Utility of pre-instruction diagnostic tests for estimating probabilities of final course grades in introductory physics

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Supported in part by NSF DUE #1504986 and #1914712

Acknowledgments

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

  Vince Coletta (Loyola Marymount University)

  Steven Pollock (University of Colorado, Boulder)

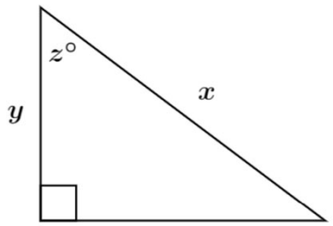
  Christopher Varney (University of West Florida)

Assessment Pretests

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

Mathematics Diagnostic Pretest

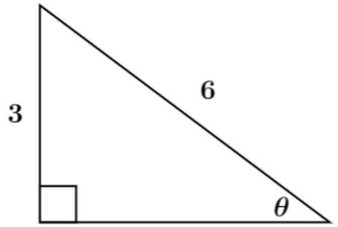
What is the length of side x?



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.

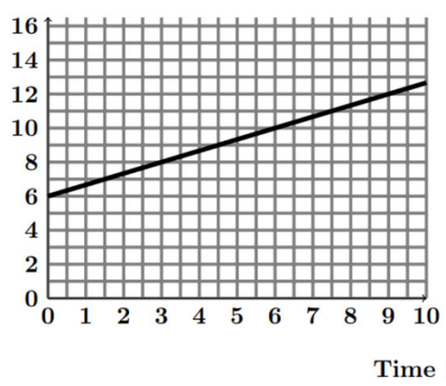
$\gamma\theta + \eta = \lambda\theta + \omega$

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.)

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

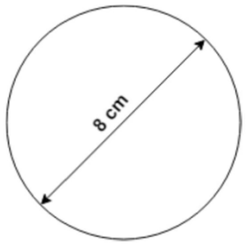
A. $\frac{ac^2}{bd}$ B. $\frac{ad}{bc^2}$ C. $\frac{bd}{ac^2}$ D. $\frac{bc^2}{ad}$

(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. $\frac{3}{4}$

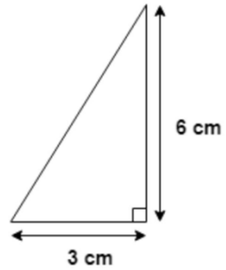
(There may be more than one correct answer, but please select only ONE answer.)



(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.)

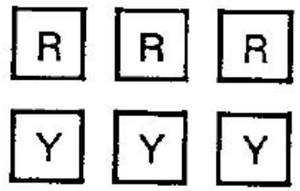
Scientific reasoning skills: The 24-item Lawson test

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

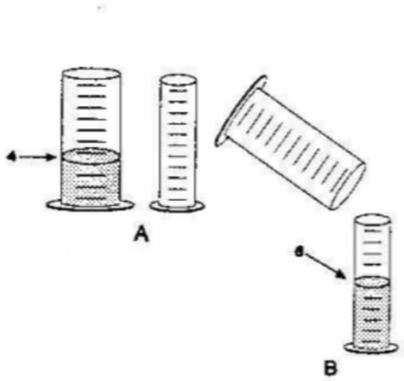
Six square pieces of wood are put into a cloth bag and mixed about. The six pieces are identical in size and shape, however, three pieces are red and three are yellow. Suppose someone reaches into the bag (without looking) and pulls out one piece. *What are the chances that the piece is red?*



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).

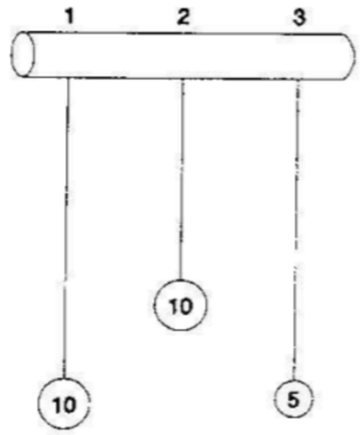


Both cylinders are emptied (not shown) and water is poured into the wide cylinder up to the 6th mark. *How high would this water rise if it were poured into the empty narrow cylinder?*

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.

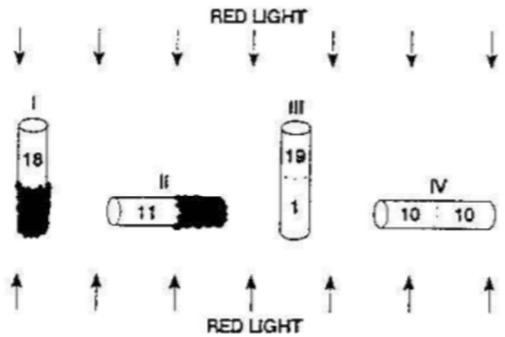


Suppose you want to find out whether the length of the string has an effect on the time it takes to swing back and forth. *Which strings would you use to find out?*

