Learning Vectors Online: Comparing Multiple-Choice to Drawing Vectors
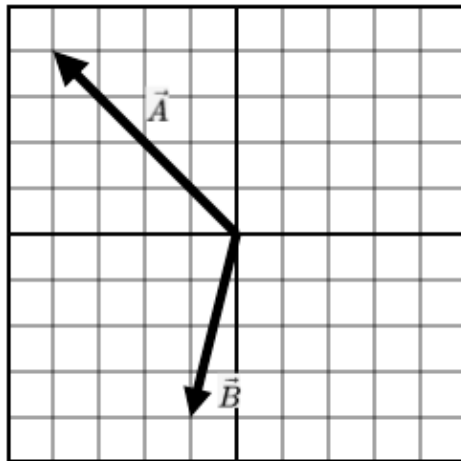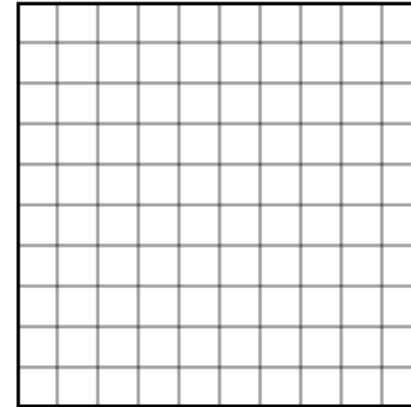
Michael Kline
Andrew Heckler

THE OHIO STATE UNIVERSITY

Vector Addition Answer Format

What is the vector sum $\vec{A} + \vec{B}$?

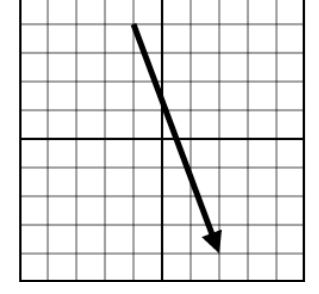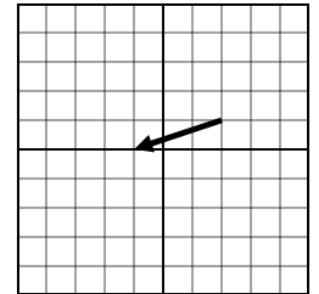Draw Vectors in the grid or enter the values below.

Free Response

Draw Vectors

□ ↗ $\vec{A} + \vec{B}$

Multiple Choice
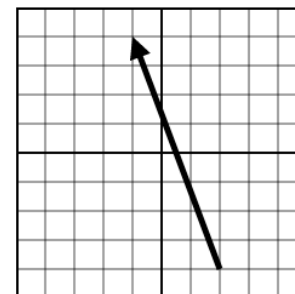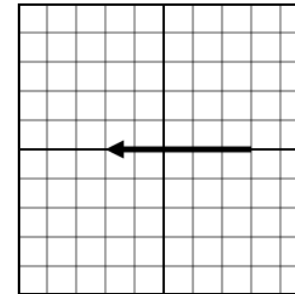
Background

- Many studies have demonstrated and investigated difficulties with student's understanding of vector addition, particularly vectors on a grid [1-10]

- Carefully structured and graded multiple-choice physics assessments have been shown to be viable replacements to free-response questions requiring algebraic calculations [11, 12]

- In other contexts, the figural response answer format has been shown to be more difficult, slightly more discriminating and reliable, and had higher omit rates than multiple choice [13]
  - Paper is from 1991, we haven't found more recent work

Experiment Schedule
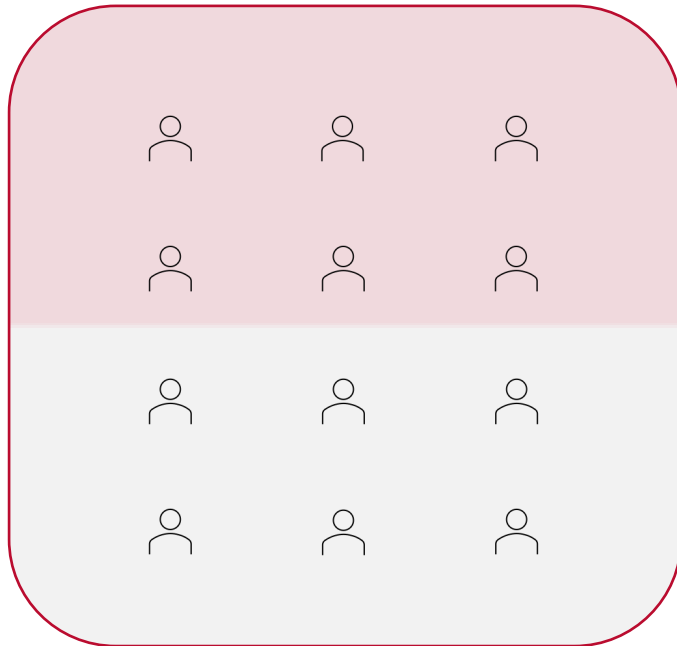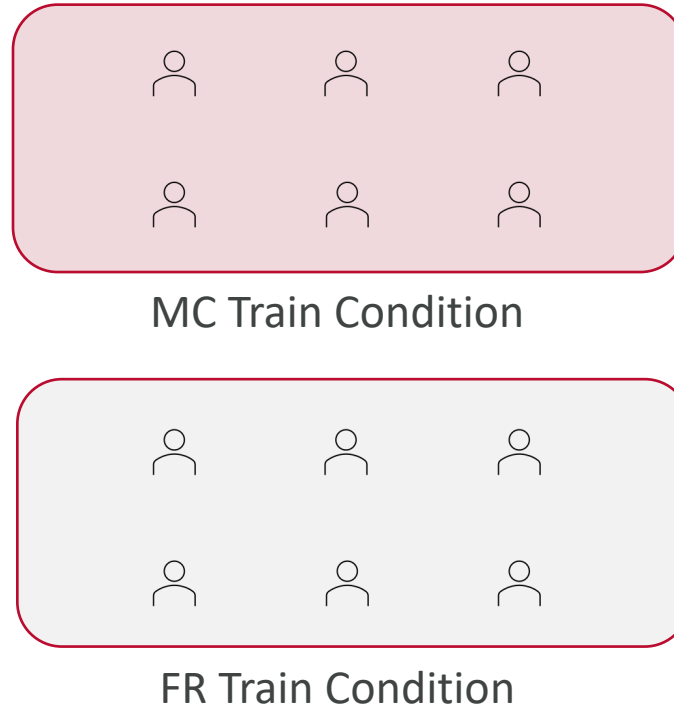
Students who answered quickly on more than 20% of the questions were not included (based on response time effort score [14])

