Words vs. graphs: Tracking student understanding of forces

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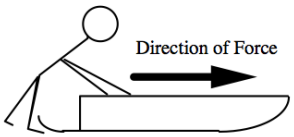
The Force and Motion Conceptual Evaluation

- 47-item multiple-choice survey[1]
- Several question clusters that assess different topics[2]

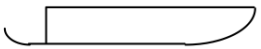
A sled on ice moves in the ways described in questions 1-7 below. *Friction is so small that it can be ignored*. A person wearing spiked shoes standing on the ice can apply a force to the sled and push it along the ice. Choose the one force (**A** through **G**) which would **keep the sled moving** as described in each statement below.



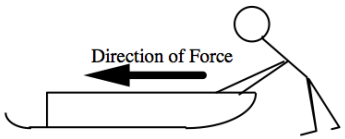
A. The force is toward the **right** and is **increasing** in strength (magnitude).

B. The force is toward the **right** and is of **constant** strength (magnitude).

C. The force is toward the **right** and is **decreasing** in strength (magnitude).



D. No applied force is needed



E. The force is toward the **left** and is **decreasing** in strength (magnitude).

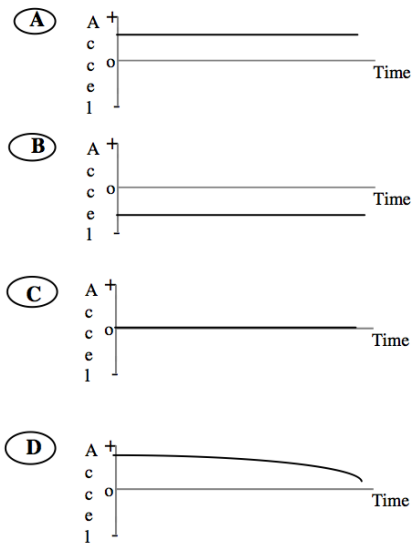
F. The force is toward the **left** and is of **constant** strength (magnitude).

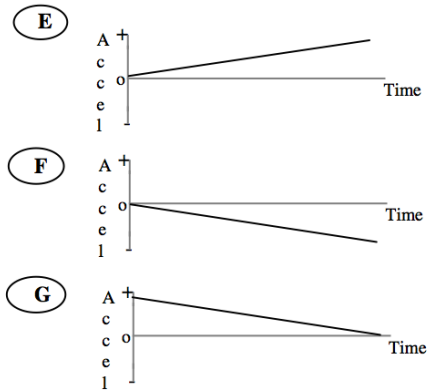
G. The force is toward the **left** and is **increasing** in strength (magnitude).

Questions 22-26 refer to a toy car which can move to the right or left on a horizontal surface along a straight line (the + distance axis). The positive direction is to the right.

Different motions of the car are described below. Choose the letter (**A** to **G**) of the **acceleration-time** graph which corresponds to the motion of the car described in each statement.

You may use a choice more than once or not at all. If you think that none is correct, answer choice **J**.





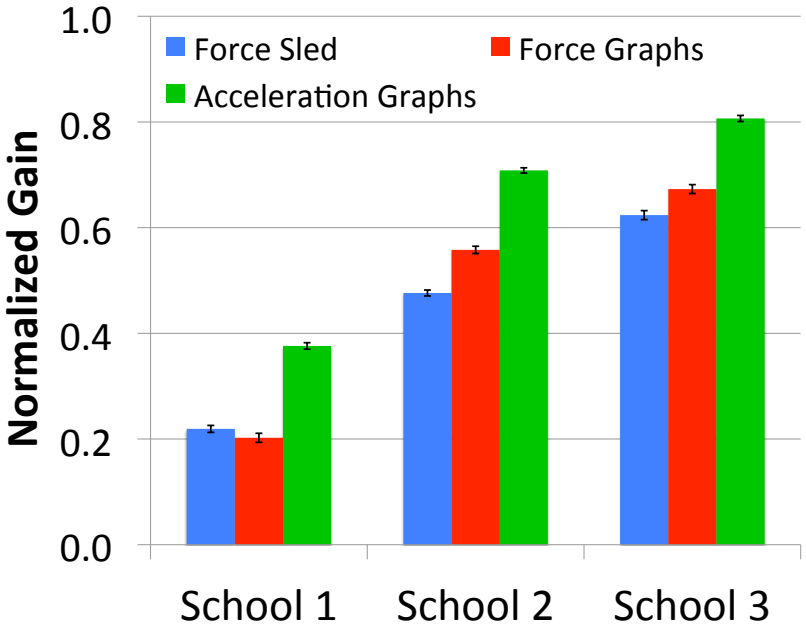
J None of these graphs is correct.

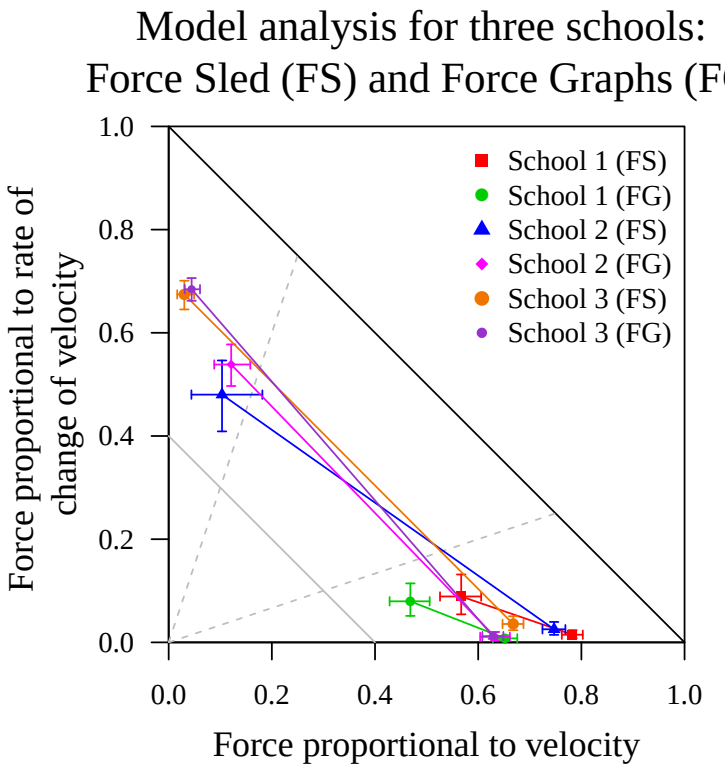
[1] R. K. Thornton and D. R. Sokoloff, Am. J. Phys. **66**, 338 (1998).