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

Control of variables

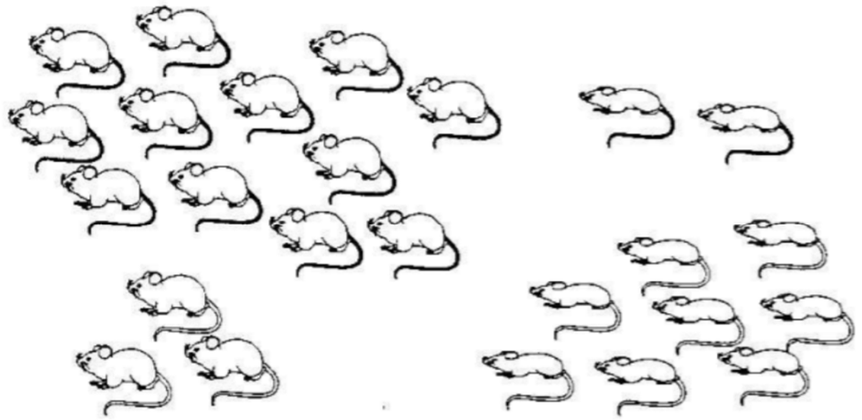
Twenty fruit flies are placed in each of four glass tubes. The tubes are sealed. Tubes I and II are partially covered with black paper; Tubes III and IV are not covered. The tubes are placed as shown. Then they are exposed to red light for five minutes. The number of flies in the uncovered part of each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

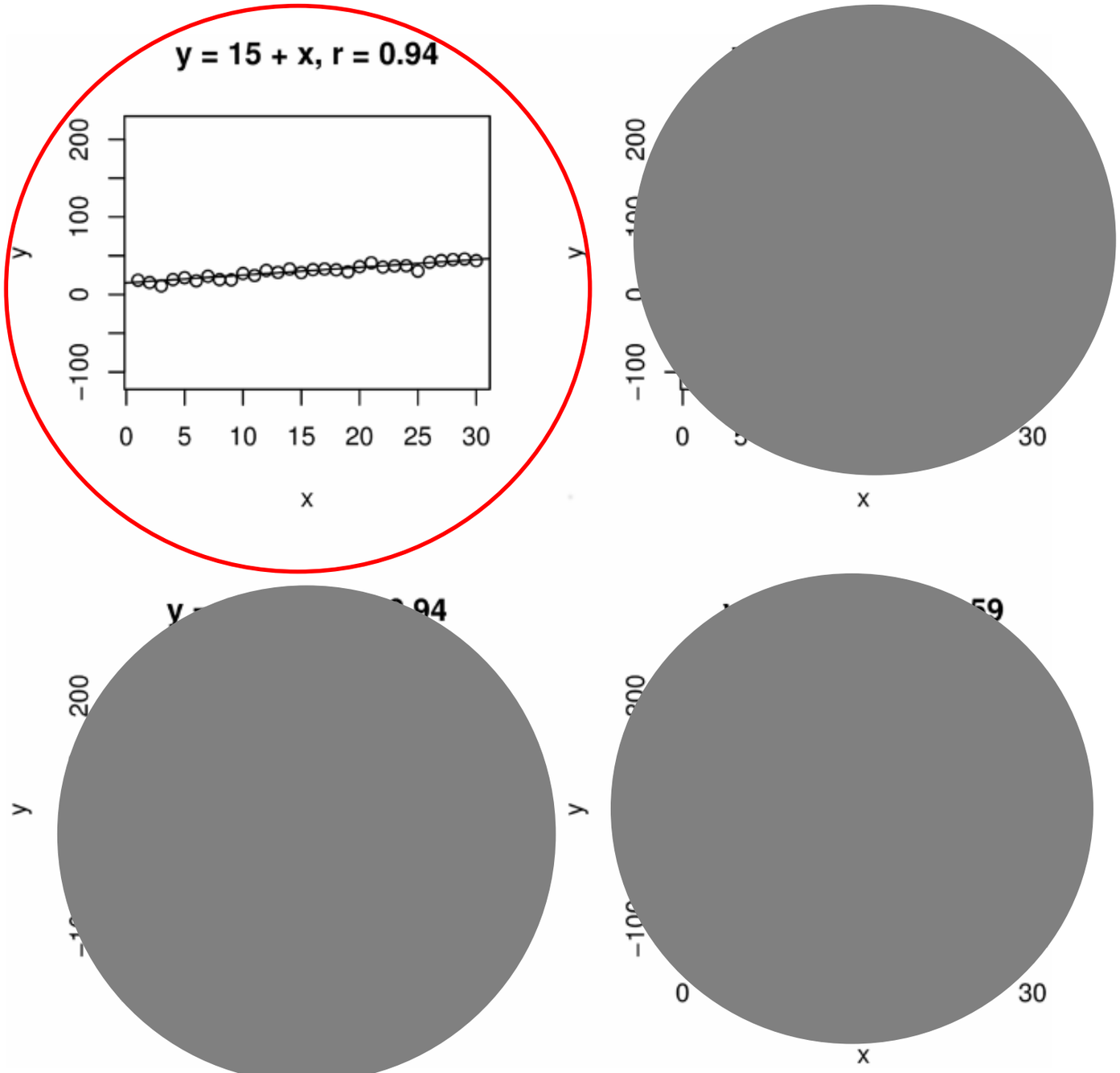
a. appears to be a link
b. appears not to be a link
c. cannot make a reasonable guess

Correlational reasoning

Relation Between Scores and Grades

- Correlation coefficients between pretest scores and final course grades vary greatly from course to course:
  - $r \approx +0.10 - +0.50$.
- However, slopes of fit lines for grades vs. pretest score are relatively high, therefore…
- …pretest scores on diagnostic assessments can approximately predict *probabilities* of final course grades

