Predictors of performance in introductory physics courses

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Data Sources

- Diagnostic pretest covering pre-college mathematics
  - calculators allowed
- Pre-instruction tests of scientific reasoning skill and physics concept knowledge:
  - Lawson Test of Scientific Reasoning
  - Force Concept Inventory

Acknowledgments

- Diagnostic data have been provided by (among others):

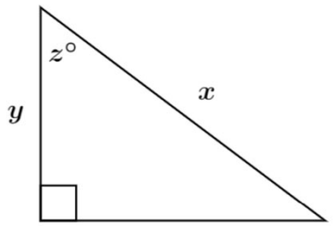
  Vince Coletta (Loyola Marymount University)

  Steven Pollock (University of Colorado, Boulder)

  Christopher Varney (University of West Florida)

Mathematics Diagnostic Pretest

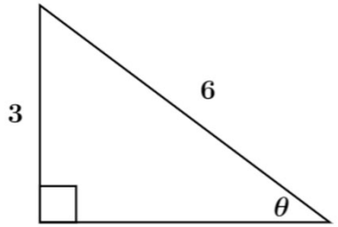
What is the length of side x?



A. $ycos(z°)$ D. $y/cos(z°)$ G. $cos(z°)/y$ J. $\sqrt{y^2+z^2}$
B. $ysin(z°)$ E. $y/sin(z°)$ H. $sin(z°)/y$ K. $\sqrt{z^2-y^2}$
C. $ytan(z°)$ F. $y/tan(z°)$ I. $tan(z°)/y$ L. y/z

(There may be more than one correct answer, but please select only ONE answer.)

What is the value of θ?



A. $cos(3/6)$ D. $cos^{-1}(3/6)$ G. $30°$ J. $27°$
B. $sin(3/6)$ E. $sin^{-1}(3/6)$ H. $45°$ K. $3/6$
C. $tan(3/6)$ F. $tan^{-1}(3/6)$ I. $60°$ L. 0.524

(There may be more than one correct answer, but please select only ONE answer.)

$cos(0°) = ?$

A. 0 B. 1 C. undefined D. 0.707 E. 0.894

(There may be more than one correct answer, but please select only ONE answer.)

$sin(90°) = ?$

A. 0 B. 1 C. undefined D. 0.707 E. 0.894

(There may be more than one correct answer, but please select only ONE answer.)

$tan(0°) = ?$

A. 0 B. 1 C. undefined D. 0.707 E. 0.894

(There may be more than one correct answer, but please select only ONE answer.)

Solve for θ.

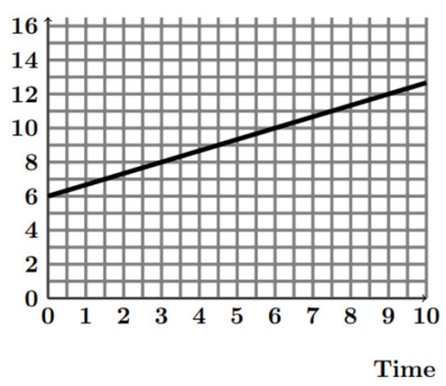
$\gamma\theta + \eta = \lambda\theta + \omega$

A. $\frac{\eta+\omega}{\gamma-\lambda}$ C. $\frac{\gamma-\lambda}{\omega-\eta}$ E. $\frac{\eta-\omega}{\gamma\lambda}$ G. $\frac{\omega-\eta}{\gamma-\lambda}$ I. $\frac{\eta-\omega+\gamma}{\lambda}$

B. $\frac{\eta-\omega}{\lambda-\gamma}$ D. $\frac{\lambda-\gamma}{\eta-\omega}$ F. $\frac{\omega-\eta}{\gamma\lambda}$ H. $\frac{\omega-\eta}{\gamma+\lambda}$ J. $\frac{\omega-\eta+\lambda}{\gamma}$

(There may be more than one correct answer, but please select only ONE answer.)

What is the slope of the graph below?



A. $\frac{1}{3}$ m/s because the object moves 1 meter in 3 seconds.

B. $\frac{1}{3}$ m/s because the line rises 1 box while it goes 3 boxes in the horizontal direction.

C. $\frac{2}{3}$ m/s because the object moves 2 meters in 3 seconds.

D. $\frac{2}{3}$ m/s because the line rises 2 boxes while it goes 3 boxes in the horizontal direction.

(There may be more than one correct answer, but please select only ONE answer.)

$$\left(\frac{a}{3}\right)^3 = ?$$

A. $\frac{a^3}{3}$ B. $\frac{a}{27}$ C. $\frac{a^3}{27}$

(There may be more than one correct answer, but please select only ONE answer.)

$$2\left(\frac{a}{b}\right) = ?$$

A. $\frac{2a}{b}$ B. $\frac{2a}{2b}$ C. $\frac{a}{2b}$

(There may be more than one correct answer, but please select only ONE answer.)

$$\frac{a/b}{c^2/d} = ?$$

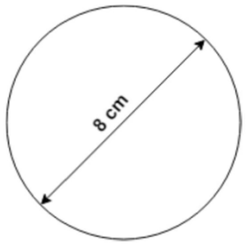
A. $\frac{ac^2}{bd}$ B. $\frac{ad}{bc^2}$ C. $\frac{bd}{ac^2}$ D. $\frac{bc^2}{ad}$

(There may be more than one correct answer, but please select only ONE answer.)

$$2\left(\frac{3}{4}\right) = ?$$

A. $\frac{6}{8}$ B. $\frac{12}{8}$ C. $\frac{3}{8}$ D. $\frac{3}{2}$ E. $\frac{3}{4}$

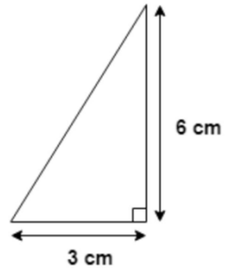
(There may be more than one correct answer, but please select only ONE answer.)



(a) Area of the circle = ?

A. 8π cm^3	F. 8π cm^2	K. 8π cm
B. 16π cm^3	G. 16π cm^2	L. 16π cm
C. 32π cm^3	H. 32π cm^2	M. 32π cm
D. 64π cm^3	I. 64π cm^2	N. 64π cm
E. 128π cm^3	J. 128π cm^2	O. 128π cm

(There may be more than one correct answer, but please select only ONE answer.)



(b) Area of the triangle = ?

A. 4.5 cm^3	F. 4.5 cm^2	K. 4.5 cm
B. 9 cm^3	G. 9 cm^2	L. 9 cm
C. 12 cm^3	H. 12 cm^2	M. 12 cm
D. 18 cm^3	I. 18 cm^2	N. 18 cm
E. 36 cm^3	J. 36 cm^2	O. 36 cm

(There may be more than one correct answer, but please select only ONE answer.)

Solve for x.

$$\frac{3}{2} = 7x$$

A. $\frac{14}{3}$ B. $\frac{3}{14}$ C. $\frac{21}{2}$ D. $\frac{21}{14}$

(There may be more than one correct answer, but please select only ONE answer.)

$$v^2 = v_0^2 + 2ad$$

$$v_0 = 0$$

$$a = \frac{\Delta v}{\Delta t}$$

$$\Delta v = 60$$

$$\Delta t = 8$$

$$v = 30$$

d =?

A. $d = 30$ B. $d = 60$ C. $d = 120$ D. $d = 240$ E. $d = 480$

(There may be more than one correct answer, but please select only ONE answer.)

$$cy = dx$$

$$a - y = bx$$

x =?

A. $\frac{ac}{d+b}$ C. $\frac{ac}{bc-d}$ E. $\frac{ac}{db}$ G. $\frac{a}{b+\frac{d}{c}}$ I. $\frac{1}{b}\left(a-\frac{d}{c}\right)$