[2] T. I. Smith and M. C. Wittmann, Phys. Rev. ST Phys. Educ. Res. **4**, 020101 (2008).

FMCE: Previous Results

- Normalized gains
- Model analysis[3]
- Results differ from cluster to cluster as well as from school to school[4]





[3] L. Bao and E. F. Redish, Phys. Rev. ST Phys. Educ. Res. **2**, 010103 (2006).

[4] T. I. Smith et al., Phys. Rev. ST Phys. Educ. Res. **10**, 020102 (2014).

Isomorphic Questions

Question 1 (Force Sled)

Which force would keep the sled moving toward the right and speeding up at a steady rate (constant acceleration)?

Question 16 (Force Graphs)

The car moves toward the right and is speeding up at a steady rate (constant acceleration).

Question 22 (Acceleration Graphs)

The car moves toward the right (away from the origin), speeding up at a steady rate.

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Question 22 (Acceleration Graphs)

The car moves toward the right (away from the origin), speeding up at a steady rate.

Case 1: Moving to the right and speeding up at a steady rate.

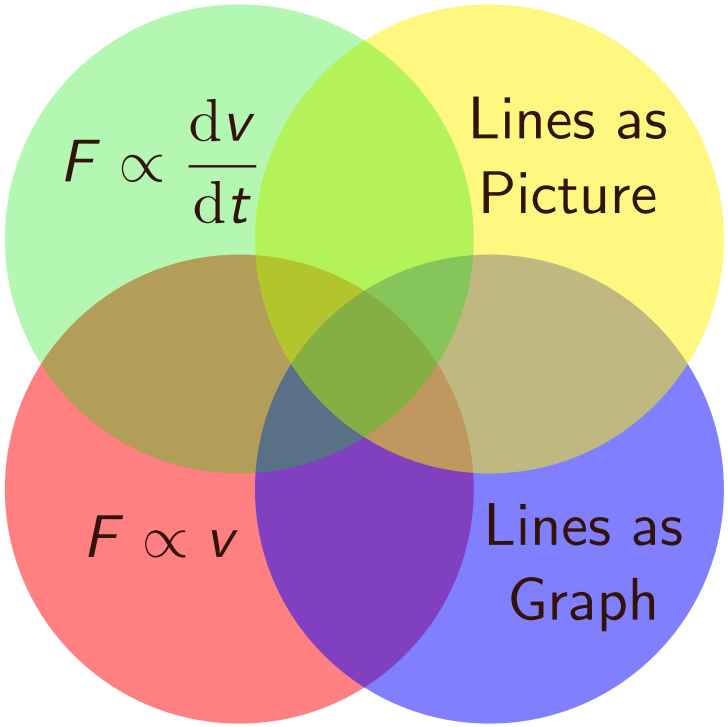
Defining Cases

Identifying isomorphic questions

Case	Described Motion	Question		
		FS	FG	AG
1	moving right, speeding up	1	16	22
2	moving right, steady speed	2	14	26
3	moving right, slowing down	3	18	23
4	moving left, speeding up	4	19	25

Underlying Assumptions

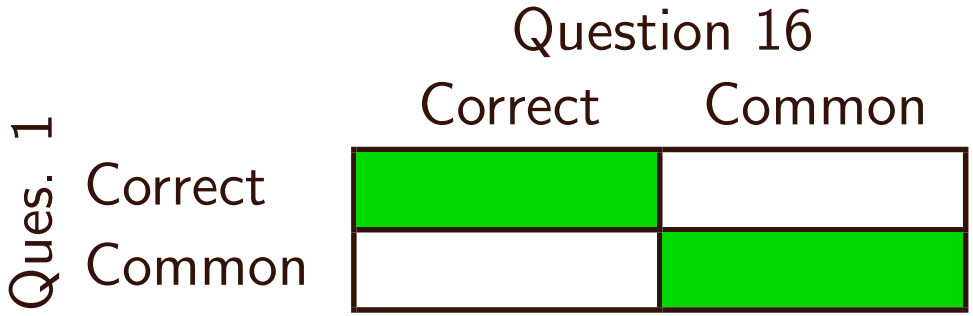
- Students use many different mental models[5] to answer questions on the FMCE
- Different questions and clusters are more or less conducive to particular models
- Many students exist in a superposition state
- Answers depend on both the student and the question



[5] T. I. Smith and M. C. Wittmann, Phys. Rev. ST Phys. Educ. Res. **4**, 020101 (2008), R. J. Beichner, Am. J. Phys. **62**, 750 (1994), L. C. McDermott et al., Am. J. Phys. **55**, 503 (1987)

Contingency Tables

- Compare Force Graphs to Force Sled or Force Graphs to Acceleration Graphs
- Number of students who gave each response pair



- Diagonal cells show within-student coherent responses
- Large numbers show between-students consistent responses
- Cohen's w[6] indicates the strength of the correlation between individual students' responses.[7]
  weak: $w < 0.1$; moderate: $w \approx 0.3$; strong: $w > 0.5$
- Ignore models with fewer than 5% of responses on pre- and post-test

[6] J. Cohen, *Statistical power analysis for the behavioral sciences*, 2nd (Lawrence Erlbaum Associates, 1988).

[7] R. Rosenblatt and A. F. Heckler, Phys. Rev. ST Phys. Educ. Res. **7**, 020112 (2011).

Case 1: Moving right, Speeding up, School 1

Pretest Force Graphs

Force Sled	$F \propto \frac{\Delta v}{\Delta t}$	$F \propto v$
$F \propto \frac{\Delta v}{\Delta t}$	4	9
$F \propto v$	1	181

$w = 0.48$

Post-test Force Graphs

Force Sled	$F \propto \frac{\Delta v}{\Delta t}$	$F \propto v$
$F \propto \frac{\Delta v}{\Delta t}$	39	15
$F \propto v$	17	124

$w = 0.60$

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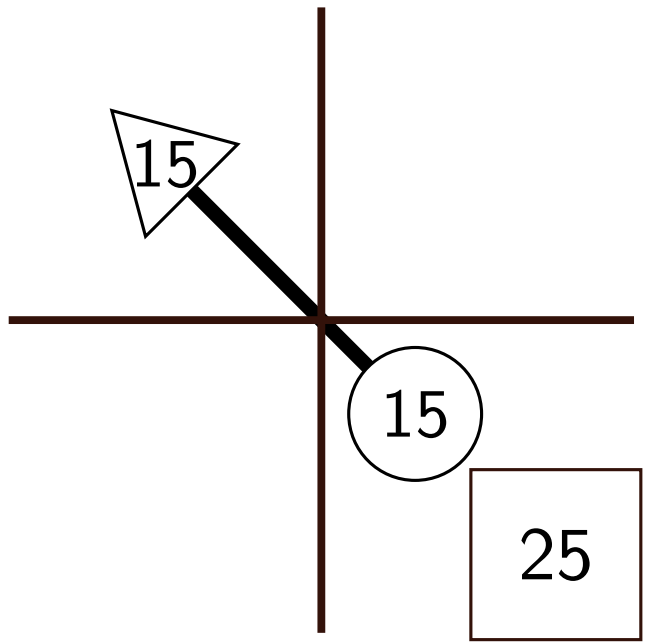
- Within-student coherence increases
- How do individual students change from pre to post?