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



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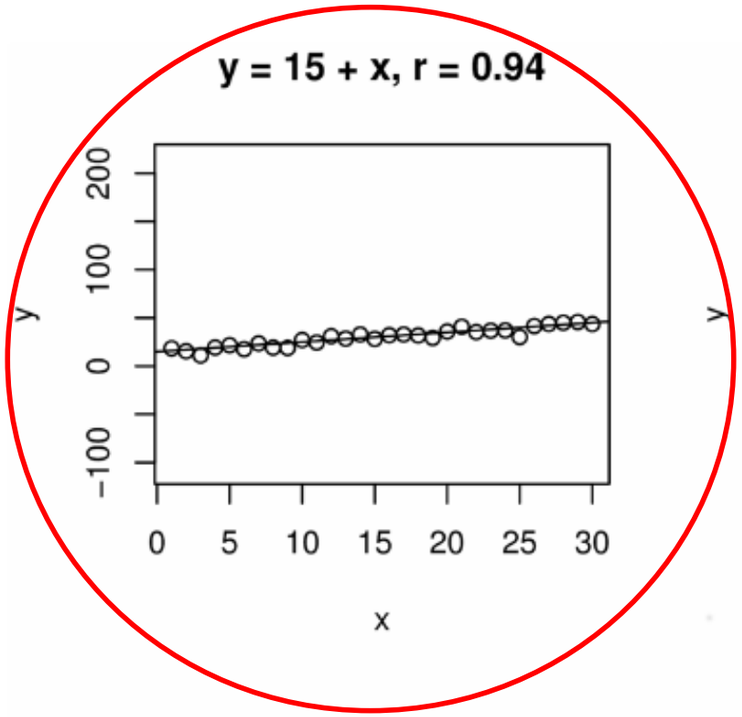