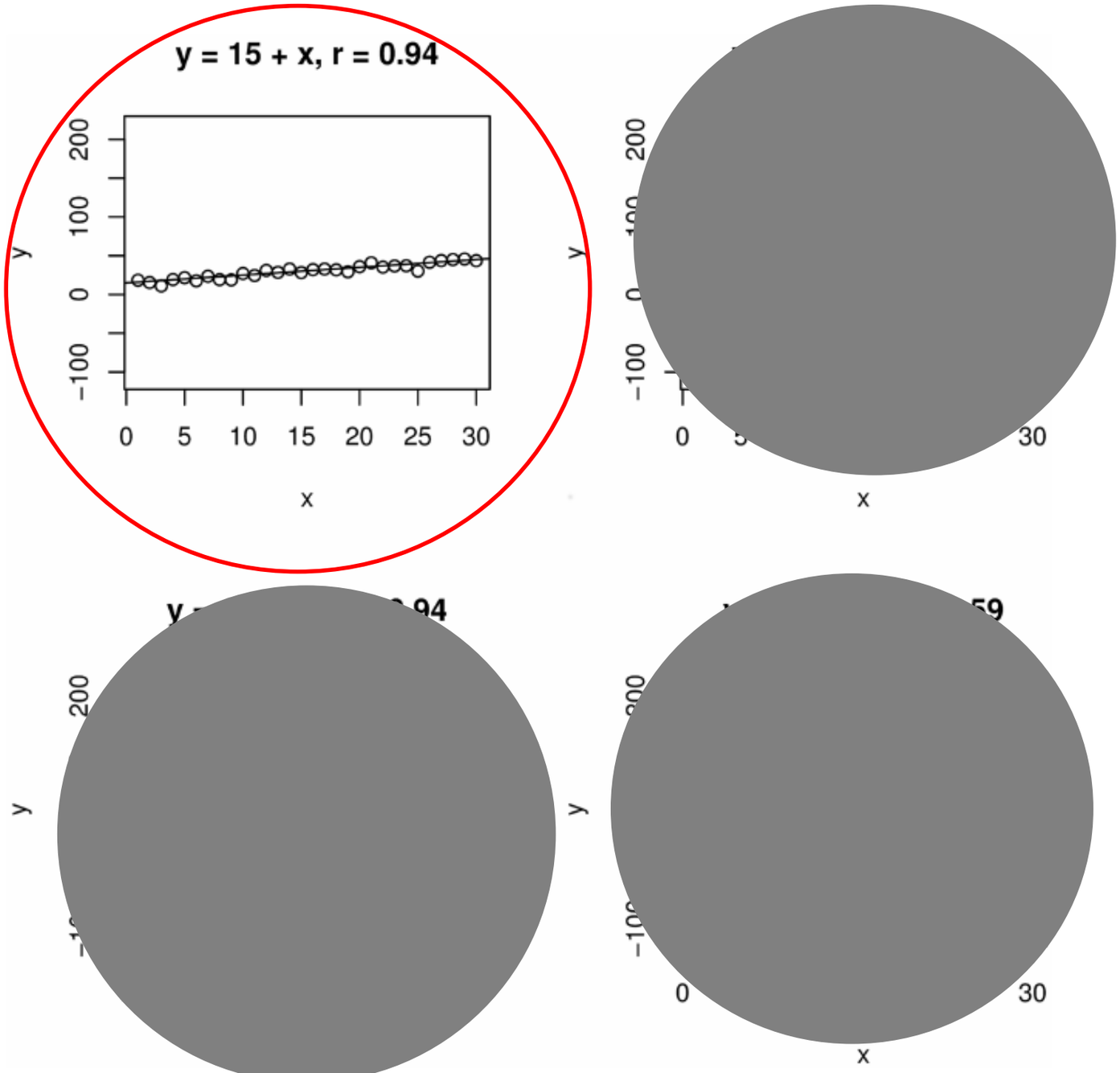
B. $\frac{ac}{d-b}$ D. $\frac{ac}{bc+d}$ F. $\frac{a}{db}$ H. $\frac{a}{b+d}$ J. $\frac{c}{d}\left(a-b\right)$

(There may be more than one correct answer, but please select only ONE answer.)

Relation Between Scores and Grades

- Correlation coefficient between mathematics pretest score and final course grades varies greatly from course to course:
  - $r \approx +0.10 - +0.50$.
- However, slope of fit line for grades vs. math score is relatively high, therefore…
- …pretest score on mathematics diagnostic can *approximately* predict final course grade

High correlation, small slope:
Changes in predictor variable have little effect (though highly predictable)



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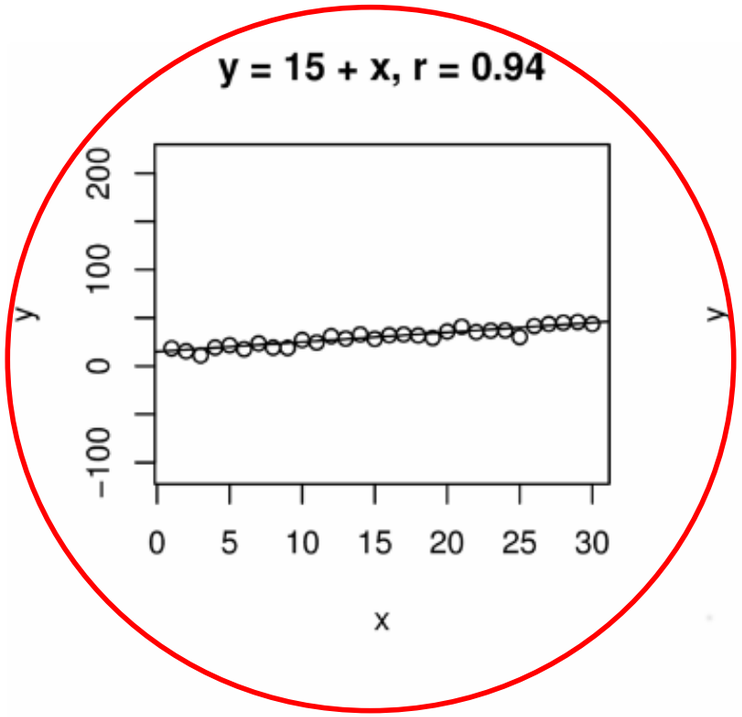

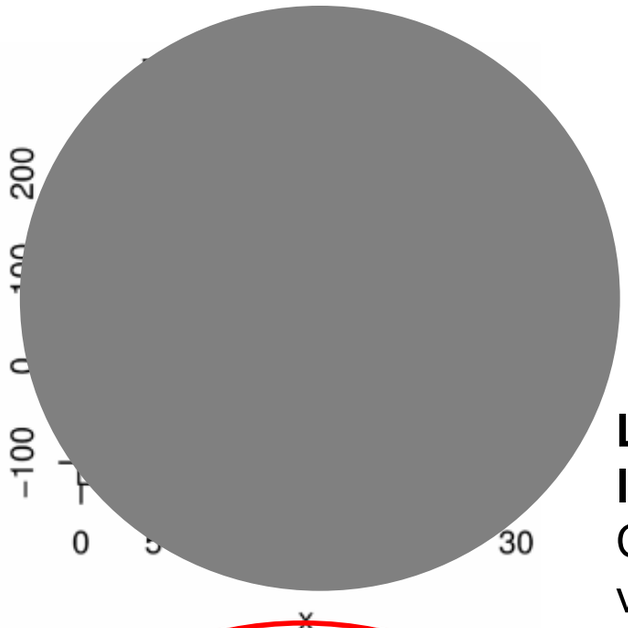

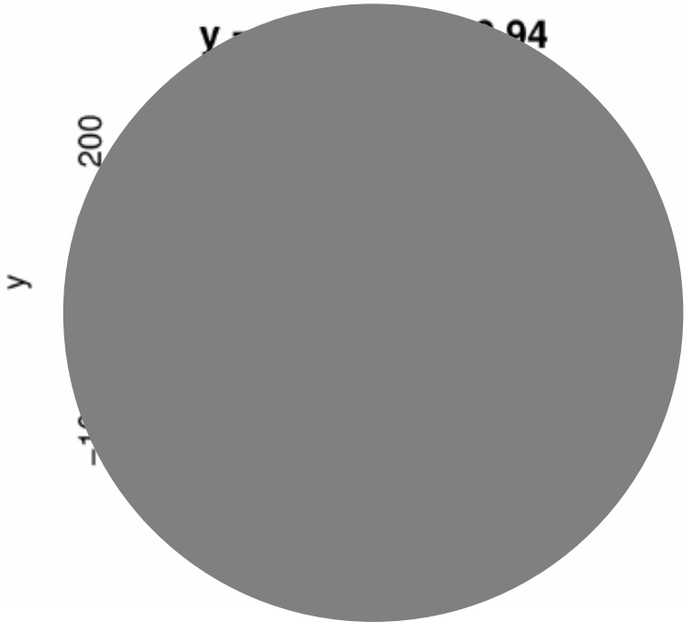

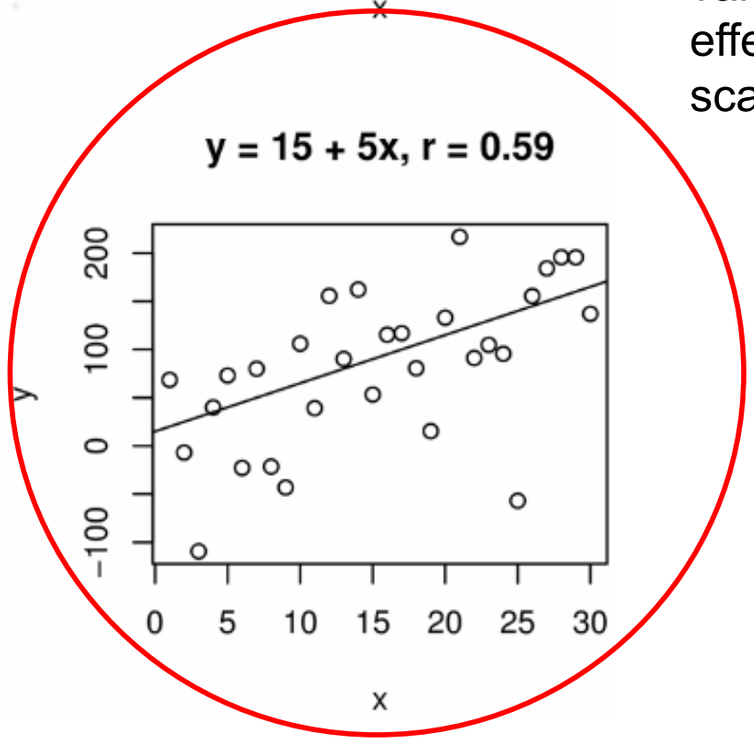

Low correlation, large slope:
Changes in predictor variable have large effect (despite large scatter)