Consistency Plots

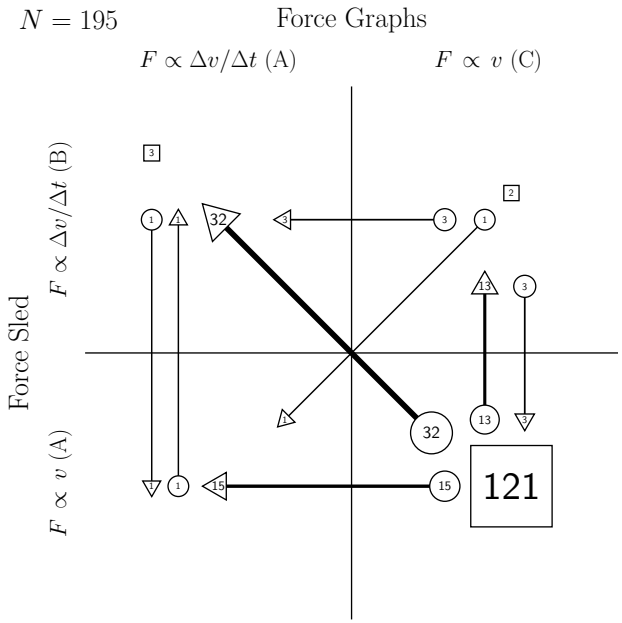
- Visualizing student transitions between table cells[8]
- "Arrows" show the number of students who went from one pair of pretest responses to a different pair
  - Start in circles (pretest)
  - End in triangles (post-test)
- Squares show students who did not change their answers



[8] M. C. Wittmann and K. E. Black, Phys. Rev. ST Phys. Educ. Res. **10**, 010114 (2014)

Case 1: Moving right, Speeding up

School 1



Pretest		Post-test	
4	9	39	15
1	181	17	124
$w = 0.48$		$w = 0.60$	

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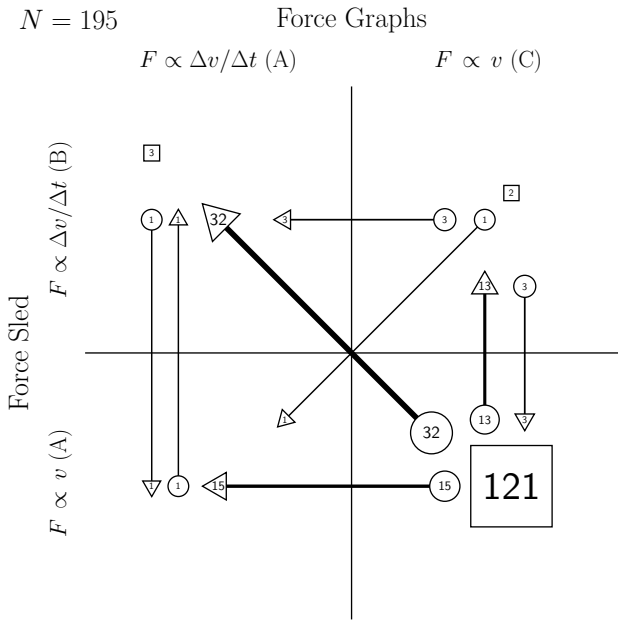

Pretest		Post-test	
4	9	39	15
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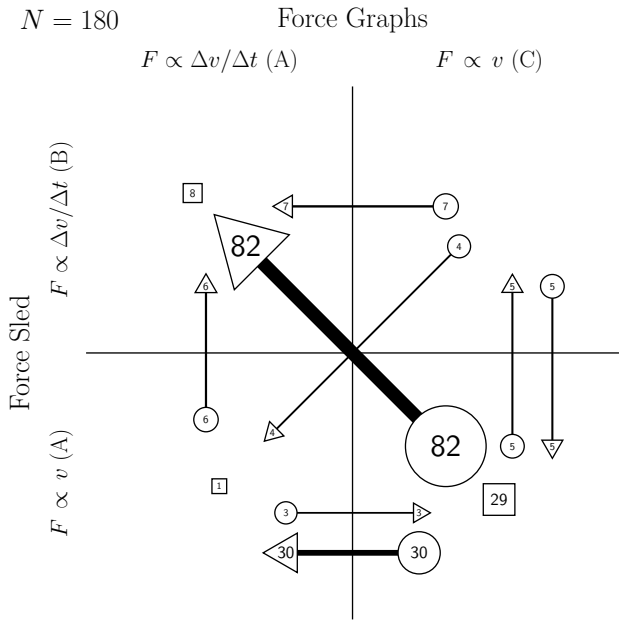
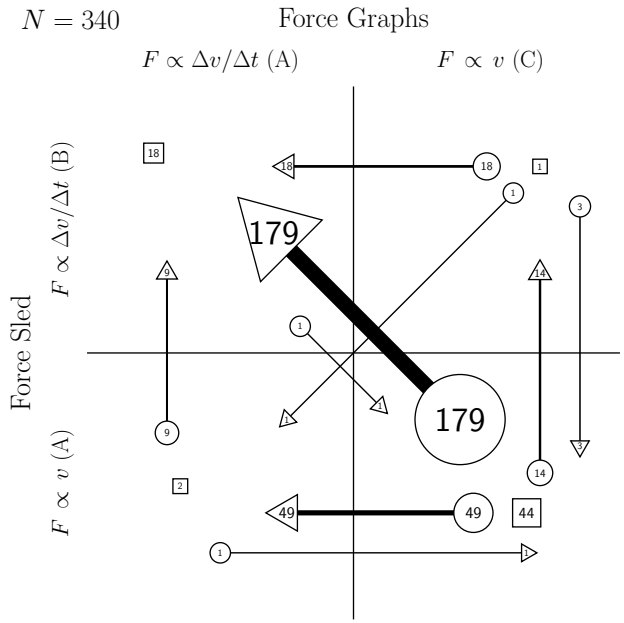
School 2