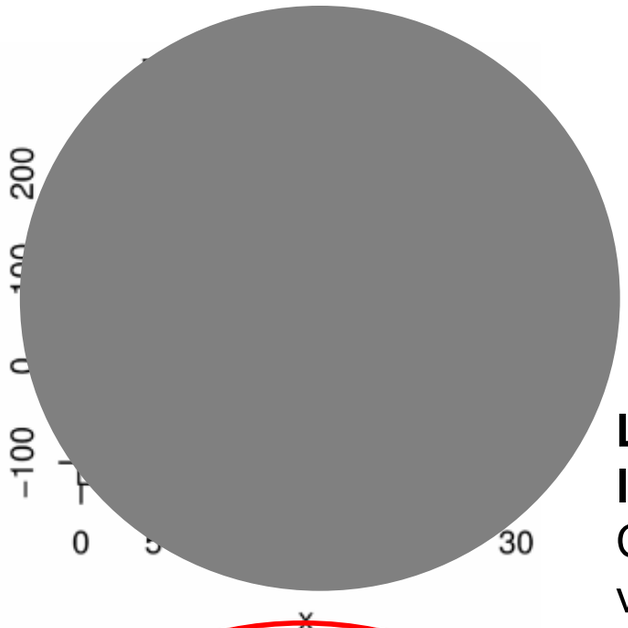

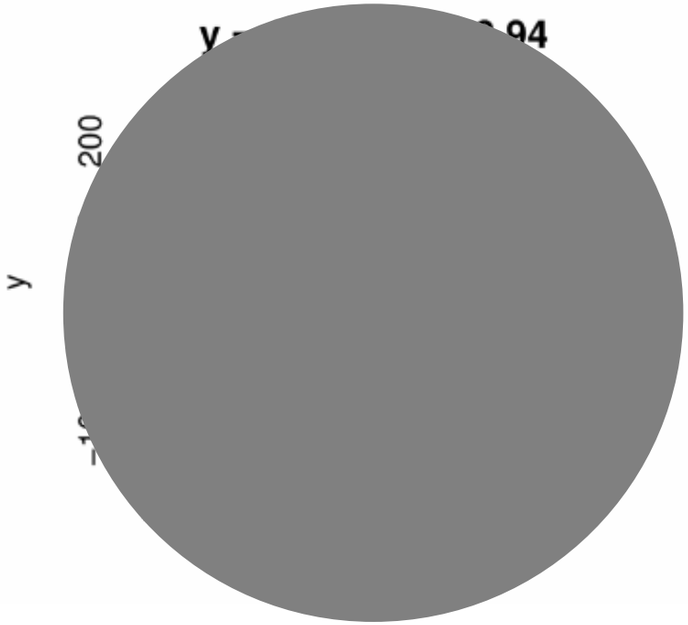

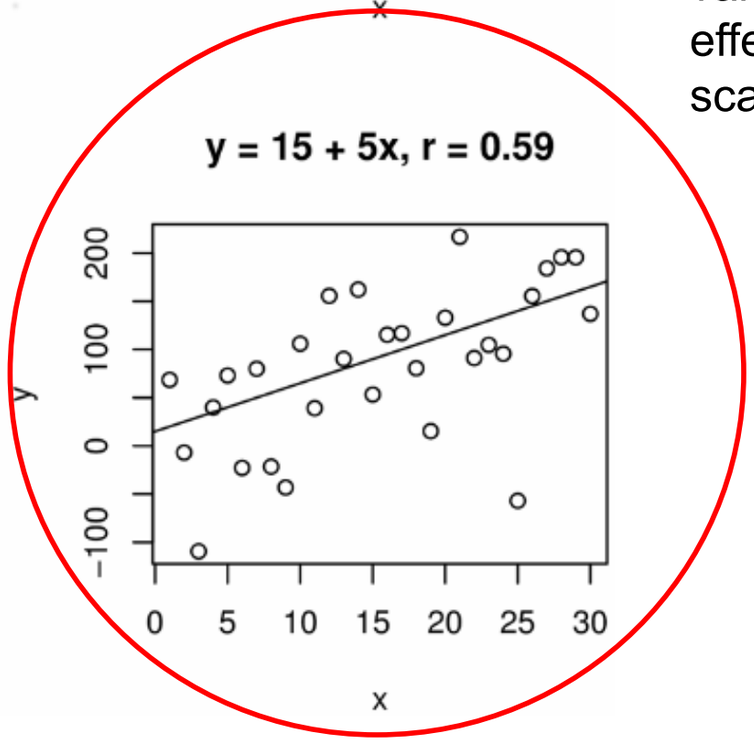

Low correlation, large slope:
Changes in predictor variable have large effect (despite large scatter)

High correlation, small slope:
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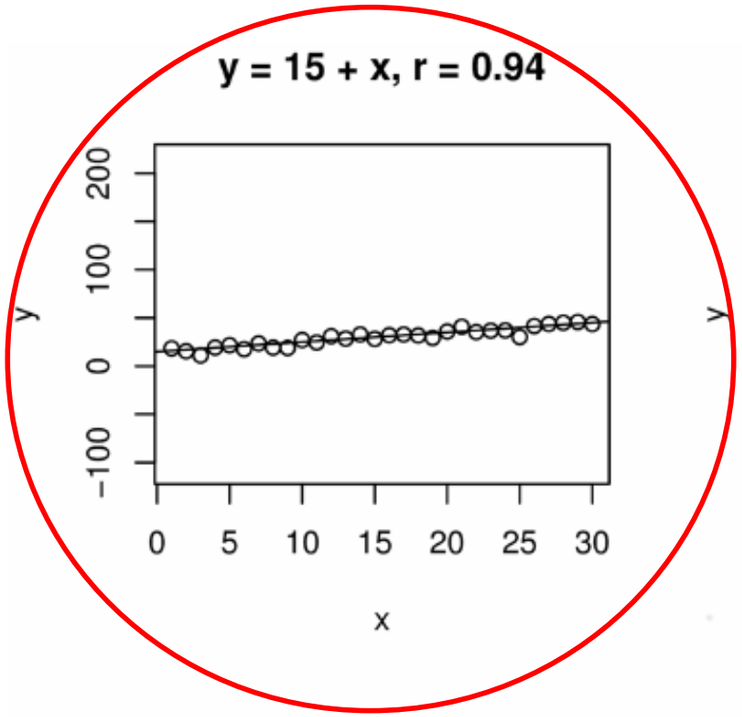