High correlation, small slope:
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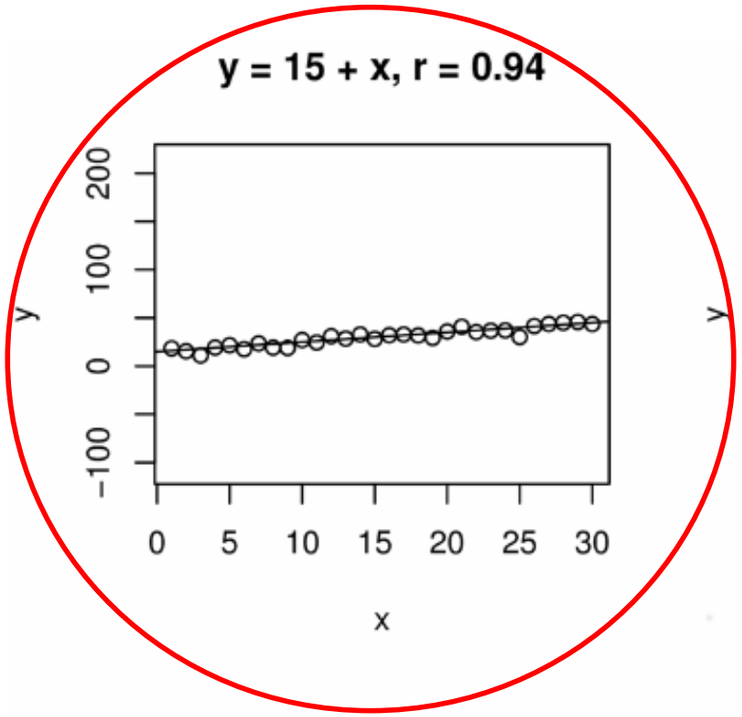

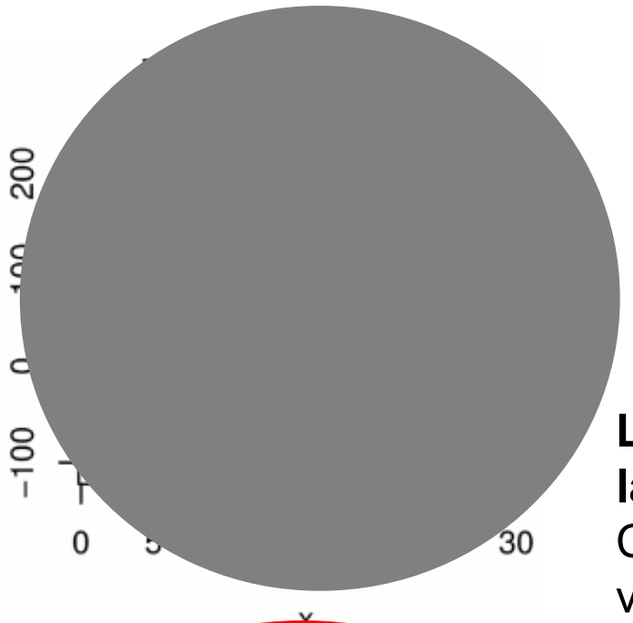

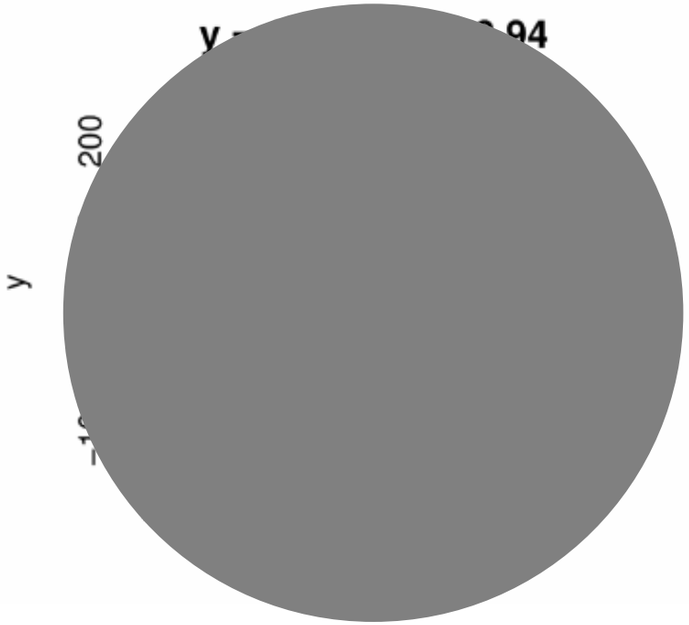

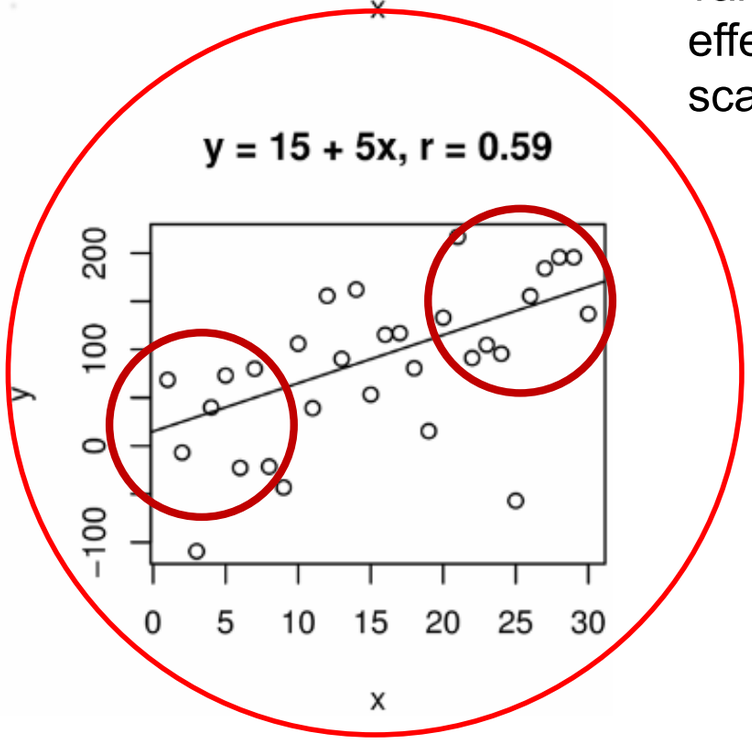

Low correlation, large slope:
Changes in predictor variable have large effect (despite large scatter)

Low Course Grade vs. Mathematics Diagnostic Pretest Score

Course	Campus	*N*	Top-quartile Math: % with bottom-quartile grades	Bottom-quartile Math: % with bottom-quartile grades	Low-grade odds ratio

Low Course Grade vs. Mathematics Diagnostic Pretest Score

Course	Campus	*N*	Top-quartile Math: % with bottom-quartile grades	Bottom-quartile Math: % with bottom-quartile grades	Low-grade odds ratio

Students whose mathematics pretest scores placed them among the ***top*** quarter of the class (75th percentile and higher): what percentage of them received low (bottom-quartile, C+ or lower) course grades?

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Students whose mathematics pretest scores placed them among the ***bottom*** quarter of the class (25th percentile or lower): what percentage of them received low (bottom-quartile, C+ or lower) course grades?

Low Course Grade vs. Mathematics Diagnostic Pretest Score

Course	Campus	*N*	Top-quartile Math: % with bottom-quartile grades	Bottom-quartile Math: % with bottom-quartile grades	Low-grade odds ratio
Alg-1 2021	ASU-P	81			

Alg-1: Algebra-based course, first semester

ASU-P: Arizona State University, Polytechnic campus

Low Course Grade vs. Mathematics Diagnostic Pretest Score

Course	Campus	*N*	Top-quartile Math: % with bottom-quartile grades	Bottom-quartile Math: % with bottom-quartile grades	Low-grade odds ratio
Alg-1 2021	ASU-P	81	15%		

Alg-1: Algebra-based course, first semester

ASU-P: Arizona State University, Polytechnic campus

Low Course Grade vs. Mathematics Diagnostic Pretest Score

Course	Campus	*N*	Top-quartile Math: % with bottom-quartile grades	Bottom-quartile Math: % with bottom-quartile grades	Low-grade odds ratio
Alg-1 2021	ASU-P	81	15%	46%	

Alg-1: Algebra-based course, first semester

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Course	Campus	*N*	Top-quartile Math: % with bottom-quartile grades	Bottom-quartile Math: % with bottom-quartile grades	Low-grade odds ratio
Alg-1 2021	ASU-P	81	15%	46%	3.2

Low-scorers on the math diagnostic pretest were ***3.2*** times more likely to get a low grade than high scorers

Alg-1: Algebra-based course, first semester

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Question: How consistent was this result?