Pretest		Post-test	
8	16	103	5
10	146	35	37
$w = 0.31$		$w = 0.54$	

School 3



Pretest		Post-test	
19	23	224	15
12	286	52	49
$w = 0.47$		$w = 0.49$	

Case 1: Moving right, Speeding up

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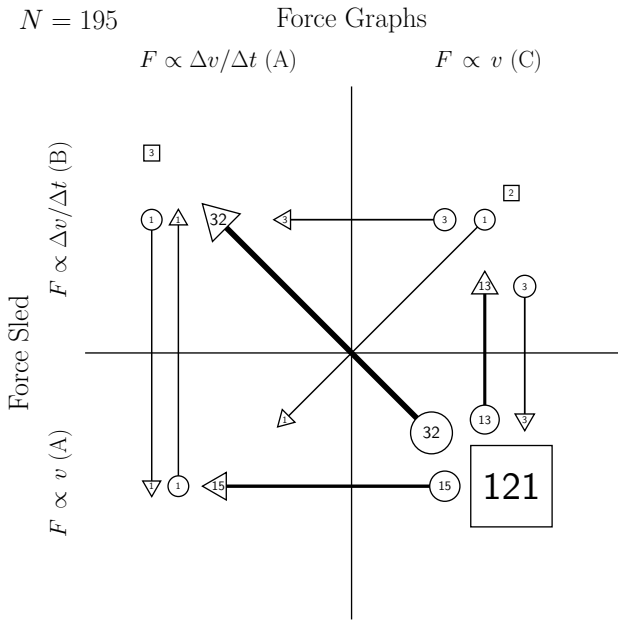

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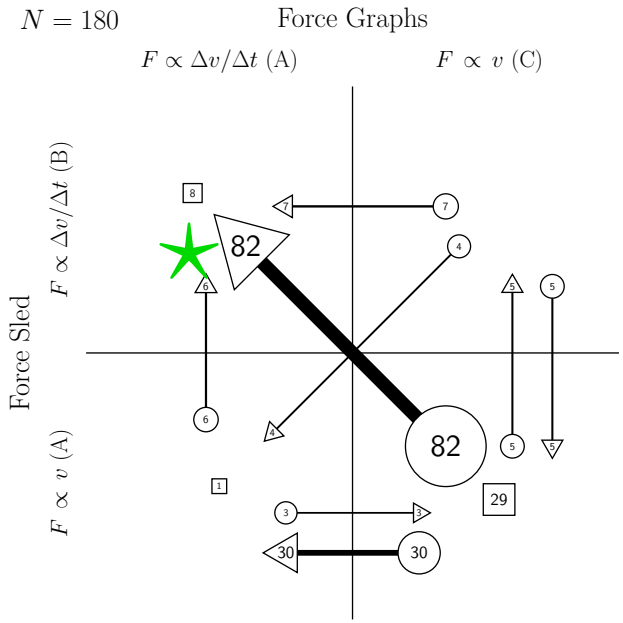

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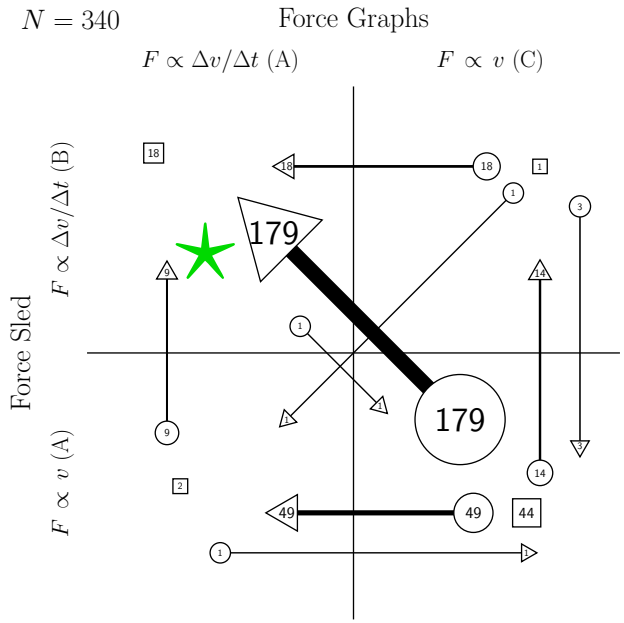

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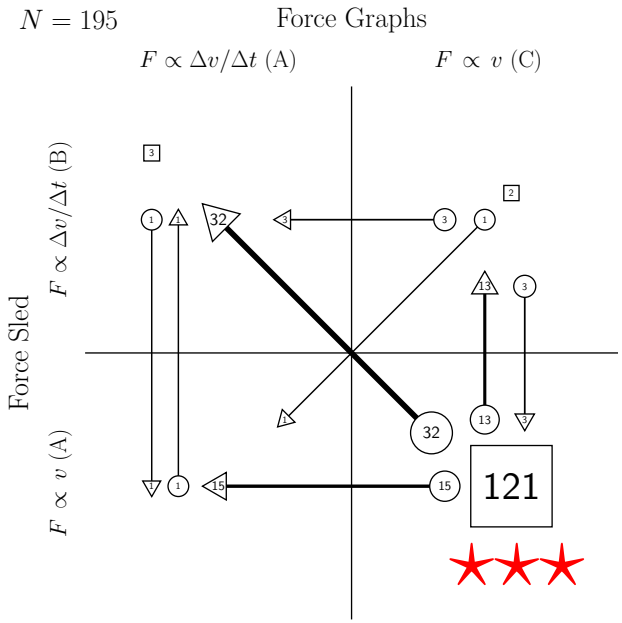

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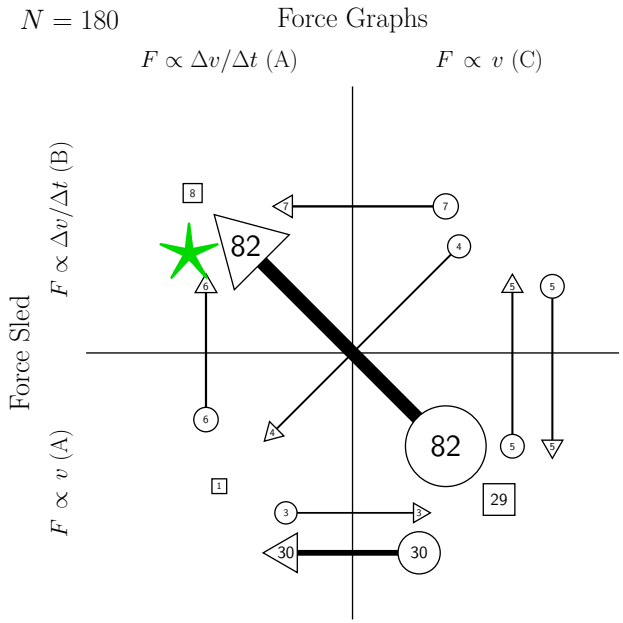