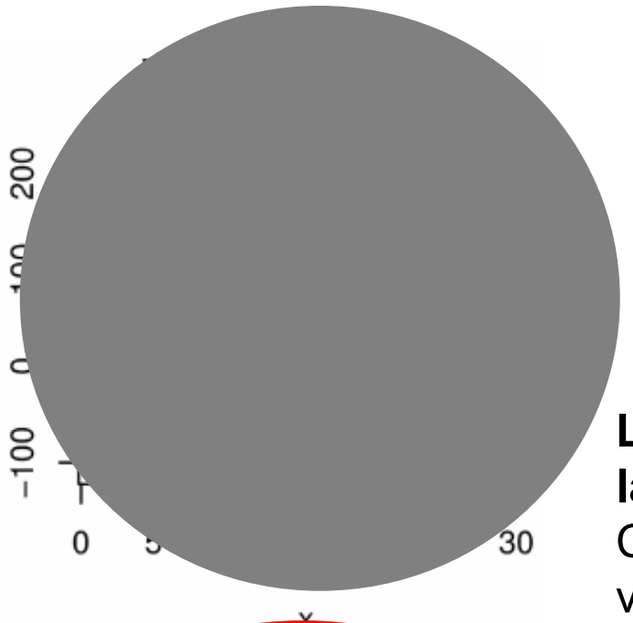

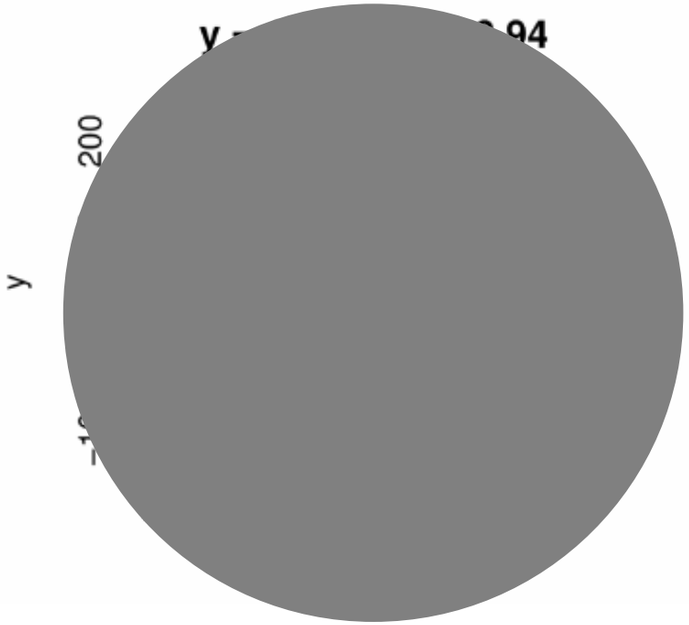

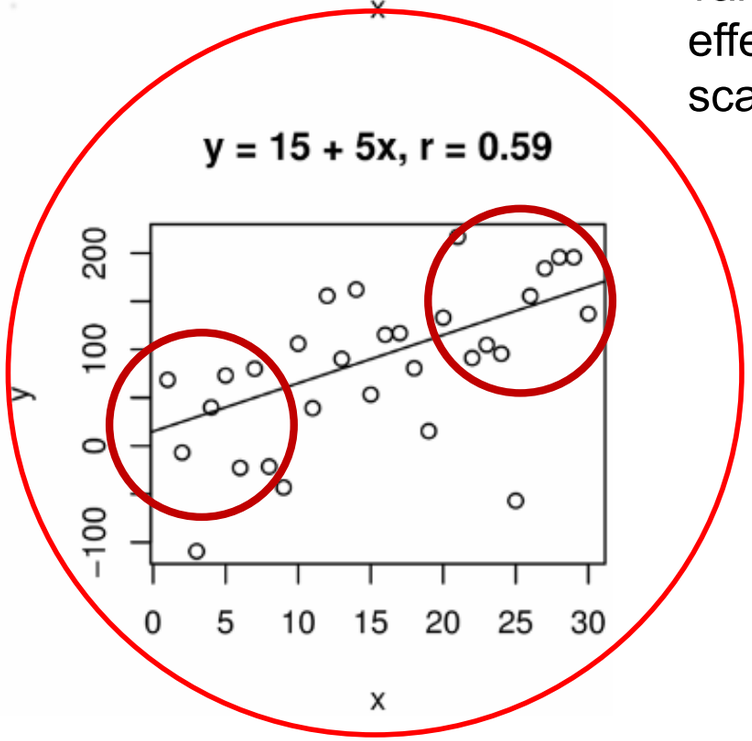

Low correlation, large slope:
Changes in predictor variable have large effect (despite large scatter)

What varies from class to class?

- Specific sets of variables that yield best fit in multivariable linear regressions—there is no universal “best fit” model.

What does not vary from class to class?

- Students with high scores on diagnostic pretests have much higher probability of receiving high grades than students with low pretest scores, and much lower probability of receiving low grades.

What does not vary[1] from class to class?

- Students with high scores on diagnostic pretests have much higher probability of receiving high grades than students with low pretest scores, and much lower probability of receiving low grades.

[1]true in 95% of cases observed

What does not vary[1] from class to class?

- Students with high[2] scores on diagnostic pretests have much higher probability of receiving high[2] grades than students with low pretest scores, and much lower probability of receiving low grades.

[1]true in 95% of cases observed

[2]top quartile in their class

What does not vary[1] from class to class?

- Students with high[2] scores on diagnostic pretests have much[3] higher probability of receiving high[2] grades than students with low pretest scores, and much[3] lower probability of receiving low grades.

[1]true in 95% of cases observed

[2]top quartile in their class

[3]generally between 200-500%

What does not vary[1] from class to class?

- Students with high[2] scores on diagnostic pretests have much[3] higher probability of receiving high[2] grades than students with low[4] pretest scores, and much[3] lower probability of receiving low[4] grades.

[1]true in 95% of cases observed

[2]top quartile in their class

[3]generally between 200-500%

[4]bottom quartile in their class

Comparing probabilities of high and low grades

- What is the probability of a student with a high score on a pre-instruction assessment getting a high grade in the class?
- How does that compare to a low-scoring student's probability of getting a high grade?
- What is the probability of a student with a high score on a pre-instruction assessment getting a low grade in the class?
- How does that compare to a low-scoring student's probability of getting a low grade?

Sample Description

- 25 introductory physics classes from 4 universities, over 2000 total students
- Instruction in most classes was “non-traditional,” generally highly interactive using research-based instructional materials and methods

Course and Institution Code

Alg-1: Algebra-based course, first semester

Alg-2: Algebra-based course, second semester

Calc-1: Calculus-based course, first semester

Calc-2: Calculus-based course, second semester

ASU-P: Arizona State University, Polytechnic campus

ASU-T: Arizona State University, Tempe campus

LMU: Loyola Marymount University

UWF: University of West Florida

CU: University of Colorado, Boulder

Consistent result:

High (top-quartile) scorers on the diagnostic pretests were much more likely to get ***high*** (top-quartile) grades than were low scorers

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 2021a	ASU-P	39	51%	10%	5.0
Alg-1 2021b	ASU-P	42	44%	10%	4.6
Alg-1 2022a	ASU-P	40	27%	6%	4.4
Alg-1 2022b	ASU-P	52	49%	10%	5.1
Alg-1 2023a	ASU-P	42	39%	10%	4.1
Alg-1 2023b	ASU-P	46	64%	9%	7.3
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 2021a	UWF	53	43%	0%	“∞”
Calc-1 2021b	UWF	42	43%	0%	“∞”
Calc-2 2021	UWF	58	43%	14%	3.1
AVERAGE	**(unweighted)**	**(710)**	**43%**	**12%**	**3.7**