Pre-test

Training

MC Train Condition

FR Train Condition
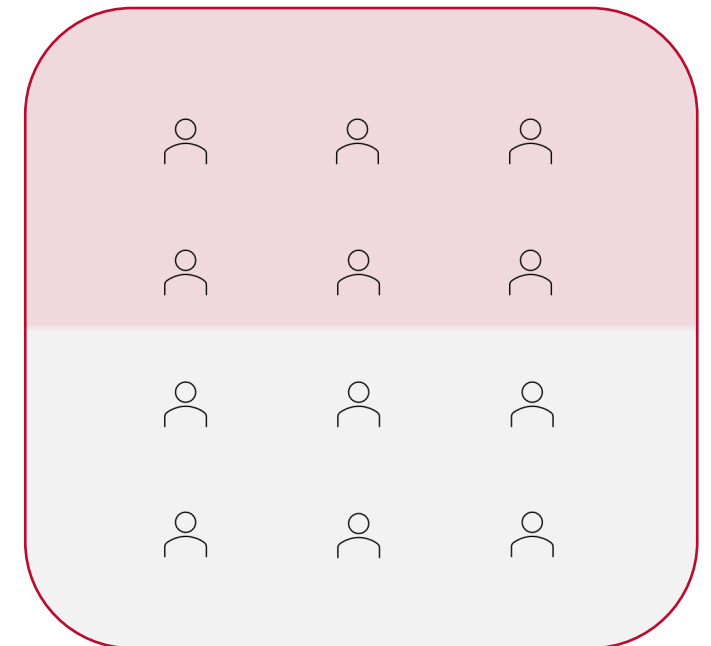
Post-test

Pre- and Post-test Questions

Multiple Choice

Free Response

THE OHIO STATE UNIVERSITY
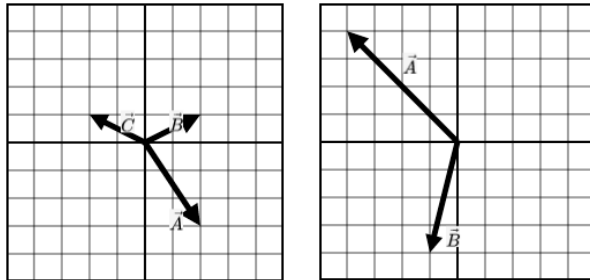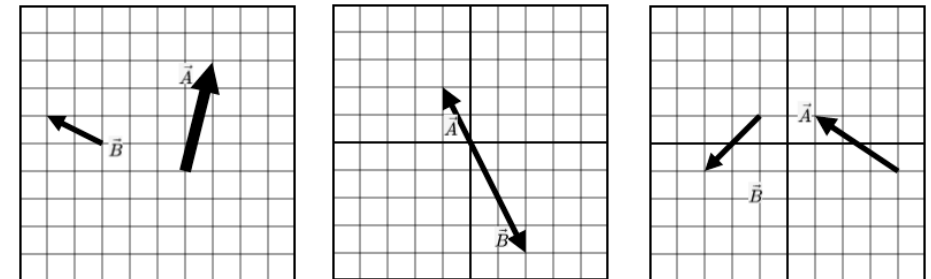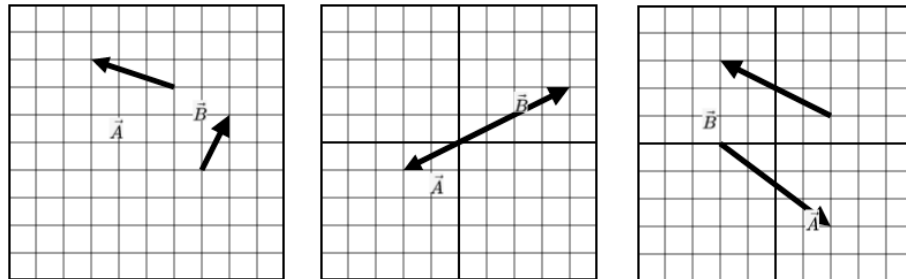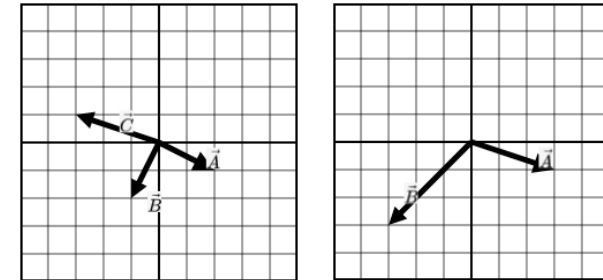
Assessment

Differences Between MC/FR Answer Formats

Pre-test Score Distributions
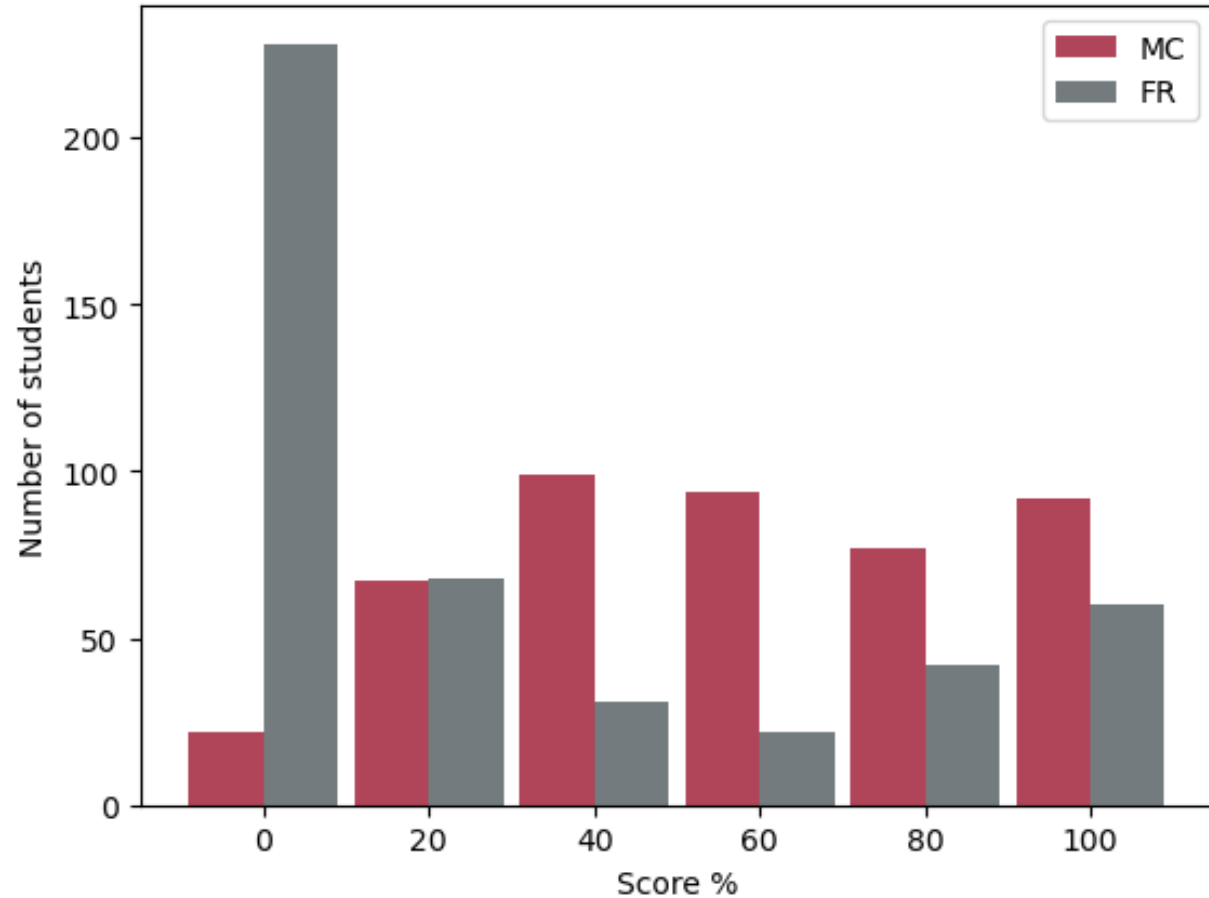
Algebra-Based Course