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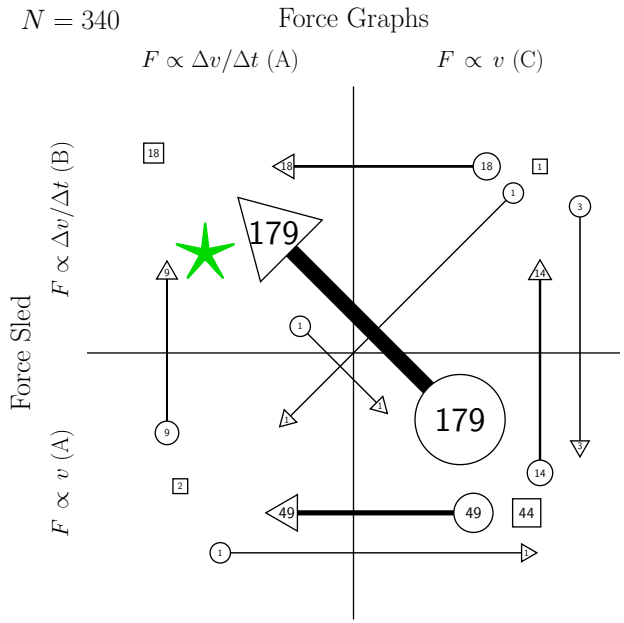

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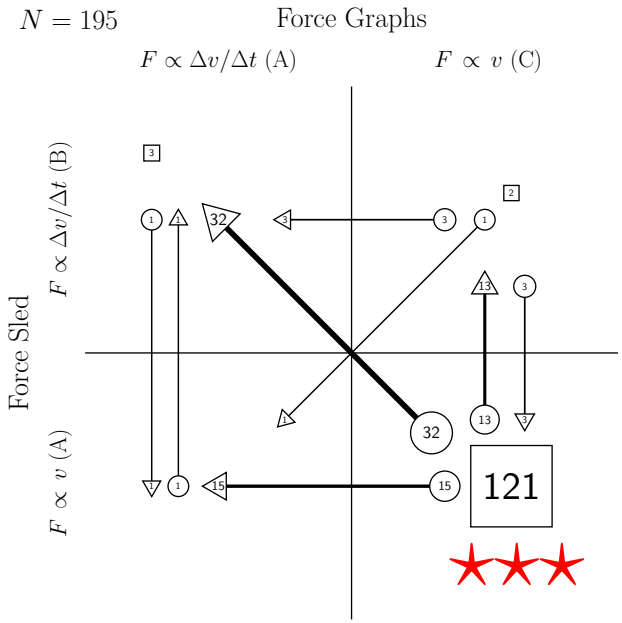

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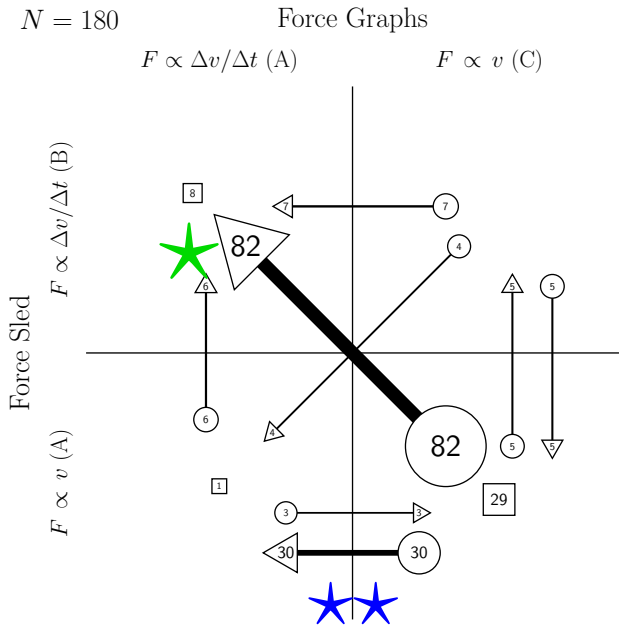

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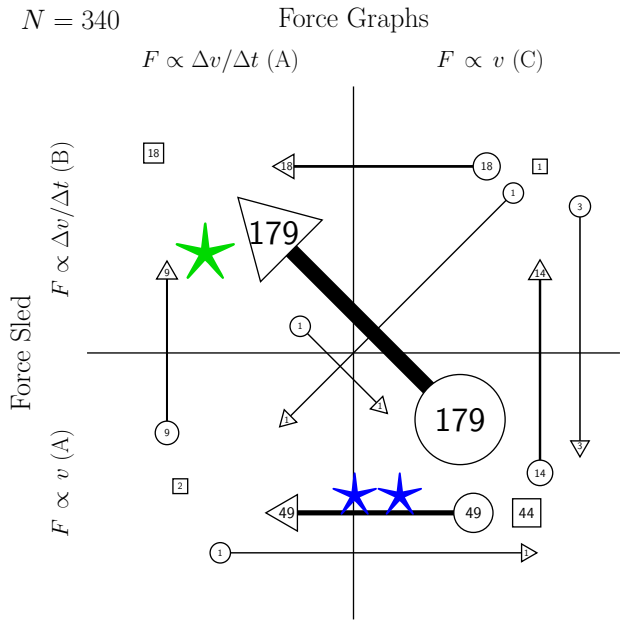