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High scorers on math pretest were 3.7 times more likely to get a high grade than were low scorers

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 2021a	ASU-P	35	46%	23%	2.0
Alg-1 2021b	ASU-P	38	32%	8%	4.0
Alg-1 2022a	ASU-P	41	49%	10%	5.0
Alg-1 2022b	ASU-P	54	57%	10%	5.6
Alg-1 2023a	ASU-P	36	39%	33%	1.2
Alg-1 2023b	ASU-P	44	55%	9%	6.0
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%	“∞”
AVERAGE	**(unweighted)**	**(1530)**	**50%**	**9%**	**5.5**

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

	Campus	*N*	Top-quartile Lawson: % with top-quartile grades	Bottom-quartile Lawson: % with top-quartile grades	High-grade odds ratio
Alg-1 2021	LMU	27	44%	0%	"∞"
AVERAGE	(unweighted)	(1530)	**50%**	**9%**	**5.5**

High scorers on Lawson pretest were 5.5 times more likely to get a high grade than were low scorers

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 2018	ASU-P	48	40%	8%	4.8
Alg-1 2019	ASU-P	63	38%	13%	3.0
Alg-1 2021a	ASU-P	35	57%	0%	“∞”
Alg-1 2021b	ASU-P	37	32%	17%	1.9
Alg-1 2022a	ASU-P	41	21%	15%	1.4
Alg-1 2022b	ASU-P	52	26%	7%	3.9
Alg-1 2023a	ASU-P	40	30%	20%	1.3
Alg-1 2023b	ASU-P	47	55%	18%	3.1
Alg-1	CU	470	41%	12%	3.5
Alg-1 2007	LMU	23	87%	0%	“∞”
Alg-1 2009	LMU	51	63%	0%	“∞”
Alg-1 2012	LMU	44	50%	0%	“∞”
Alg-1 2013	LMU	30	51%	0%	“∞”
Alg-1 2014	LMU	33	43%	12%	3.6
Alg-1 2015	LMU	24	67%	0%	“∞”
Alg-1 2016	LMU	34	71%	0%	“∞”
Alg-1 2018	LMU	47	34%	14%	2.4
Alg-1 2021	LMU	27	44%	0%	“∞”
Calc-1 2012	ASU-P	40	43%	0%	“∞”
Calc-1 2013a	ASU-P	18	44%	0%	“∞”
Calc-1 2013b	ASU-P	48	54%	17%	3.3
Calc-1 2021a	UWF	62	29%	26%	1.1
Calc-1 2021b	UWF	53	40%	15%	2.6
AVERAGE	**(unweighted)**	**(1367)**	**46%**	**8%**	**5.4**

High Course Grade vs. FCI

ıpus	*N*	Top-quartile FCI: % with top-quartile grades	Bottom-quartile FCI: % with top-quartile grades	High-grade odds ratio
	48	40%	8%	4.8
		40%	15%	2.8
AVERAGE	(unweighted) (1367)	**46%**	**8%**	**5.4**

High scorers on FCI pretest were 5.4 times more likely to get a high grade than were low scorers

High scorers on Math pretest were 3.7 times more likely to get a high grade than were low scorers

High scorers on Lawson pretest were 5.5 times more likely to get a high grade than were low scorers

High scorers on FCI pretest were 5.4 times more likely to get a high grade than were low scorers

What about probabilities of getting low 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 2021a	ASU-P	39	10%	41%	4.0
Alg-1 2021b	ASU-P	42	16%	48%	3.0
Alg-1 2022a	ASU-P	40	0%	42%	“∞”
Alg-1 2022b	ASU-P	52	26%	29%	1.1
Alg-1 2023a	ASU-P	42	20%	31%	1.5
Alg-1 2023b	ASU-P	46	3%	21%	7.3
Alg-2 2022	ASU-P	75	11%	26%	2.4
Alg-2 2023	ASU-P	92	11%	30%	2.8
Alg-2 2021	ASU-T	129	11%	30%	2.8
Calc-1 2021a	UWF	53	0%	41%	“∞”
Calc-1 2021b	UWF	42	19%	38%	2.0
Calc-2 2021	UWF	58	24%	44%	1.8
AVERAGE	**(unweighted)**	**(710)**	**13%**	**35%**	**2.8**

Low scorers on Math pretest were 2.8 times more likely to get a low grade than were high scorers

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 2021a	ASU-P	35	0%	34%	“∞”
Alg-1 2021b	ASU-P	38	11%	53%	5.0
Alg-1 2022a	ASU-P	41	15%	52%	3.5
Alg-1 2022b	ASU-P	54	15%	28%	1.9
Alg-1 2023a	ASU-P	36	14%	36%	2.6
Alg-1 2023b	ASU-P	44	9%	45%	5.0
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
Calc-2	CU	276	12%	44%	3.8
Alg-1 2007	LMU	24	0%	58%	“∞”
Alg-1 2009	LMU	51	5%	48%	10.4
Alg-1 2011	LMU	57	15%	46%	3.0
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%	“∞”
AVERAGE	**(unweighted)**	**(1530)**	**10%**	**45%**	**4.6**