The distribution of scores in FR format is bimodal, peaking at 0% and 100%

Pre-test Score Distributions

Algebra-Based Course
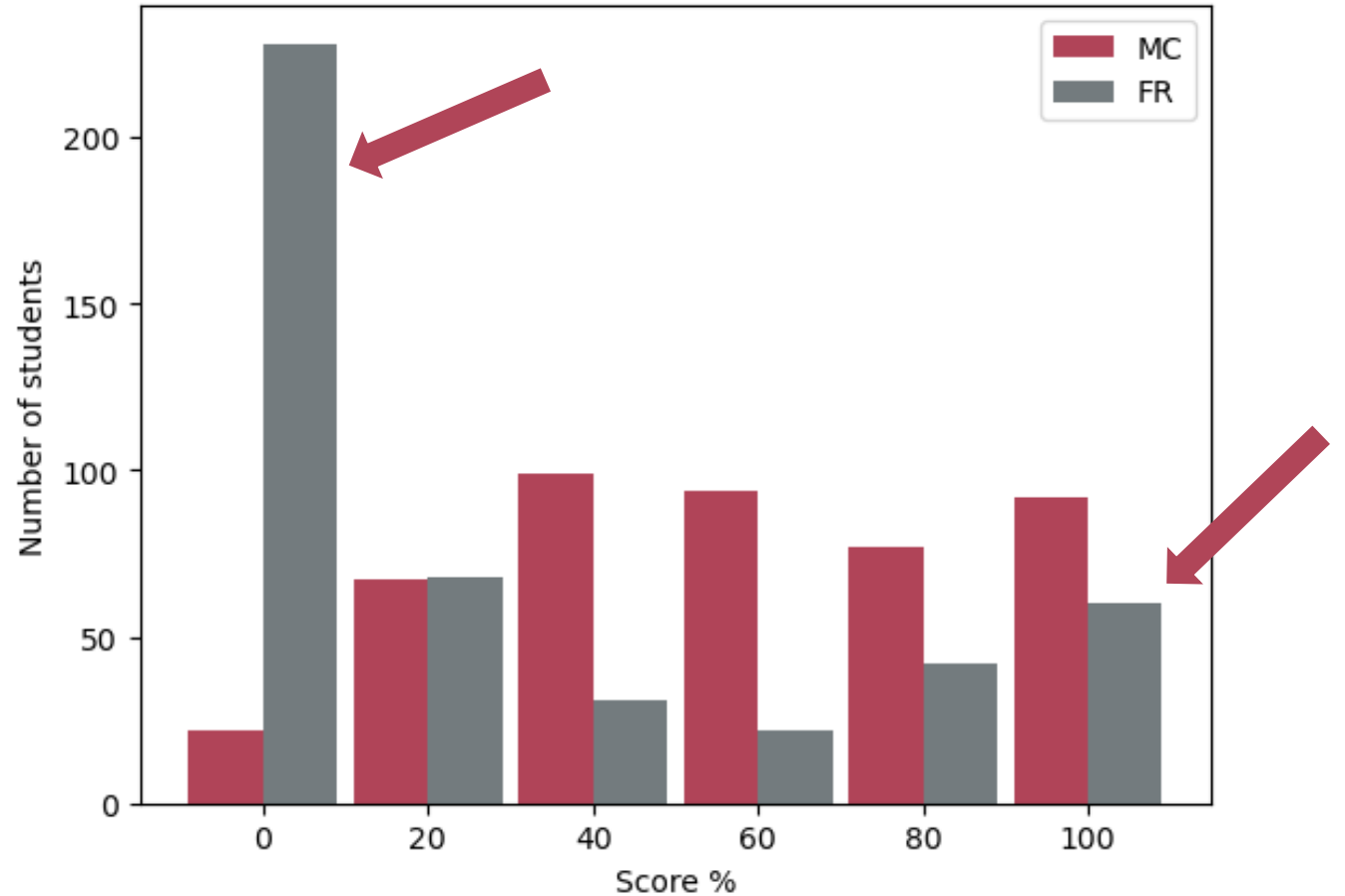
The distribution of scores in FR format is bimodal, peaking at 0% and 100%