Pretest		Post-test	
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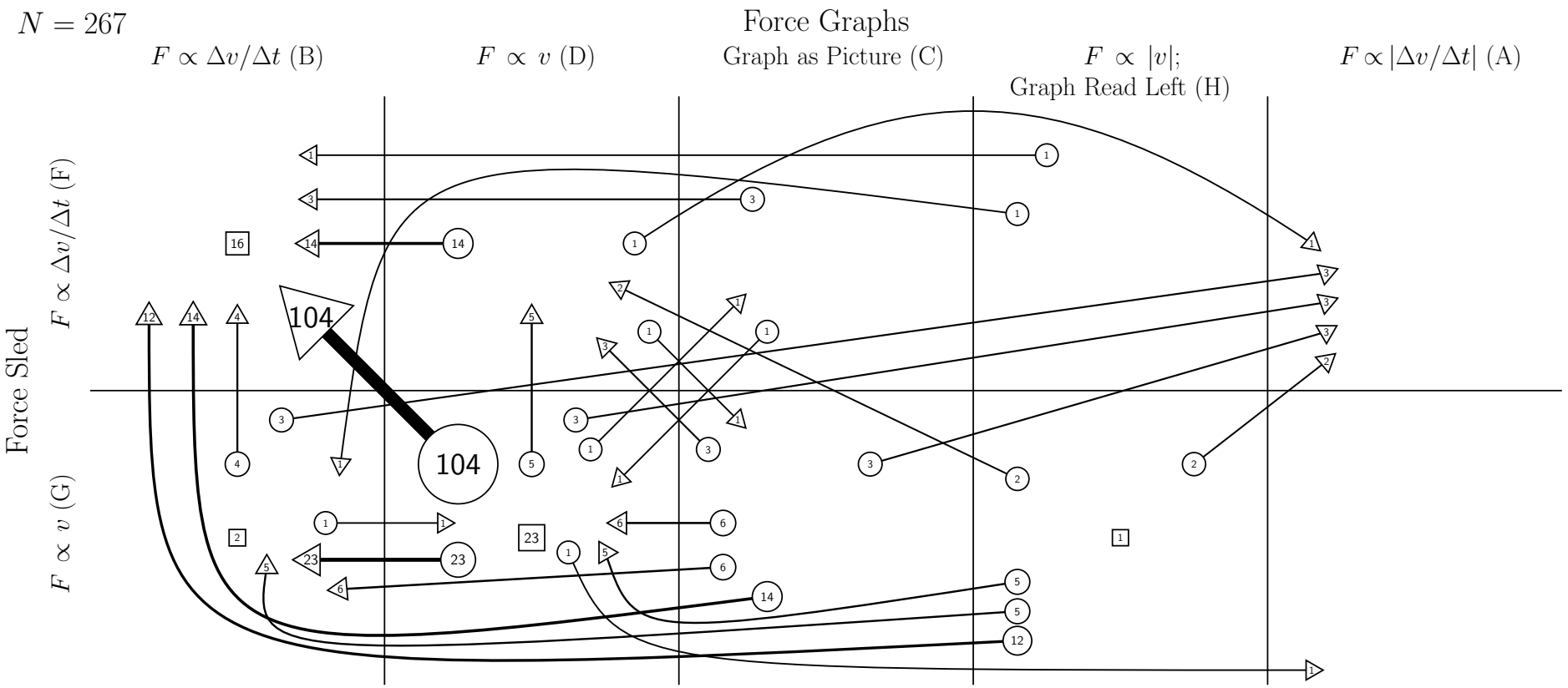
Case 4: Moving left, Speeding up, School 3



Pretest

16	16	4	2	0
10	160	32	27	0

$w = 0.45$

Post-test

168	10	1	0	12
37	36	1	1	1

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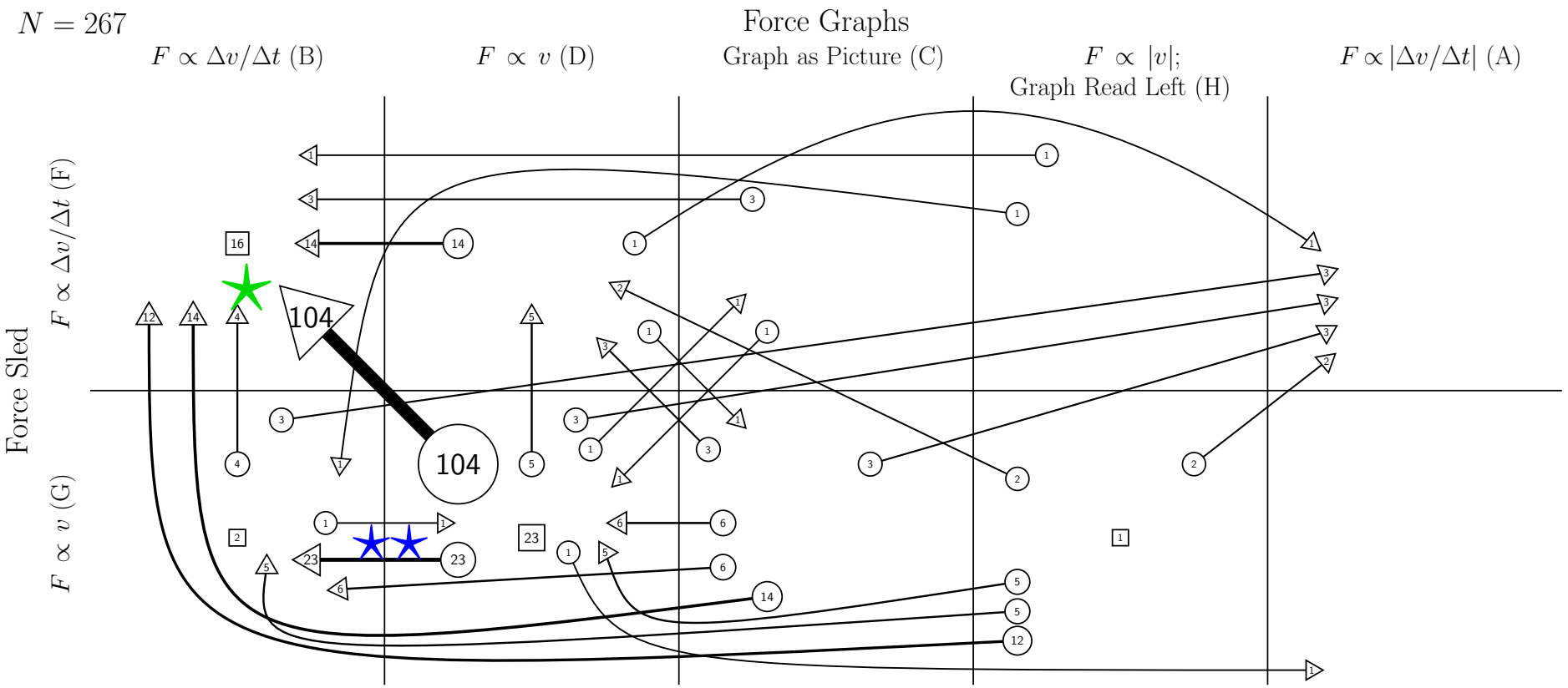