Low scorers on Lawson pretest were 4.6 times more likely to get a low grade than were high scorers

Low Course Grade vs. FCI

Course	Campus	*N*	Top-quartile FCI: % with bottom-quartile grades	Bottom-quartile FCI: % with bottom-quartile grades	Low-grade odds ratio
Alg-1 2018	ASU-P	48	21%	50%	2.4
Alg-1 2019	ASU-P	63	6%	47%	7.4
Alg-1 2021a	ASU-P	35	0%	56%	“∞”
Alg-1 2021b	ASU-P	37	11%	43%	4.0
Alg-1 2022a	ASU-P	41	21%	39%	1.9
Alg-1 2022b	ASU-P	52	18%	33%	1.8
Alg-1 2023a	ASU-P	40	20%	37%	1.8
Alg-1 2023b	ASU-P	47	9%	43%	5.1
Alg-1	CU	470	19%	22%	1.1
Alg-1 2007	LMU	23	0%	52%	“∞”
Alg-1 2009	LMU	51	8%	47%	6.0
Alg-1 2012	LMU	44	9%	50%	5.4
Alg-1 2013	LMU	30	24%	37%	1.5
Alg-1 2014	LMU	33	7%	32%	4.7
Alg-1 2015	LMU	24	0%	67%	“∞”
Alg-1 2016	LMU	34	12%	47%	4.0
Alg-1 2018	LMU	47	15%	31%	2.2
Alg-1 2021	LMU	27	0%	44%	“∞”
Calc-1 2012	ASU-P	40	10%	43%	4.3
Calc-1 2013a	ASU-P	18	0%	44%	“∞”
Calc-1 2013b	ASU-P	48	17%	8%	0.5
Calc-1 2021a	UWF	62	13%	40%	3.1
Calc-1 2021b	UWF	53	8%	25%	3.3
AVERAGE	**(unweighted)**	**(1367)**	**11%**	**41%**	**3.8**

Low scorers on FCI pretest were 3.8 times more likely to get a low grade than were high scorers

Consistent result:

Low (bottom-quartile) scorers on the diagnostic pretests were much more likely to get ***low*** (bottom-quartile) grades than were high scorers

High scorers on Math pretest were 3.7 times more likely to get a high grade than were low scorers

High scorers on Lawson pretest were 5.5 times more likely to get a high grade than were low scorers

High scorers on FCI pretest were 5.4 times more likely to get a high grade than were low scorers

Low scorers on Math pretest were 2.8 times more likely to get a low grade than were high scorers

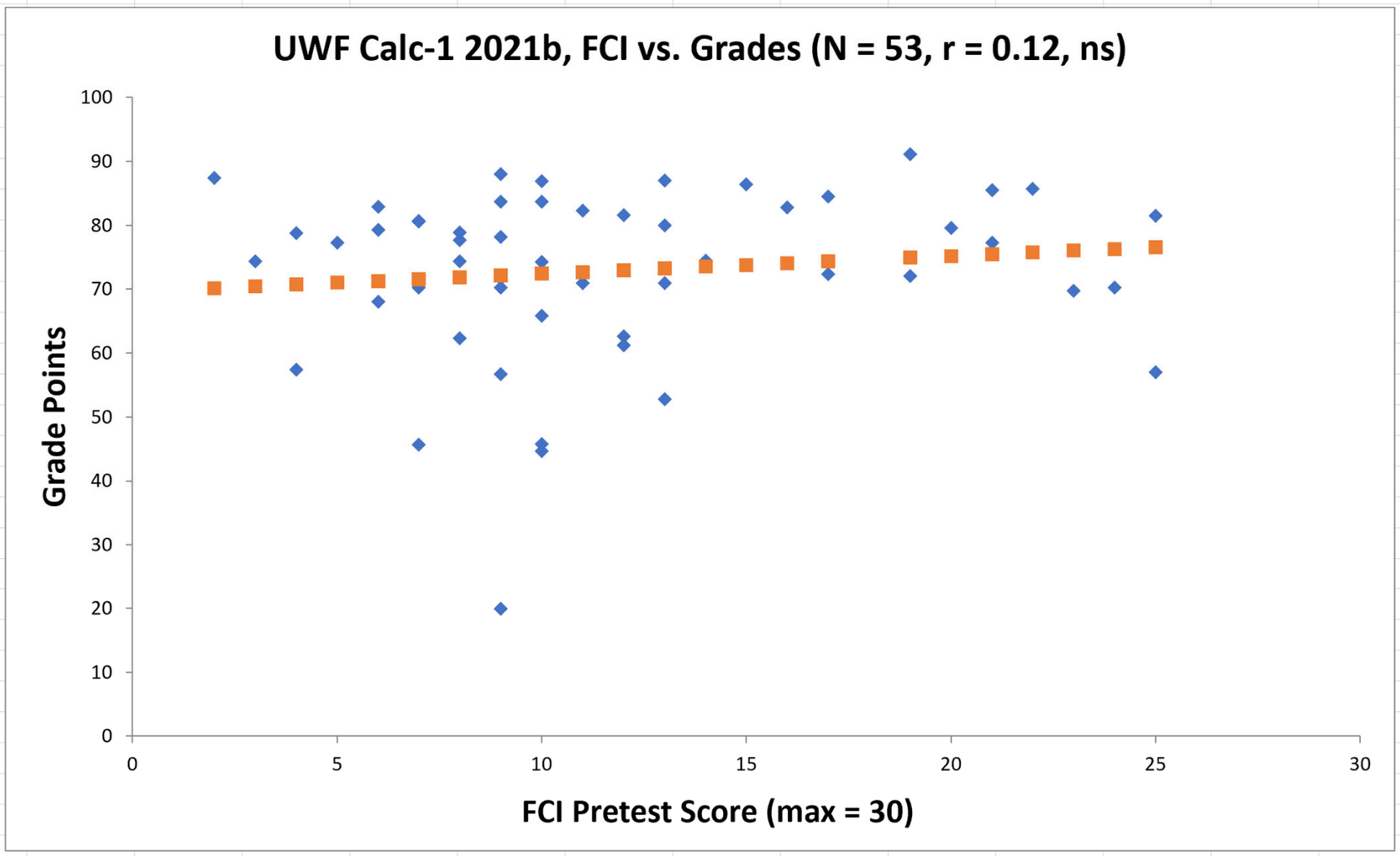
Low scorers on Lawson pretest were 4.6 times more likely to get a low grade than were high scorers