Alg-1: Algebra-based course, first semester

ASU-P: Arizona State University, Polytechnic campus

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Answer: Very consistent.

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Alg-1 2021	ASU-P	81	15%	46%	3.2
Alg-1 2022	ASU-P	92			

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Alg-1 2021	ASU-P	81	15%	46%	3.2
Alg-1 2022	ASU-P	92	11%	44%	4.0

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Alg-2 2022	ASU-P	75			
Alg-2 2023	ASU-P	92			

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Alg-2 2021	ASU-T	129			

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Calc-1 2021	UWF	103			
Calc-2 2021	UWF	59			

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*Students who scored low on math diagnostic pretest had **consistently** more low grades than those who scored high*

High Course Grade vs. Mathematics Diagnostic Pretest Score

Course	Campus	*N*	Top-quartile Math: % with top-quartile grades	Bottom-quartile Math: % with top-quartile grades	High-grade odds ratio
Alg-1 2021	ASU-P	81			

High Course Grade vs. Mathematics Diagnostic Pretest Score

Course	Campus	*N*	Top-quartile Math: % with top-quartile grades	Bottom-quartile Math: % with top-quartile grades	High-grade odds ratio
Alg-1 2021	ASU-P	81			

Students whose mathematics pretest scores placed them among the top quarter of the class (75th percentile and higher): what percentage of them received ***high*** (top-quartile, A − or higher) course grades?

Students whose mathematics pretest scores placed them among the bottom quarter of the class (25th percentile or lower): what percentage of them received ***high*** (top-quartile, A− or higher) course grades?

High Course Grade vs. Mathematics Diagnostic Pretest Score

Course	Campus	*N*	Top-quartile Math: % with top-quartile grades	Bottom-quartile Math: % with top-quartile grades	High-grade odds ratio
Alg-1 2021	ASU-P	81	47%	11%	4.5

Alg-1: Algebra-based course, first semester

ASU-P: Arizona State University, Polytechnic campus

High Course Grade vs. Mathematics Diagnostic Pretest Score

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Alg-1 2021	ASU-P	81	47%	11%	4.5
Alg-1 2022	ASU-P	92	38%	9%	4.4
Alg-2 2022	ASU-P	75	46%	21%	2.2
Alg-2 2023	ASU-P	92	41%	13%	3.2
Alg-2 2021	ASU-T	129	30%	39%	0.8
Calc-1 2021	UWF	103	41%	1%	58.5
Calc-2	UWF	59	65%	37%	1.8

Alg-1: Algebra-based course, first semester
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*Students who scored high on math diagnostic pretest had **consistently** more high grades than those who scored high*

Factors other than math preparation may influence course performance

- For example:
  - Scientific reasoning skills, as measured by the Lawson Test of Scientific Reasoning
  - Physics concept knowledge, as measured by the Force Concept Inventory

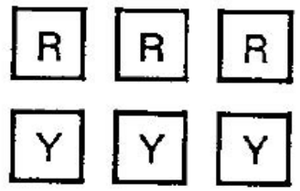
Scientific reasoning skills: The 24-item Lawson test

Suppose you are given two clay balls of equal size and shape. The two clay balls also weigh the same. One ball is flattened into a pancake-shaped piece. *Which of these statements is correct?*

a. The pancake-shaped piece weighs more than the ball
b. The two pieces still weigh the same
c. The ball weighs more than the pancake-shaped piece

Understanding shape-independence of mass

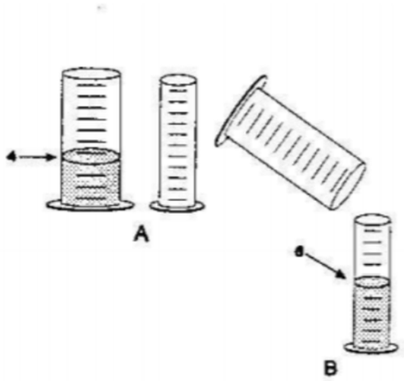
Six square pieces of wood are put into a cloth bag and mixed about. The six pieces are identical in size and shape, however, three pieces are red and three are yellow. Suppose someone reaches into the bag (without looking) and pulls out one piece. *What are the chances that the piece is red?*



a. 1 chance out of 6
b. 1 chance out of 3
c. 1 chance out of 2
d. 1 chance out of 1
e. cannot be determined

Probabilistic reasoning

To the right are drawings of a wide and a narrow cylinder. The cylinders have equally spaced marks on them. Water is poured into the wide cylinder up to the 4th mark (see A). This water rises to the 6th mark when poured into the narrow cylinder (see B).

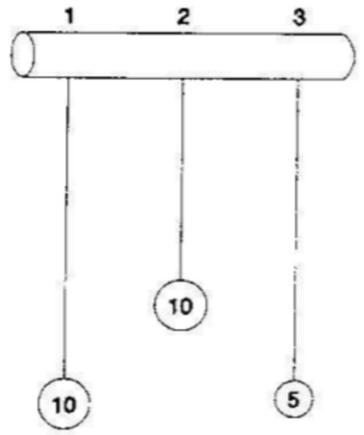


Both cylinders are emptied (not shown) and water is poured into the wide cylinder up to the 6th mark. *How high would this water rise if it were poured into the empty narrow cylinder?*

a. to about 8
b. to about 9
c. to about 10
d. to about 12
e. none of these answers is correct

Proportional reasoning

At the right are drawings of three strings hanging from a bar. The three strings have metal weights attached to their ends. String 1 and String 3 are the same length. String 2 is shorter. A 10 unit weight is attached to the end of String 1. A 10 unit weight is also attached to the end of String 2. A 5 unit weight is attached to the end of String 3. The strings (and attached weights) can be swung back and forth and the time it takes to make a swing can be timed.

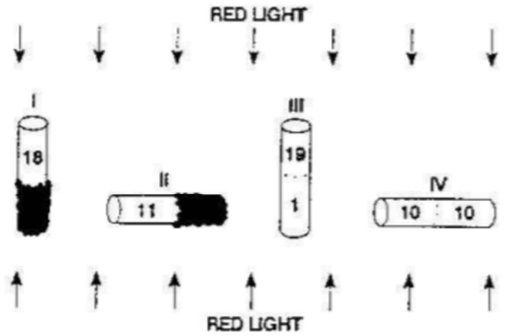


Suppose you want to find out whether the length of the string has an effect on the time it takes to swing back and forth. *Which strings would you use to find out?*

a. only one string
b. all three strings
c. 2 and 3
d. 1 and 3
e. 1 and 2

Control of variables

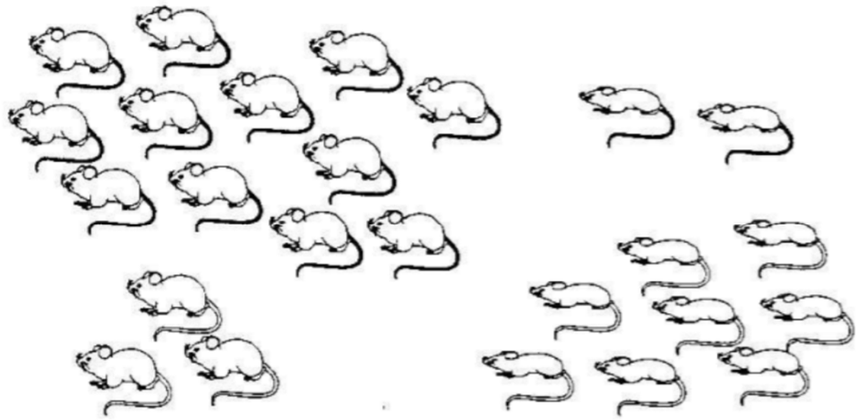
Twenty fruit flies are placed in each of four glass tubes. The tubes are sealed. Tubes I and II are partially covered with black paper; Tubes III and IV are not covered. The tubes are placed as shown. Then they are exposed to red light for five minutes. The number of flies in the uncovered part of each tube is shown in the drawing.



This experiment shows that flies respond to (respond means move to or away from):

a. red light but not gravity
b. gravity but not red light
c. both red light and gravity
d. neither red light nor gravity

Farmer Brown was observing the mice that live in his field. He discovered that all of them were either fat or thin. Also, all of them had either black tails or white tails. This made him wonder if there might be a link between the size of the mice and the color of their tails. So he captured all of the mice in one part of his field and observed them. Below are the mice that he captured.