Pre-test Score Distributions

Calculus-Based Course
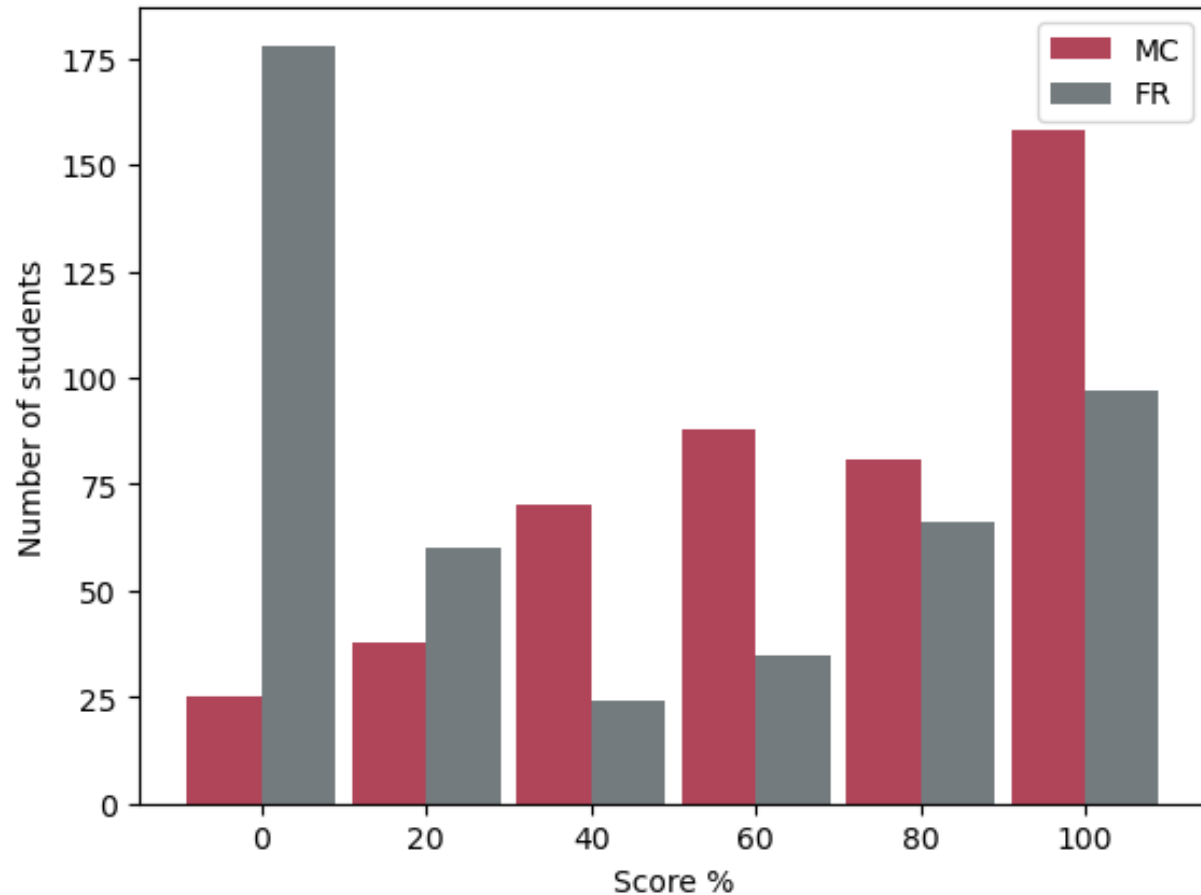
The distribution of scores in FR format is bimodal, peaking at 0% and 100%

Pre-test Score Distributions

Calculus-Based Course
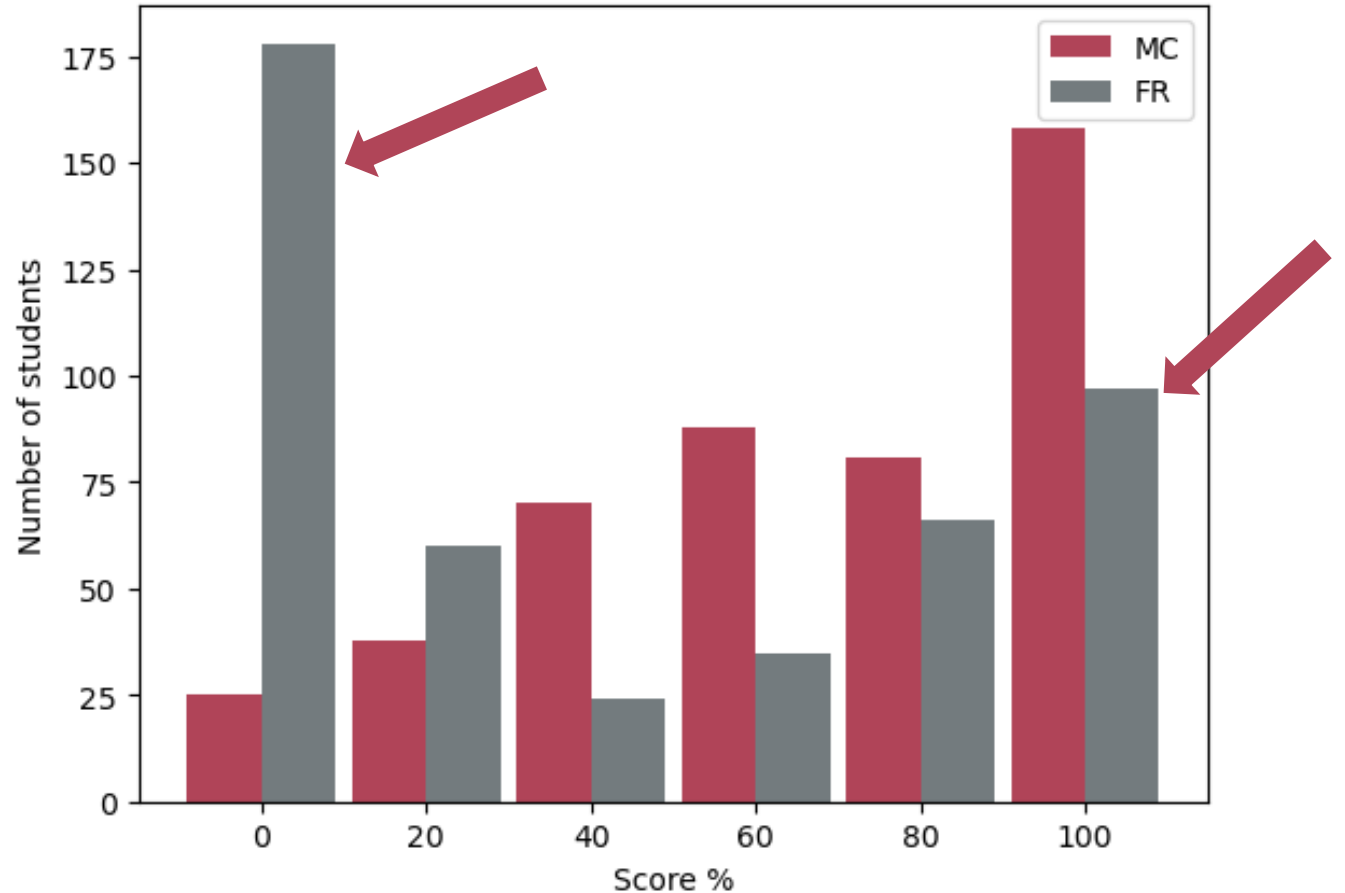
The distribution of scores in FR format is bimodal, peaking at 0% and 100%

Test Reliability (Cronbach's Alpha)

Algebra-Based Course

	MC Format	FR Format
Pre-test	0.58	0.89
Post-test	0.58	0.75

FR format has higher test reliability

11

THE OHIO STATE UNIVERSITY

Learning Vectors Online: Comparing Multiple-Choice to Drawing Vectors
Michael Kline, Andrew Heckler

Test Reliability (Cronbach's Alpha)

Calculus-Based Course

	MC Format	FR Format
Pre-test	0.69	0.89
Post-test	0.47	0.60

FR format has higher test reliability

Learning

Differences Between Practicing in MC/FR Answer Formats

Score Gains (Post % - Pre %)

