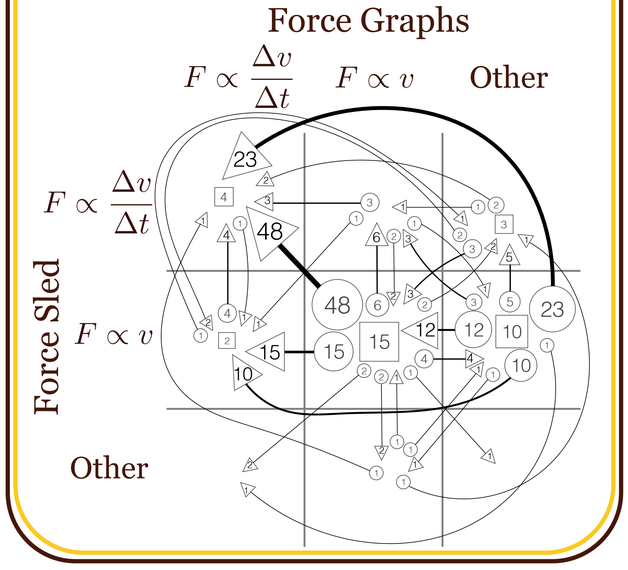
$\chi^2(4,\ N = 194) = 16.45,\ p = 0.002,\ \phi_c = 0.21,\ w = 0.29$

After Instruction

Force Sled \ Force Graphs	$F \propto \Delta v/\Delta t$	$F \propto v$	Other
$F \propto \Delta v/\Delta t$	44%	5%	6%
$F \propto v$	16%	17%	8%
Other	2%	2%	1%

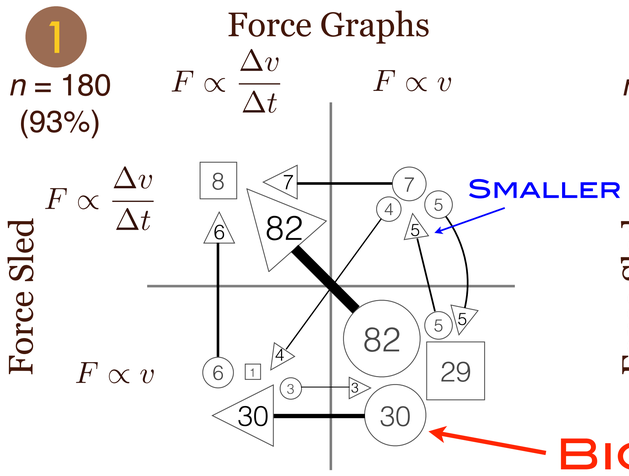
$\chi^2(4,\ N = 194) = 35.90,\ p < 0.001,\ \phi_c = 0.30,\ w = 0.43$

Force Graphs

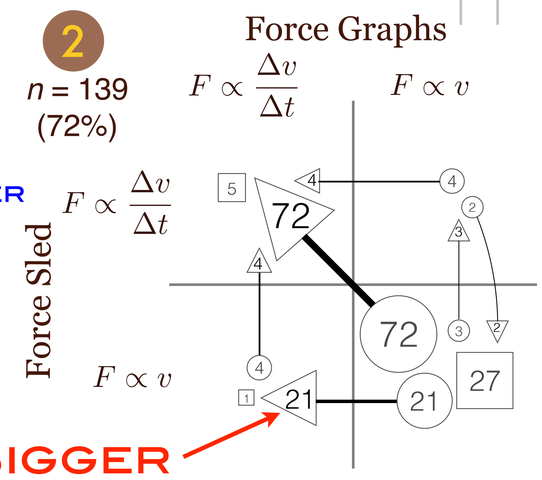


Simplified Consistency Plots (no "Other")

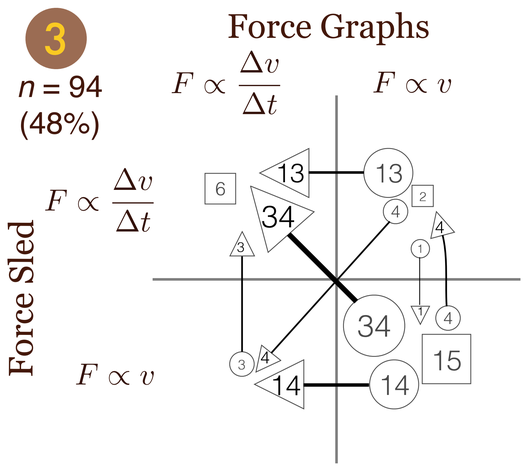
1 — $n = 180$ (93%)



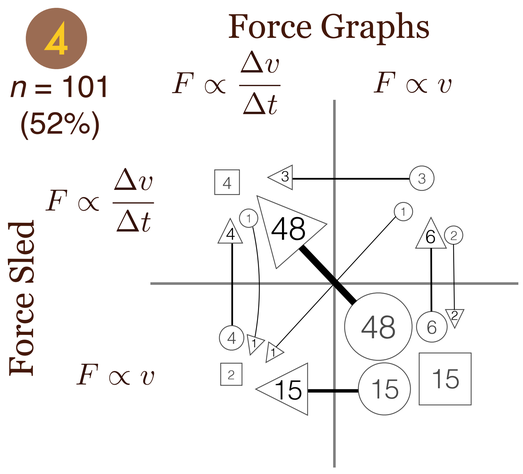
2 — $n = 139$ (72%)



3 — $n = 94$ (48%)



4 — $n = 101$ (52%)



Observations & Interpretations

- Students do not always answer physically identical questions with coherent responses
  - 71% of students had at least 1 non-matching answer pair on the pretest, and 57% on the posttest. (Off-diagonal elements)
  - However, statistically significant correlations exist between FS and FG responses.
- Student responses to questions involving physically identical content depend strongly on the context, i.e. the type of motion involved:
  - Students are more correct, more consistent, and more coherent on questions involving an object moving to the right (positive) and speeding up
- Slightly more students are correct on Force ***Sled*** than Force ***Graphs*** before instruction. (Highlighted table cells, Cases 1 & 3)
  - Students have more difficulty interpreting graphs than using verbal descriptions
  - Data from students who did not complete the posttest and additional data from other classes further support this claim
- More students are correct on Force ***Graphs*** than Force ***Sled*** after instruction (highlighted table cells, all Cases); More students move ***left*** than move ***up*** on the consistency plots
  - Instruction helps students learn how to interpret graphs better, but this is not necessarily reflected in plain-language choices
  - The graphical choices may cue students into thinking about "physics class" answers
  - The verbal choices may cue students into thinking about "real life" answers[6]

References
1. Thornton & Sokoloff, *Am. J. Phys.*, **66** (1998)
2. Smith & Wittmann, *Phys. Rev. ST Phys. Educ. Res.*, **4** (2008)
3. Cohen, *Statistical Power Analysis for the Behavioral Sciences* (1988)
4. Rosenblatt & Heckler, *Phys. Rev. ST Phys. Educ. Res.*, **7** (2011)
5. Wittmann & Black, *Phys. Rev. ST Phys. Educ. Res.*, **10** (2014)
6. McCaskey, Dancy, and Elby, *AIP Conf. Proc.*, **720** (2004)