Do you think there is a link between the size of the mice and the color of their tails?

a. appears to be a link
b. appears not to be a link
c. cannot make a reasonable guess

Correlational reasoning

Objections to Lawson Test

- Wordy, potentially confusing text: becomes a test of reading comprehension
- Ambiguous wording and/or answers, dependent on some outside knowledge or assumptions
- Mediocre graphics

High Course Grade vs. Lawson Test of Scientific Reasoning Pretest Score

Course	Campus	*N*	Top-quartile Lawson: % with top-quartile grades	Bottom-quartile Lawson: % with top-quartile grades	High-grade odds ratio

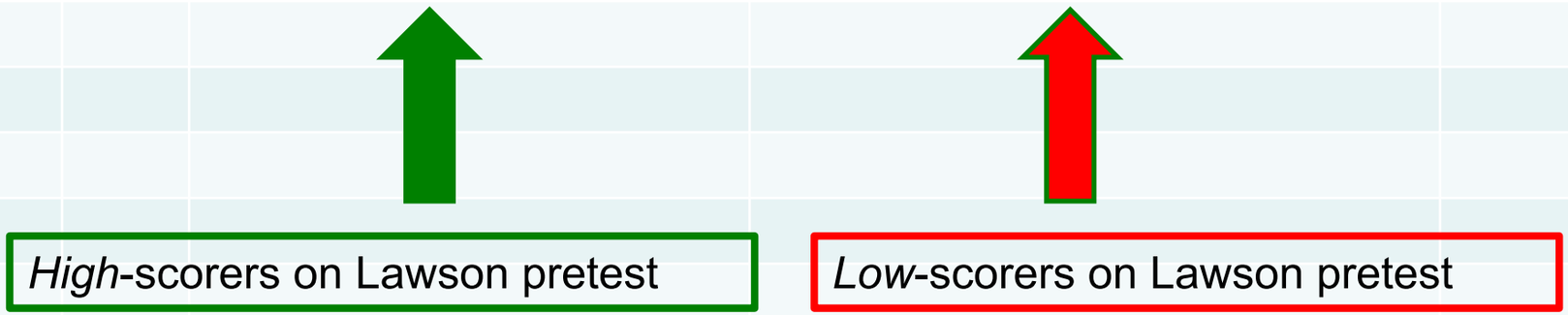
High Course Grade vs. Lawson Test of Scientific Reasoning Pretest Score

Course	Campus	*N*	Top-quartile Lawson: % with top-quartile grades	Bottom-quartile Lawson: % with top-quartile grades	High-grade odds ratio

High-scorers on Lawson pretest

High Course Grade vs. Lawson Test of Scientific Reasoning Pretest Score

Course	Campus	*N*	Top-quartile Lawson: % with top-quartile grades	Bottom-quartile Lawson: % with top-quartile grades	High-grade odds ratio



High Course Grade vs. Lawson Test of Scientific Reasoning Pretest Score

Course	Campus	*N*	Top-quartile Lawson: % with top-quartile grades	Bottom-quartile Lawson: % with top-quartile grades	High-grade odds ratio
Alg-1 2021	ASU-P	73	46%	16%	2.8

High Course Grade vs. Lawson Test of Scientific Reasoning Pretest Score

Course	Campus	*N*	Top-quartile Lawson: % with top-quartile grades	Bottom-quartile Lawson: % with top-quartile grades	High-grade odds ratio
Alg-1 2021	ASU-P	73	46%	16%	2.8
Alg-1 2022	ASU-P	95	52%	8%	6.2
Alg-2 2022	ASU-P	73	41%	6%	7.6
Alg-2 2023	ASU-P	92	52%	10%	5.0
Alg-1	CU	469	45%	8%	5.5
Calc-2	CU	276	57%	8%	6.9
Alg-1 2007	LMU	24	50%	0%	“∞”
Alg-1 2009	LMU	51	34%	11%	3.2
Alg-1 2011	LMU	57	53%	18%	2.9
Alg-1 2012	LMU	44	64%	6%	10.5
Alg-1 2013	LMU	30	53%	12%	4.6
Alg-1 2014	LMU	33	61%	0%	“∞”
Alg-1 2015	LMU	24	63%	0%	“∞”
Alg-1 2016	LMU	35	41%	0%	“∞”
Alg-1 2018	LMU	47	54%	9%	6.3
Alg-1 2021	LMU	27	44%	0%	“∞”

High Course Grade vs. Lawson Test of Scientific Reasoning Pretest Score

Course	Campus	*N*	Top-quartile Lawson: % with top-quartile grades	Bottom-quartile Lawson: % with top-quartile grades	High-grade odds ratio
Alg-1 2021	ASU-P	73	46%	16%	2.8
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Low Course Grade vs. Lawson Test of Scientific Reasoning Pretest Score

Course	Campus	*N*	Top-quartile Lawson: % with bottom-quartile grades	Bottom-quartile Lawson: % with bottom-quartile grades	Low-grade odds ratio
Alg-1 2021	ASU-P	73	6%	49%	9.0

Low Course Grade vs. Lawson Test of Scientific Reasoning Pretest Score

Course	Campus	*N*	Top-quartile Lawson: % with bottom-quartile grades	Bottom-quartile Lawson: % with bottom-quartile grades	Low-grade odds ratio
Alg-1 2021	ASU-P	73	6%	49%	9.0
Alg-1 2022	ASU-P	95	13%	42%	3.3
Alg-2 2022	ASU-P	73	16%	27%	1.7
Alg-2 2023	ASU-P	92	13%	37%	2.8
Alg-1	CU	469	10%	42%	4.4
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Alg-1 2012	LMU	44	9%	27%	3.0
Alg-1 2013	LMU	30	27%	12%	0.4
Alg-1 2014	LMU	33	0%	68%	“∞”
Alg-1 2015	LMU	24	0%	75%	“∞”
Alg-1 2016	LMU	35	11%	46%	4.0
Alg-1 2018	LMU	47	16%	42%	2.7
Alg-1 2021	LMU	27	0%	89%	“∞”

Low Course Grade vs. Lawson Test of Scientific Reasoning Pretest Score

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Is physics concept pretest score a predictor of grades?

- We use the Force Concept Inventory

High Course Grade vs. FCI

Course	Campus	*N*	Top-quartile FCI: % with top-quartile grades	Bottom-quartile FCI: % with top-quartile grades	High-grade odds ratio
Alg-1 2021	ASU-P	72	51%	6%	9.2

High Course Grade vs. FCI

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Alg-1 2021	LMU	27	0%	44%	“∞”

Factors are correlated, but not 100%

- Correlation coefficients between predictors are ≈ +0.30-+0.40
- Outliers using one prediction method can often be explained by high pretest scores on another predictor

Math and Lawson pretests are (semi-)independent predictors

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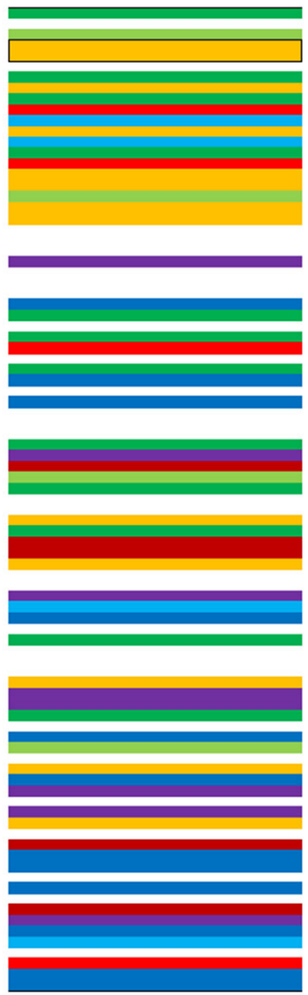
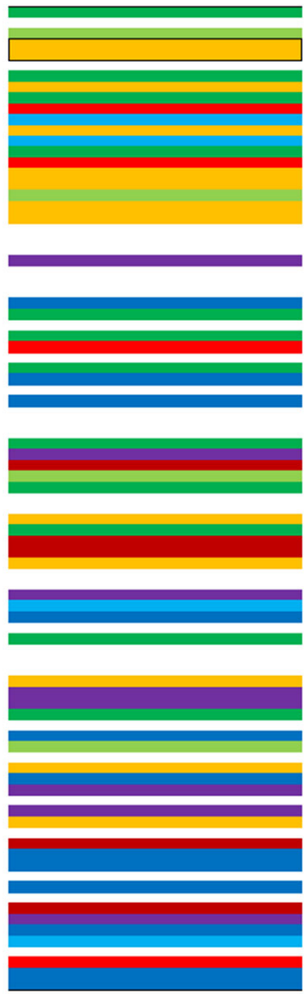


Example: Algebra-based physics, first semester, ASU-P 2022

Math and Lawson pretests are (semi-)independent predictors

Each colored band represents a student in the class, ranked top to bottom in order of course grade points