Algebra-Based Course
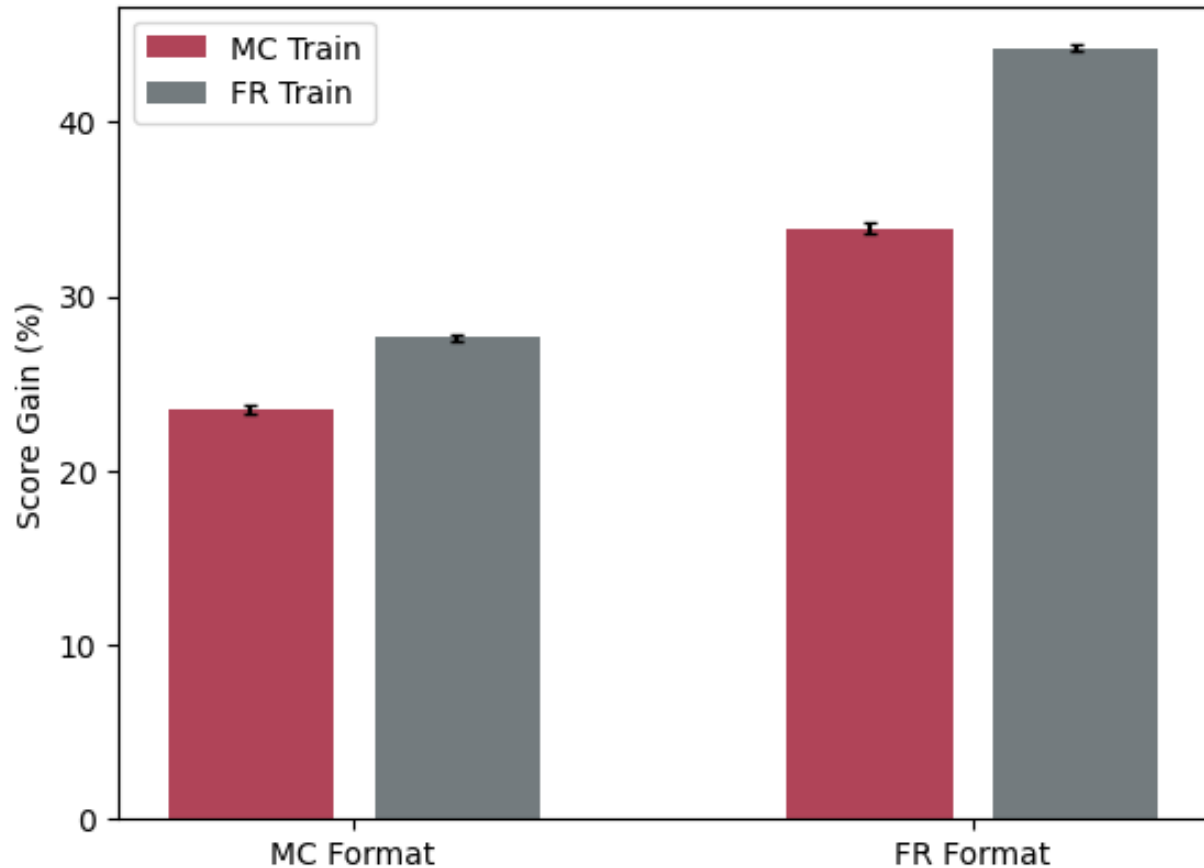
Training in FR format leads to higher gains in FR format and in MC format in algebra-based course

Score Gains (Post % - Pre %)

Calculus-Based Course
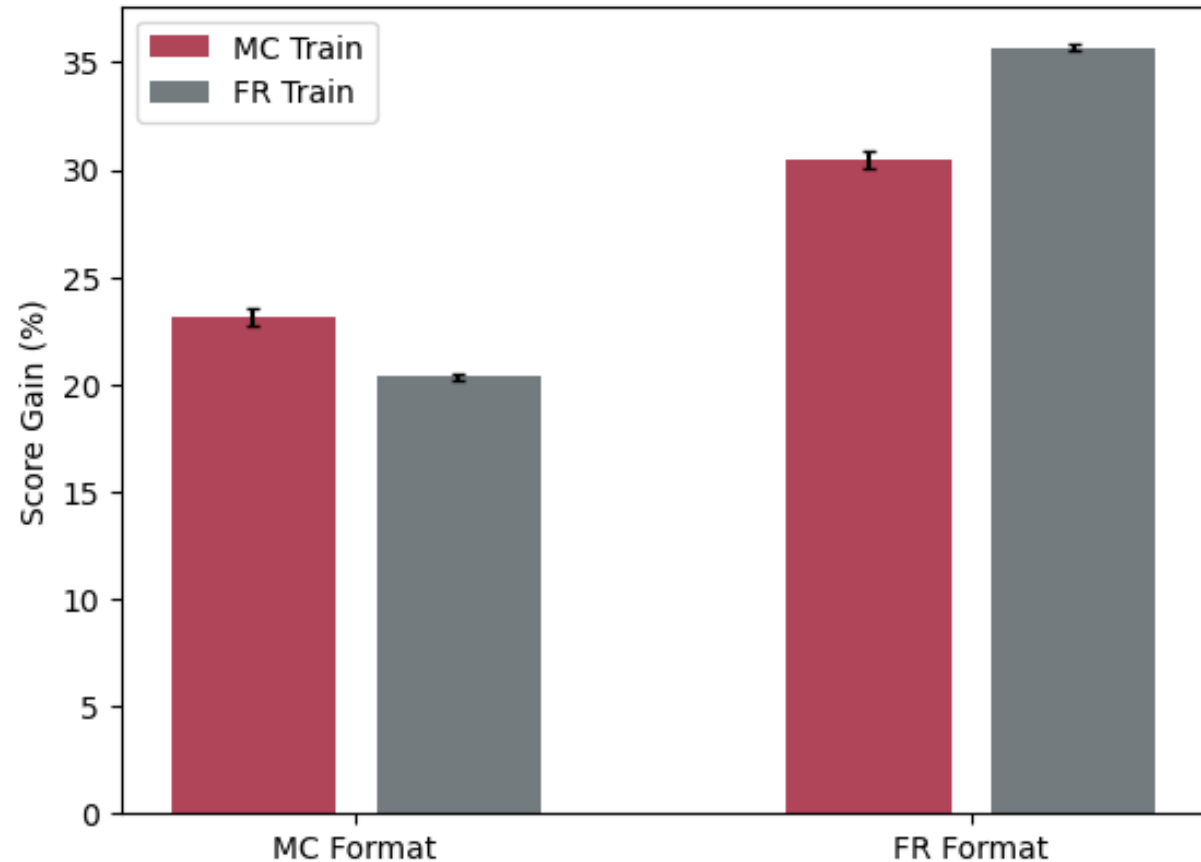
Training in FR format leads to higher gains in FR format and in MC format in algebra-based course