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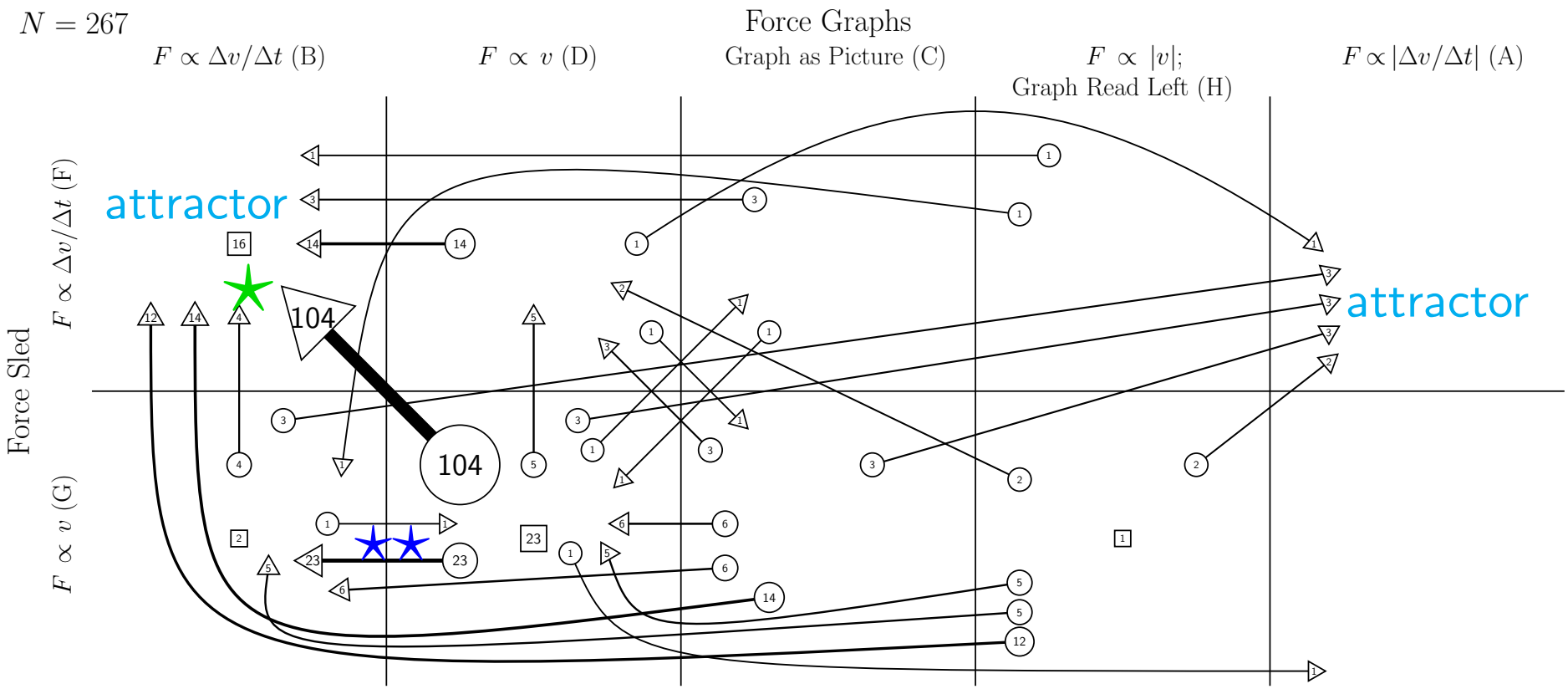

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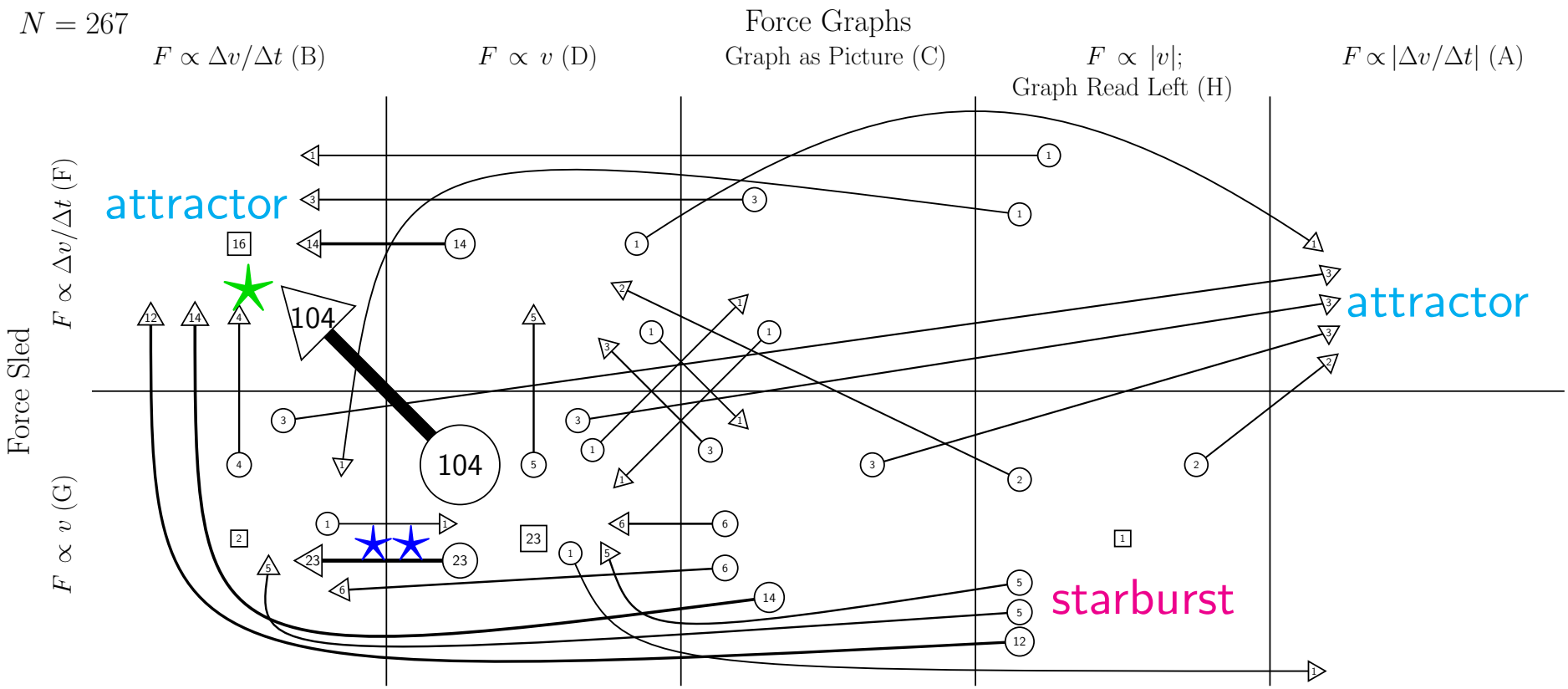