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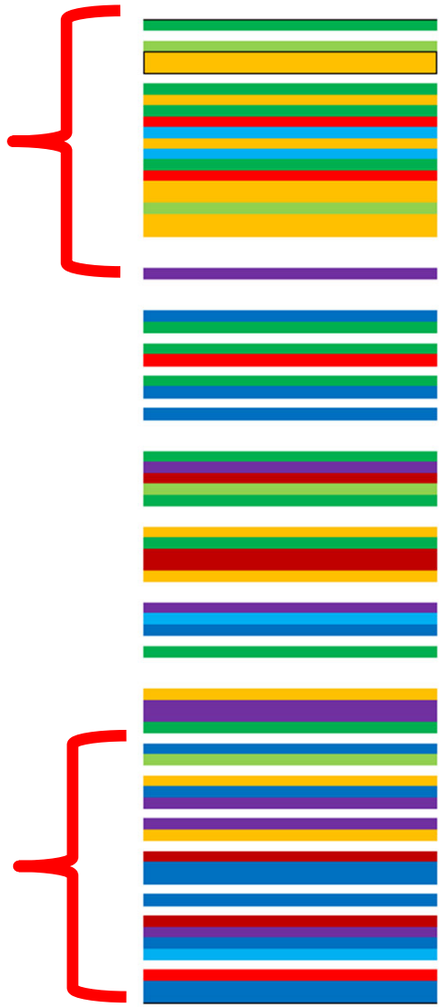
Math and Lawson pretests are (semi-)independent predictors

Top-quartile grades

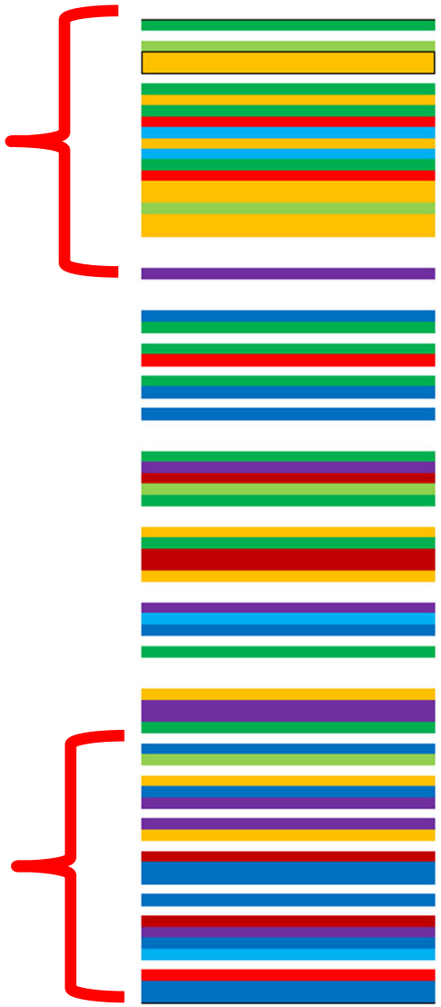


Bottom-quartile grades

Example: Algebra-based physics, first semester, ASU-P 2022

Math and Lawson pretests are (semi-)independent predictors

Top-quartile grades



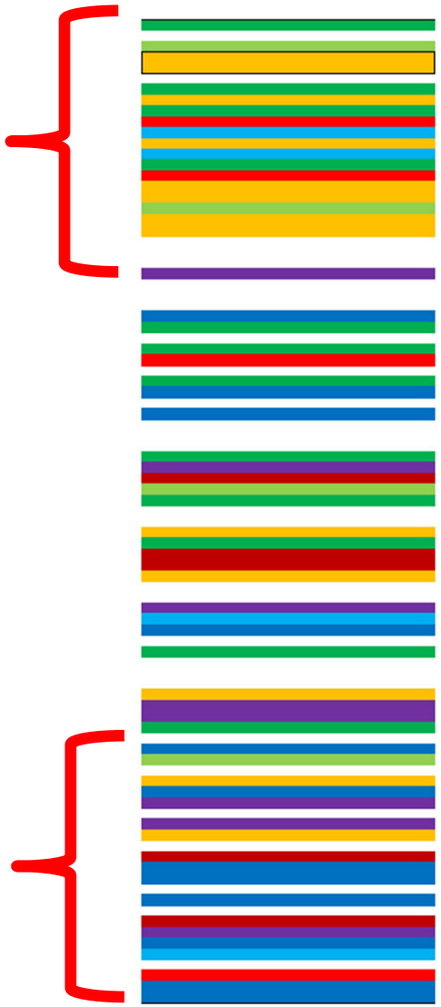
Bottom-quartile grades

High Lawson Only
High Math Only
High Lawson and Low Math
High Math and Low Lawson
High Lawson and High Math
No Highs and No Lows
Low Lawson Only
Low Math Only
Low Lawson and Low Math

Math and Lawson pretests are (semi-)independent predictors

Top-quartile grades

78% are top-quartile in Math, Lawson, or both

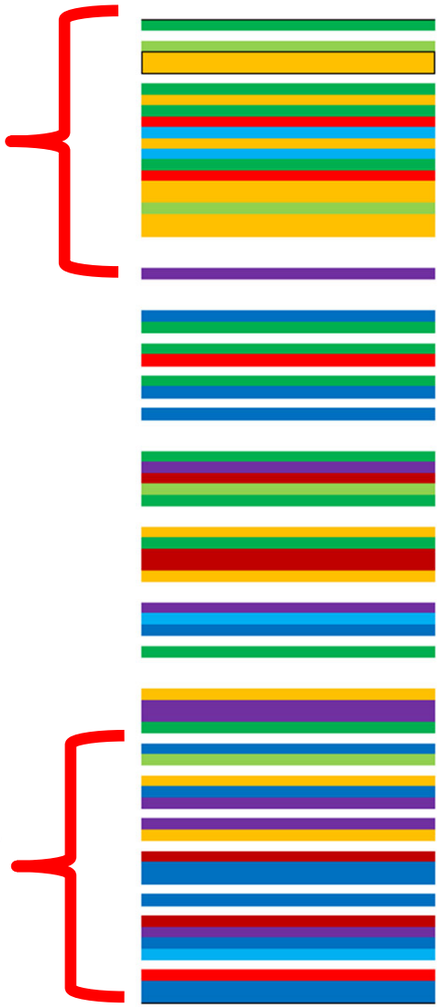


Bottom-quartile grades

High Lawson Only
High Math Only
High Lawson and Low Math
High Math and Low Lawson
High Lawson and High Math
No Highs and No Lows
Low Lawson Only
Low Math Only
Low Lawson and Low Math

Math and Lawson pretests are (semi-)independent predictors

Top-quartile grades



Bottom-quartile grades

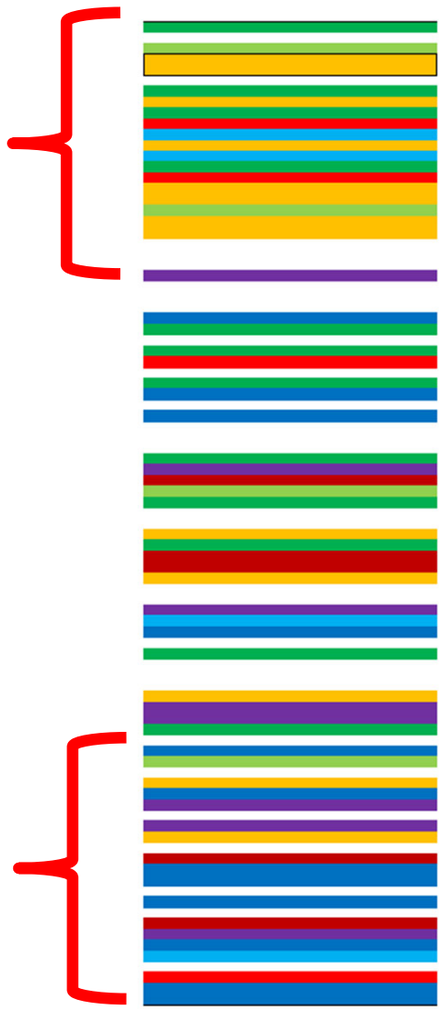
52% are bottom quartile in Math, Lawson, or both *without* compensating high score

High Lawson Only
High Math Only
High Lawson and Low Math
High Math and Low Lawson
High Lawson and High Math
No Highs and No Lows
Low Lawson Only
Low Math Only
Low Lawson and Low Math