THE OHIO STATE UNIVERSITY

$$logit(p_{ij}) = \beta_0 + \beta_{pre} * Pre_{ij} + \beta_{cond} * Condition_i + \beta_{form} * Format_j$$
$$+ \beta_{int1} * Pre_{ij} * Condition_i + \beta_{int2} * Format_j * Condition_i$$
$$+ u_{0j} + v_{0i}$$

Modeling Effect of Training Condition

Algebra-Based Course
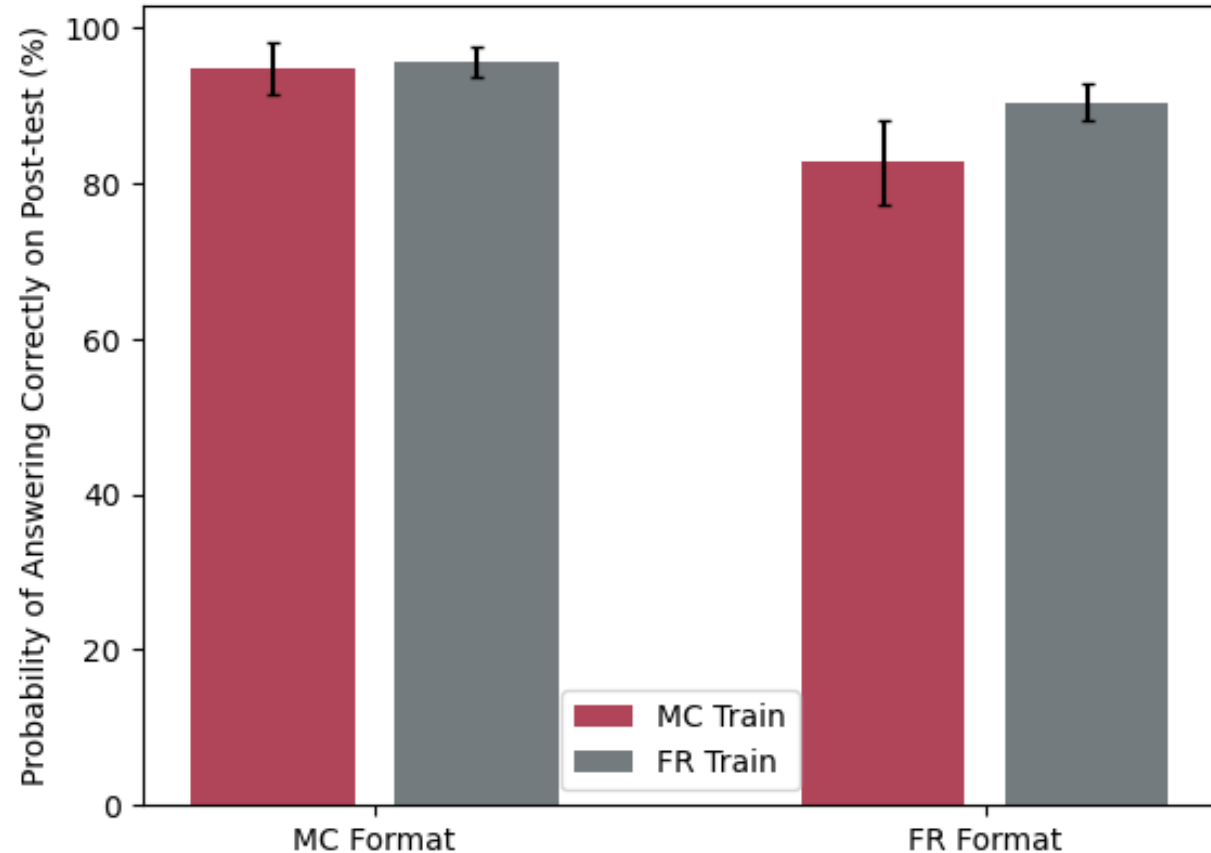
Students are more likely to answer correctly on the post-test if they practiced in FR format

THE OHIO STATE UNIVERSITY

Learning Vectors Online: Comparing Multiple-Choice to Drawing Vectors
Michael Kline, Andrew Heckler

$$logit(p_{ij}) = \beta_0 + \beta_{pre} * Pre_{ij} + \beta_{cond} * Condition_i + \beta_{form} * Format_j$$
$$+ \beta_{int1} * Pre_{ij} * Condition_i + \beta_{int2} * Format_j * Condition_i$$
$$+ u_{0j} + v_{0i}$$

Modeling Effect of Training Condition

Calculus-Based Course
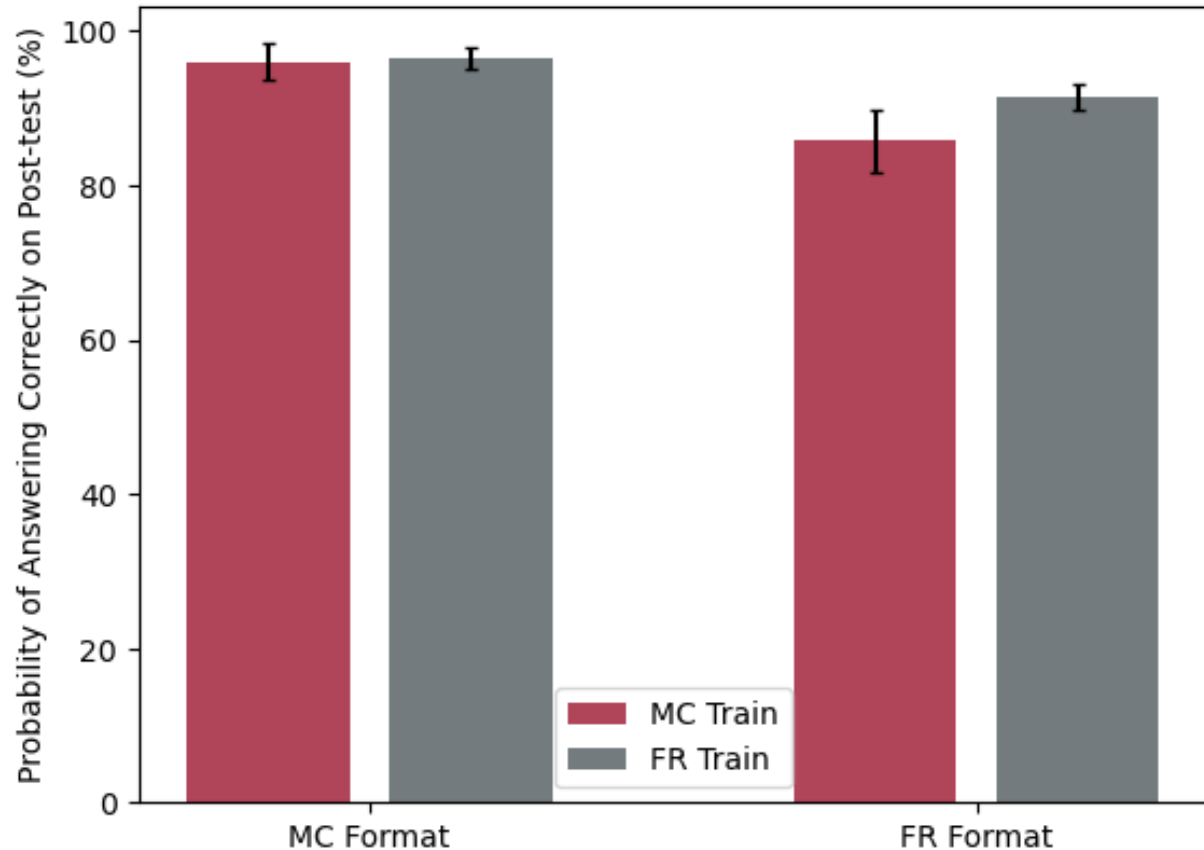
Students are more likely to answer correctly on the post-test if they practiced in FR format