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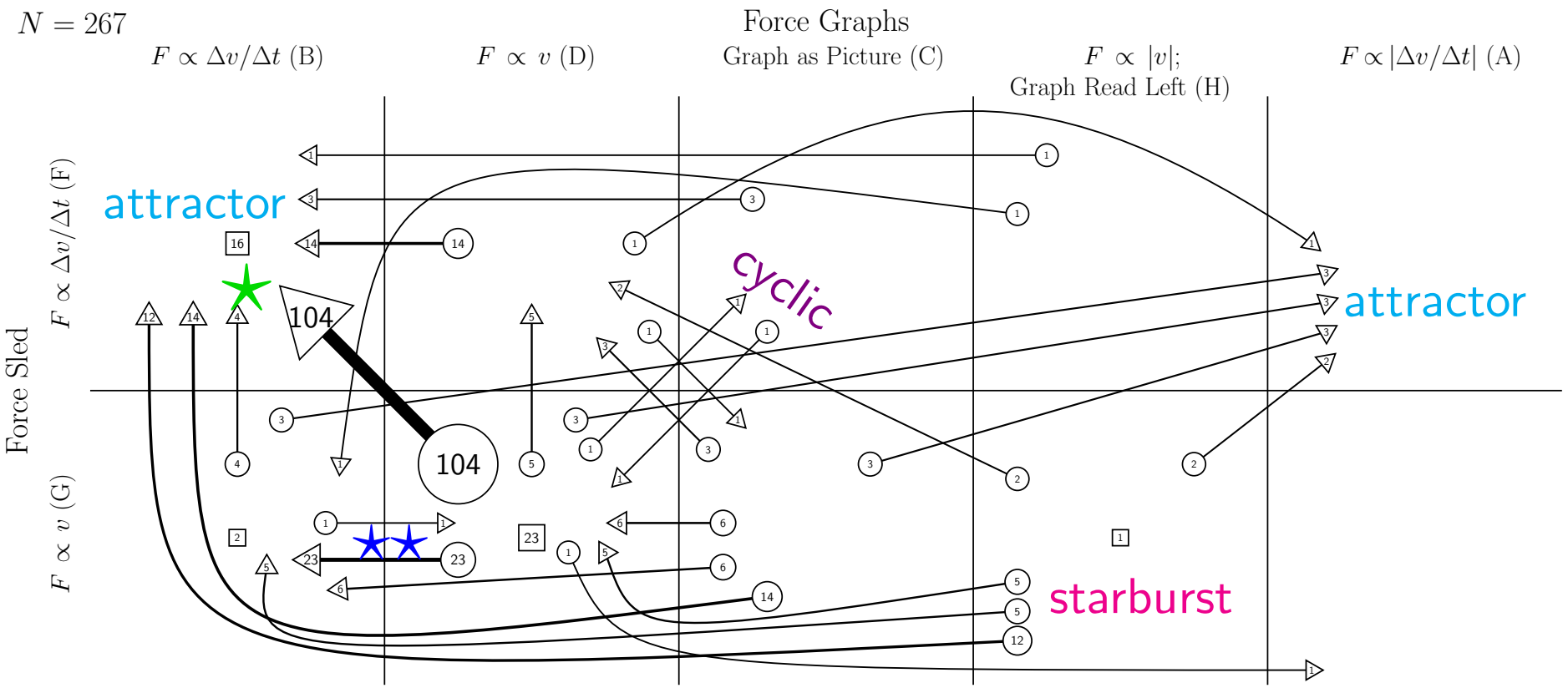

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Comparing Schools: Statistical Analyses

ANOVA results for individual student normalized gains with Tukey HSD *post hoc* comparisons between schools ($p < 0.05$); * indicates $p < 0.001$.

	Average g			p-values			
	S1	S2	S3	Main Eff.	1v2	1v3	2v3
Full FMCE	0.29	0.60	0.69	*	*	*	0.003
Cases 1–4	0.23	0.61	0.71	*	*	*	0.02
Case 1	0.31	0.65	0.77	*	*	*	0.007

S3>S2>S1

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Comparison of consistency plots using χ^2 test of independence ($p < 0.05$) with the Bonferroni correction for *post hoc* comparisons (pairwise: $p < 0.013$).

	Main Eff.	1v2	1v3	2v3
Case 1	*	*	*	0.24
Case 2	*	*	*	0.65
Case 3	*	*	*	0.49
Case 4	*	*	*	0.07

S3=S2>S1

Summary of Results

- Explicitly treating students as being in a superposition state of mental models
- Different approaches reveal discrepant similarities and differences
  - Normalized gains and model analysis: S3>S2>S1
  - Consistency plots: S3=S2>S1
- Most students at Schools 2 and 3 go from common incorrect to correct on all questions
- More students increase on Force Graphs than Force Sled, and more on Acceleration Graphs than Force Graphs
- Most students at School 1 stay in the common incorrect cell on all questions
- Contingency tables with Cohen's w show within-student coherence increasing over time
- Many different transitions for Case 4: "beginning state" + "instruction" $\neq$ "ending state"
- Possible hierarchy of incorrect responses:[9] starbursts may represent very naïve responses (only pretest); attractors may represent more sophisticated ones (only post-test)
- Cyclic transitions only visible on consistency plots

[9] R. K. Thornton, AIP Conf. Proc. **399**, 241 (1997)

Future Directions

- Synthesize results across cases
- Conduct interviews to test model definitions
- Developing statistic to report between-students consistency
- Closely examine similarities and differences between the instruction at each school

Acknowledgments

Rowan University Physics Education Research Team: Summer 2016

Physics Teacher Education Coalition

Partially supported by a PhysTEC comprehensive site award

Upcoming Posters

More Results!

Poster PST1-D12, 9:15-10:00 tonight!

More Detailed Methodology

PERC Poster Symposium: Expanding Research Questions by Expanding Quantitative Methodologies
Parallel Session I, Thurs. 7/21/16, 10:30 am (Bataglieri Room)

email: smithtr@rowan.edu