Math and Lawson pretests are (semi-)independent predictors

Top-quartile grades

Bottom-quartile grades

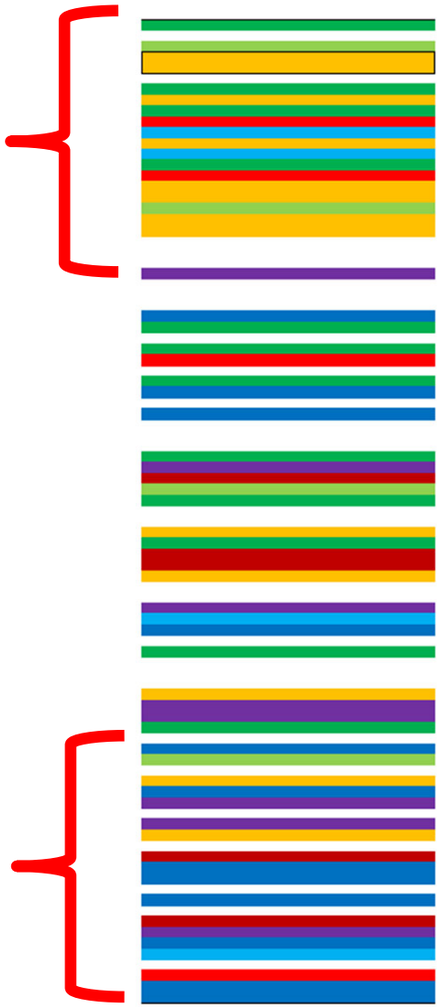


0% low Math or Lawson without compensating high score

Math and Lawson pretests are (semi-)independent predictors

Top-quartile grades

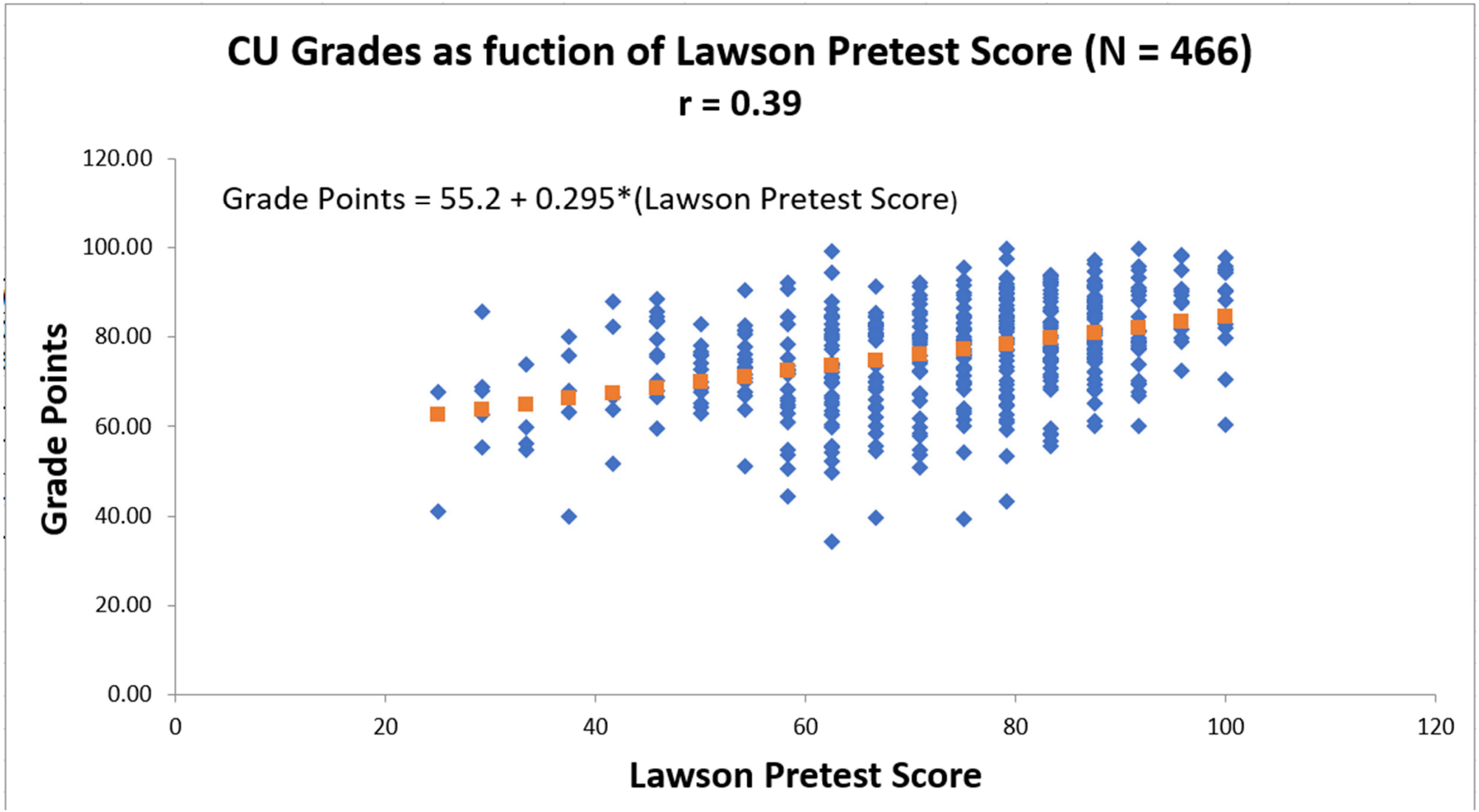
Bottom-quartile grades



Only 22% with Lawson and/or Math high (regardless of compensation)

Grades vs. Predictors: An example

CU Grades = 0.2945*Lawson Pre



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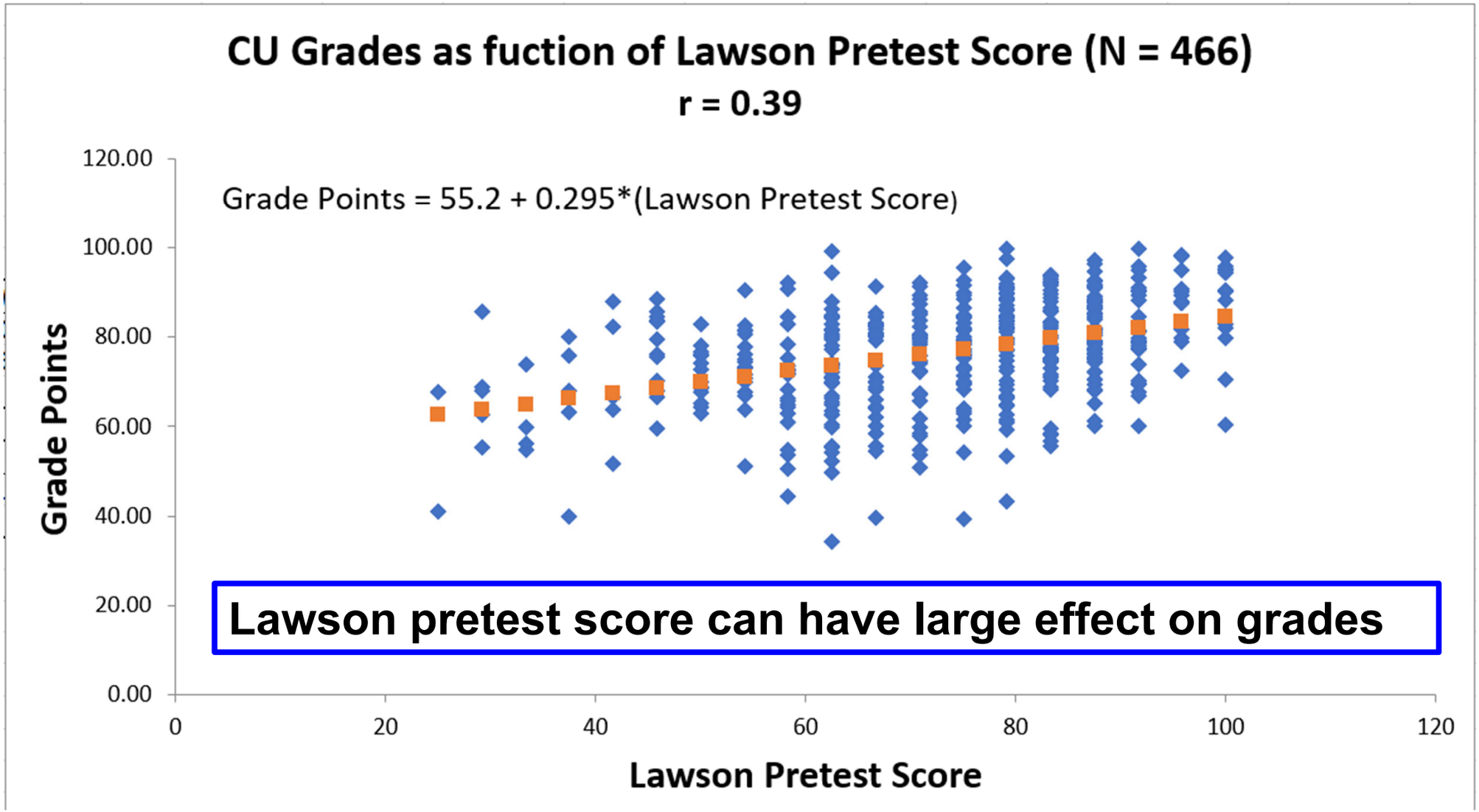