THE OHIO STATE UNIVERSITY

Learning Vectors Online: Comparing Multiple-Choice to Drawing Vectors
Michael Kline, Andrew Heckler

Conclusions

- Assessment
    - FR format has higher discriminatory power than MC format
    - FR format has a higher reliability than MC format

- Learning
    - We see higher gains when practicing vector addition in FR format

- These results are true for both algebra-based and calculus-based students

18

Learning Vectors Online: Comparing Multiple-Choice to Drawing Vectors
Michael Kline, Andrew Heckler

References

1. R. D. Knight, "The vector knowledge of beginning physics students", The Physics Teacher 33, 74–77 (1995).

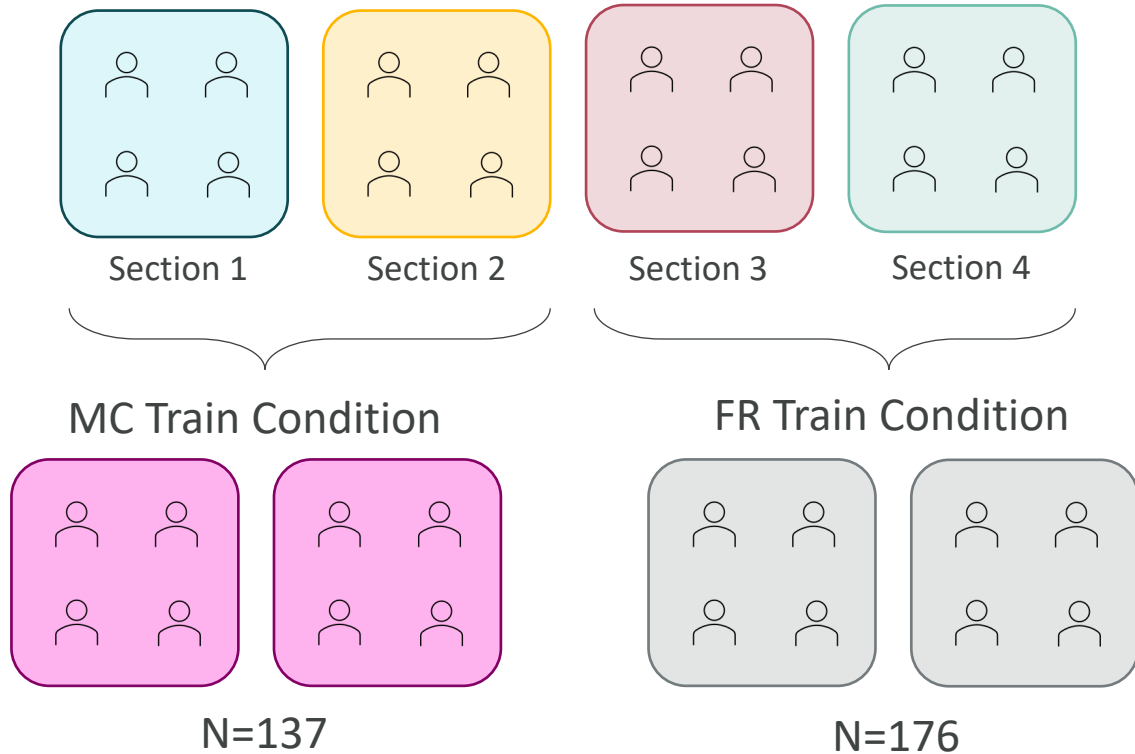2. A. F. Heckler and T. M. Scaife, "Adding and subtracting vectors: the problem with the arrow representation", Physical Review Special Topics-Physics Education Research 11, 010101 (2015).

3. N.-L. Nguyen and D. E. Meltzer, "Initial understanding of vector concepts among students in introductory physics courses", American journal of physics 71, 630–638 (2003).

4. U. Wutchana and N. Emarat, "Students' understanding of graphical vector addition in one and two dimensions", International Journal of Physics & Chemistry Education 3, 102–111 (2011).

5. S. Flores, S. E. Kanim, and C. H. Kautz, "Student use of vectors in introductory mechanics", American Journal of Physics 72, 460–468 (2004).

6. P. S. Shaffer and L. C. McDermott, "A research-based approach to improving student understanding of the vector nature of kinematical concepts", American journal of physics 73, 921–931 (2005).

7. S. F. García, C. Cuellar, M. D. G. Quezada, O. R. Sandoval, M. d. l. Á. C. Quiñones, and V. Aguirre, "Problemas de entendimiento conceptual con las operaciones entre vectores", Latin-American Journal of Physics Education 11, 7 (2017).

8. B. Latifa, E. Purwaningsih, and S. Sutopo, "Identification of students' difficulties in understanding of vector concepts using test of understanding of vector", in Journal of physics: conference series, Vol. 2098, 1 (IOP Publishing, 2021), p. 012018.

9. P. Barniol and G. Zavala, "Vector addition: effect of the context and position of the vectors", in Aip conference proceedings, Vol. 1289, 1 (American Institute of Physics, 2010), pp. 73–76.

10. J. M. Hawkins, J. R. Thompson, M. C. Wittmann, E. C. Sayre, and B. W. Frank, "Students' responses to different representations of a vector addition question", in Aip conference proceedings, Vol. 1289, 1 (American Institute of Physics, 2010), pp. 165–168.

11. S.-Y. Lin and C. Singh, "Can free-response questions be approximated by multiple-choice equivalents?", American Journal of Physics 81, 624–629 (2013).

12. A. D. Slepkov and R. C. Shiell, "Comparison of integrated testlet and constructed-response question formats", Physical Review Special Topics-Physics Education Research 10, 020120 (2014).

13. M. E. Martinez, "A comparison of multiple-choice and constructed figural response items", Journal of Educational Measurement 28, 131–145 (1991).