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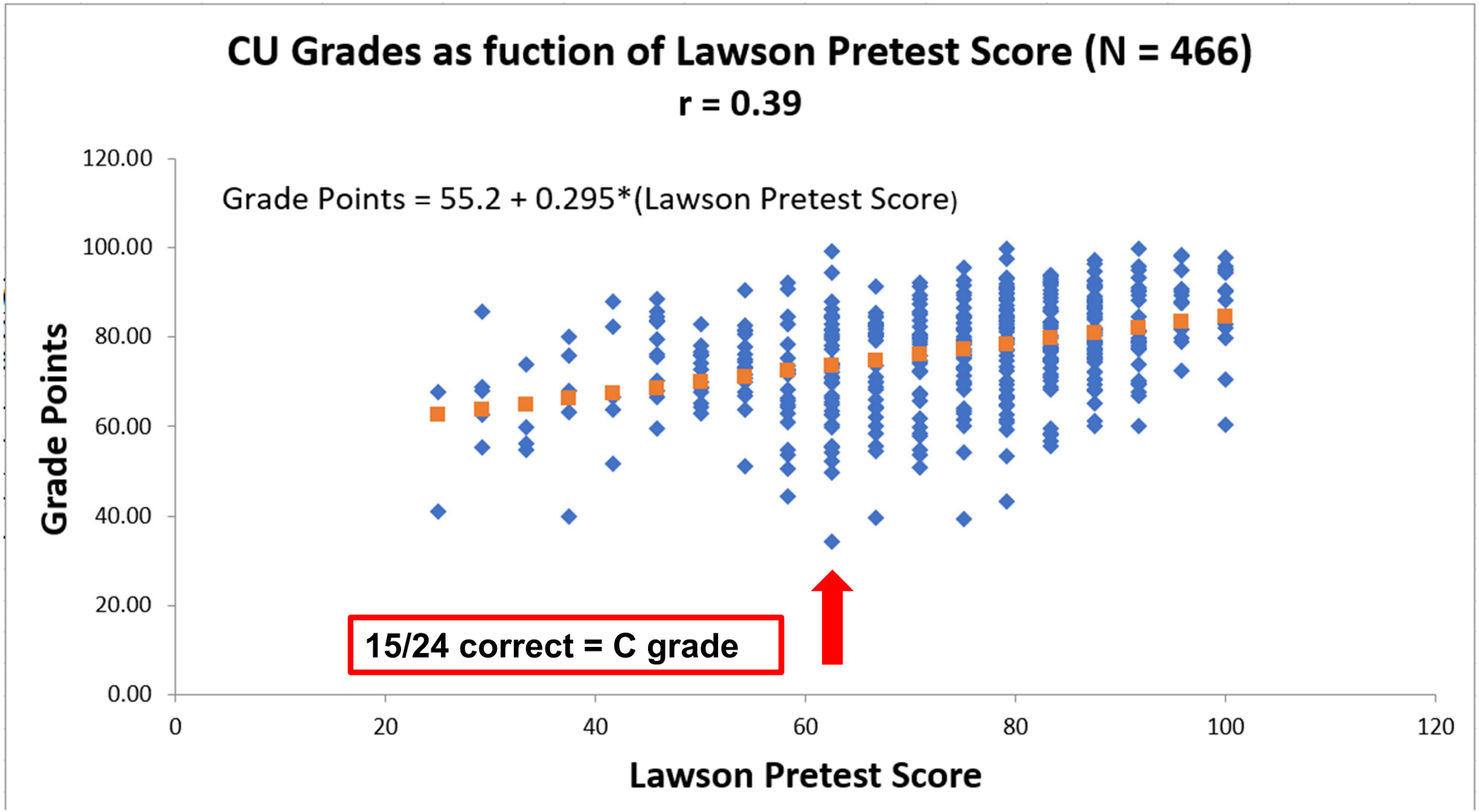

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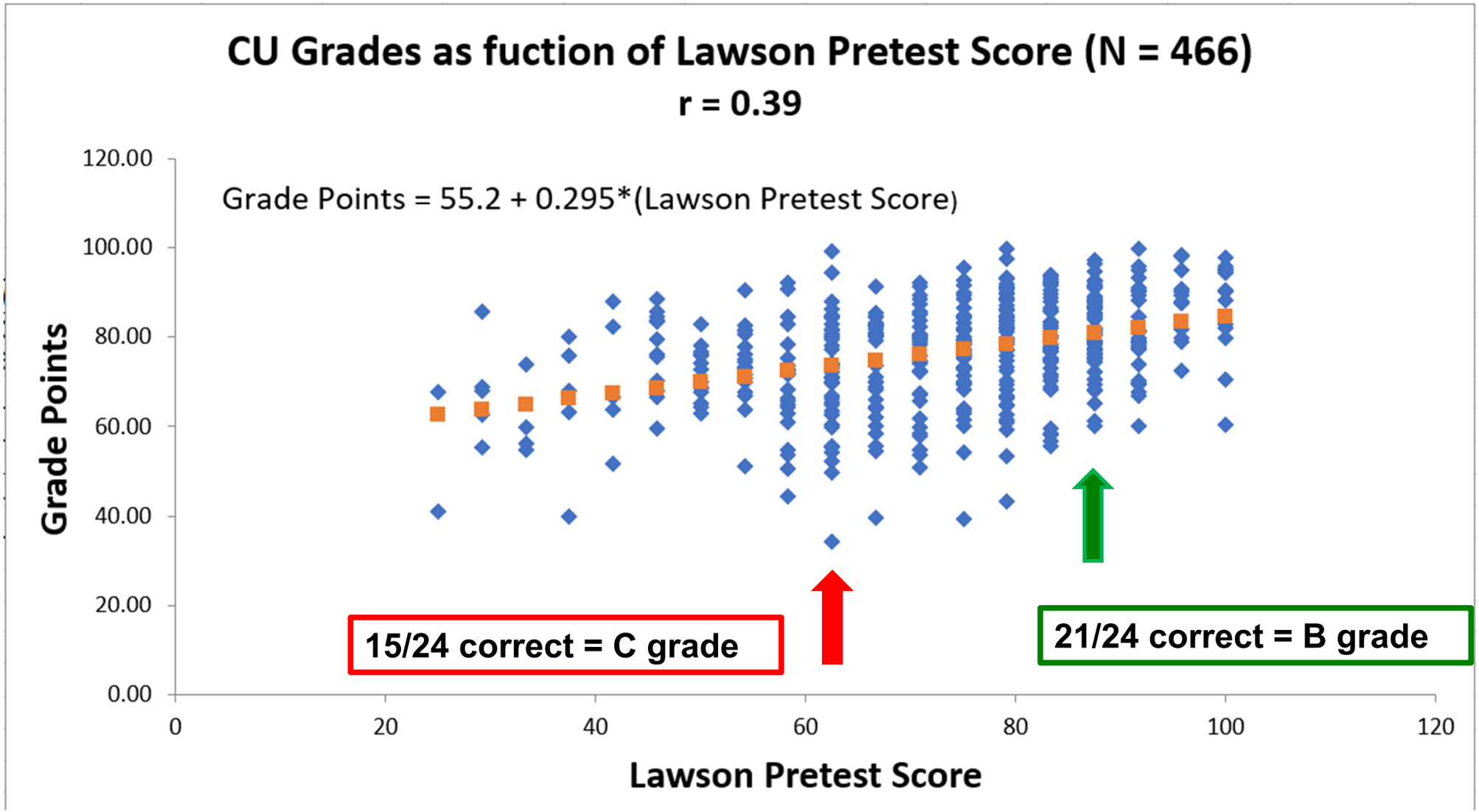

CU Grades = 0.2945*Lawson Pre

CU Grades = 0.2945*Lawson Pre = 0.08 FCI Pretest + 0.2642 Lawson Pretest

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Model: $\text{Grade Points} = 54.5979 + 0.081 \cdot \text{FCI Pretest} + 0.2642 \cdot \text{Lawson Pretest}$

Predictor	Coefficient	Estimate	Standard Error	t-statistic	p-value
Constant	β_0	54.5979	2.4001	22.7483	0
FCI Pretest	β_1	0.081	0.0353	2.2932	0.0223
Lawson Pretest	β_2	0.2642	0.0345	7.6618	0

Summary of Overall Fit

R-Squared:	r^2 =0.1633
Adjusted R-Squared:	r^2_{adj} =0.1597
Residual Standard Error:	10.7308 on 463 degrees of freedom.
Overall F-statistic:	45.1936 on 2 and 463 degrees of freedom.
Overall p-value:	0

CU Grades = 0.2945*Lawson Pre = 0.08 FCI Pretest + 0.2642 Lawson Pretest

Model: $\text{Grade Points} = 54.5979 + 0.081 \cdot \text{FCI Pretest} + 0.2642 \cdot \text{Lawson Pretest}$

Predictor	Coefficient	Estimate	Standard Error	t-statistic	p-value
Constant	β_0	54.5979	2.4001	22.7483	0
FCI Pretest	β_1	0.081	0.0353	2.2932	0.0223
Lawson Pretest	β_2	0.2642	0.0345	7.6618	0

In this class, the Lawson score had the larger influence on grades

Summary of Overall Fit

R-Squared:	r^2 =0.1633
Adjusted R-Squared:	r^2_{adj} =0.1597
Residual Standard Error:	10.7308 on 463 degrees of freedom.
Overall F-statistic:	45.1936 on 2 and 463 degrees of freedom.
Overall p-value:	0

Summary

- Numerous factors influence students' physics course performance
- Previous preparation in calculational skill, reasoning, and physics concept knowledge is important (as well as effort)
- Our results are consistent with findings reported by:
  - L. Ding, PRPER **10,** 023101 (2014)]
  - Salehi et al., PRPER **15**, 020114 (2019)
  - Stewart et al., PRPER **17**, 010107 (2021)