14. S. L. Wise and X. Kong, "Response time effort: a new measure of examinee motivation in computer-based tests", Applied Measurement in Education 18, 163–183 (2005).
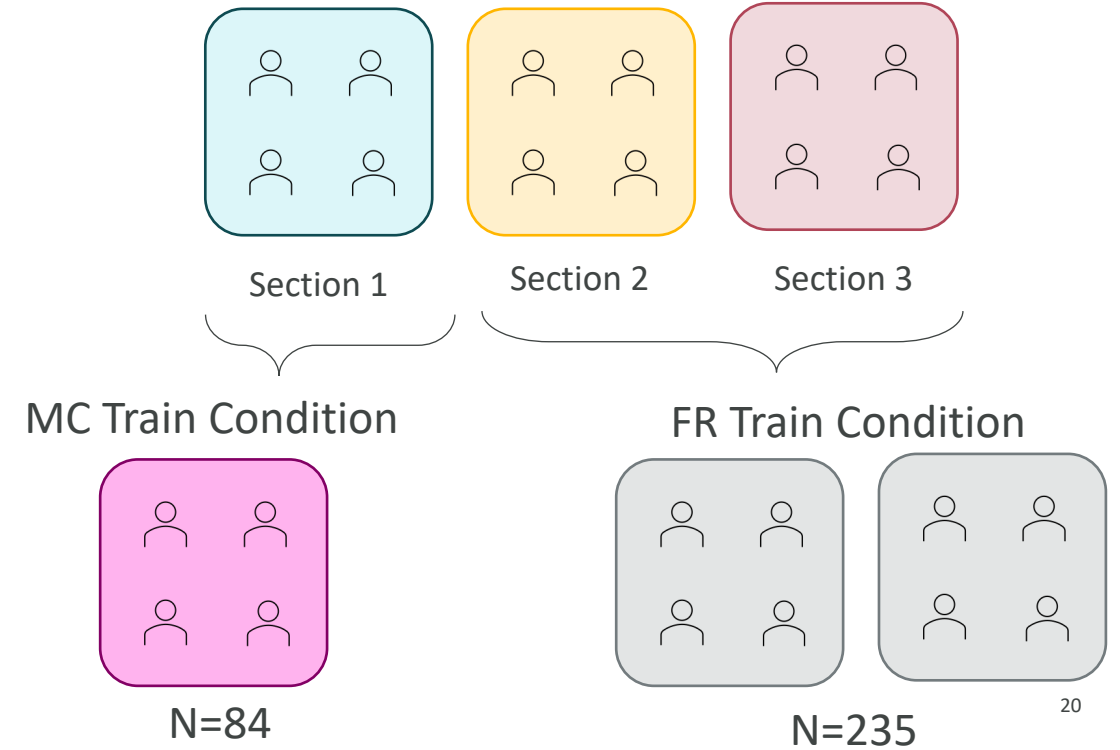
THE OHIO STATE UNIVERSITY

Quasi-Experimental Design

Algebra-Based Course

Section 1 Section 2 Section 3 Section 4

MC Train Condition

FR Train Condition

N=137

N=176

Calculus-Based Course

Section 1 Section 2 Section 3

MC Train Condition

FR Train Condition

N=84

N=235

THE OHIO STATE UNIVERSITY
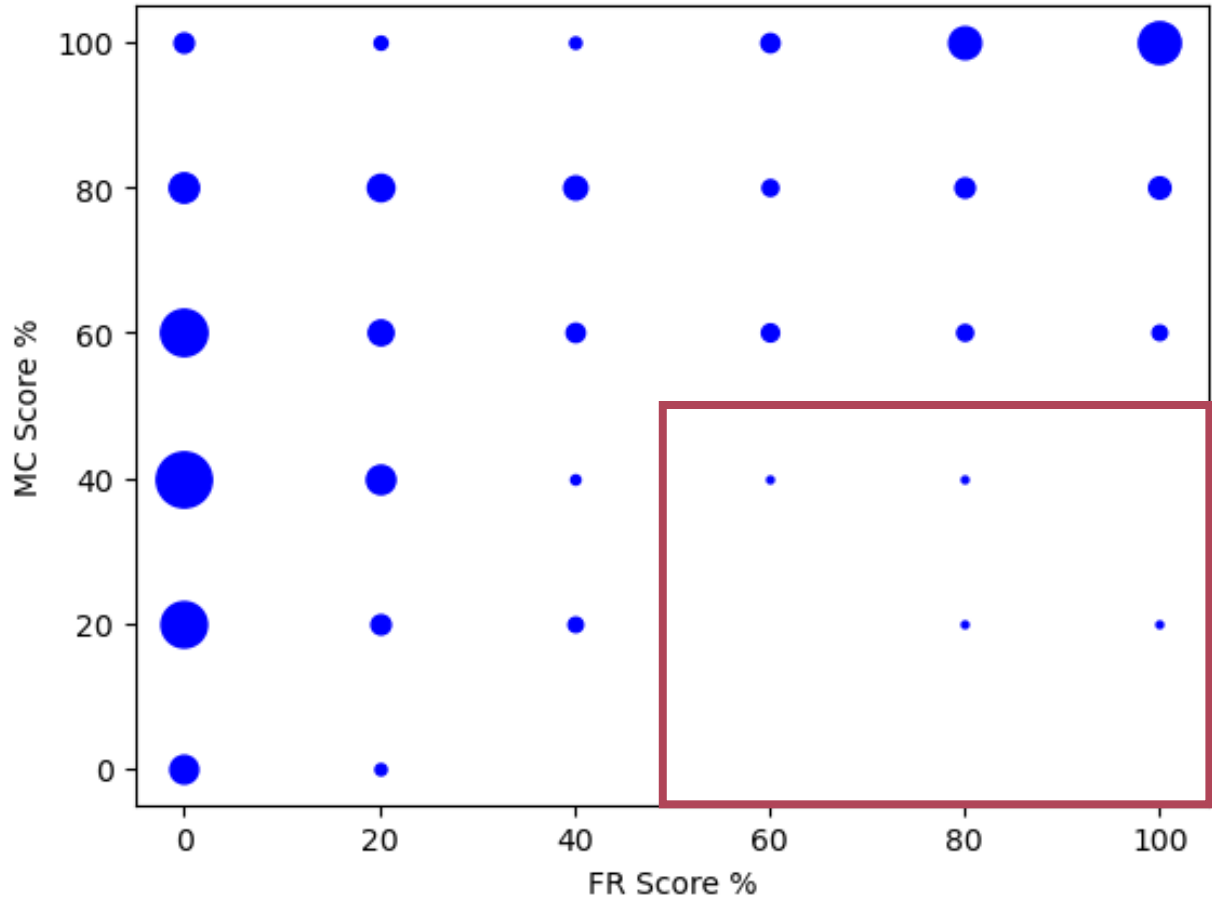
Hierarchy Between MC/FR Formats

Algebra-Based Course

Hierarchy Between MC/FR Formats

Calculus-Based Course

THE OHIO STATE UNIVERSITY