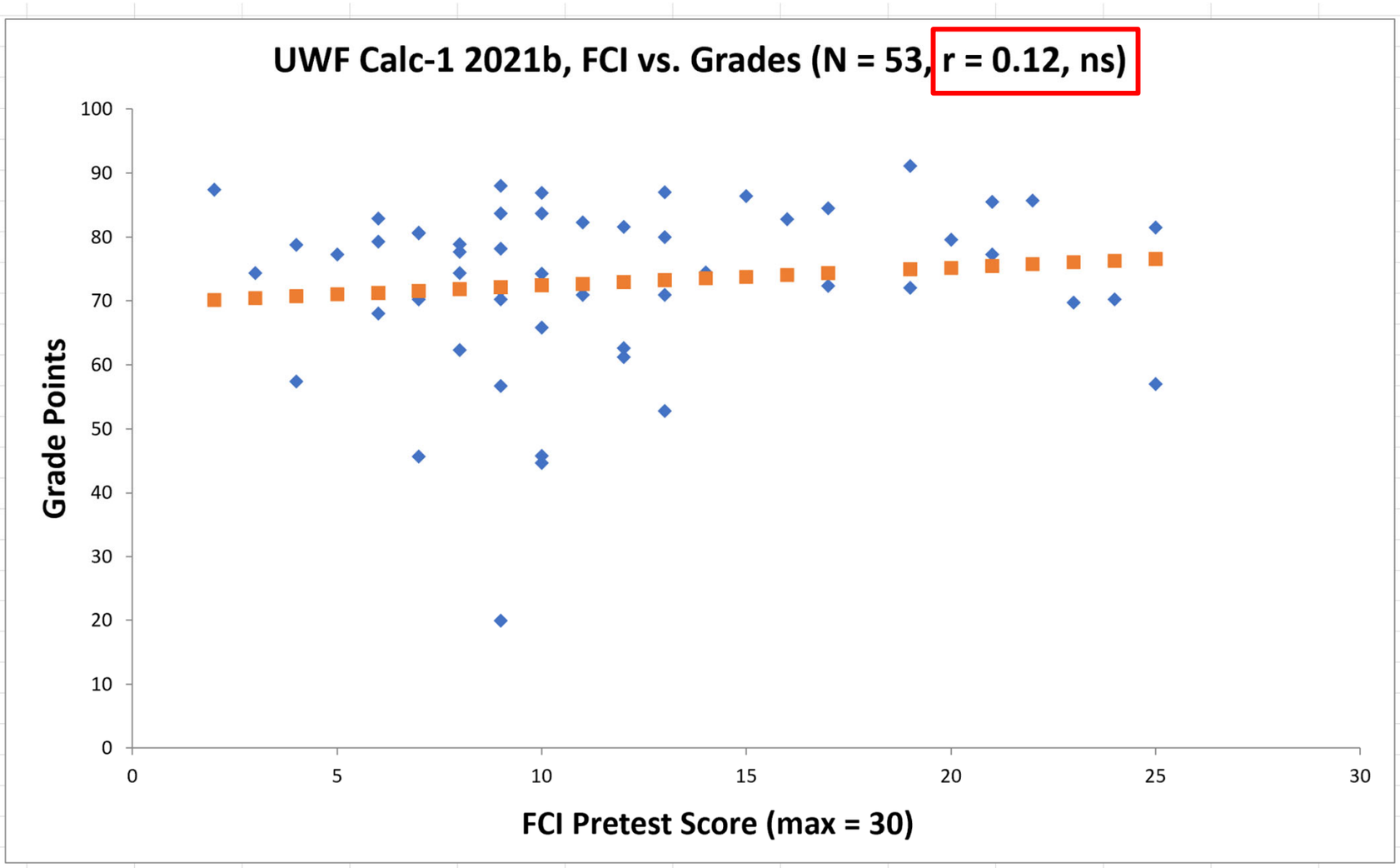
Low scorers on FCI pretest were 3.8 times more likely to get a low grade than were high scorers

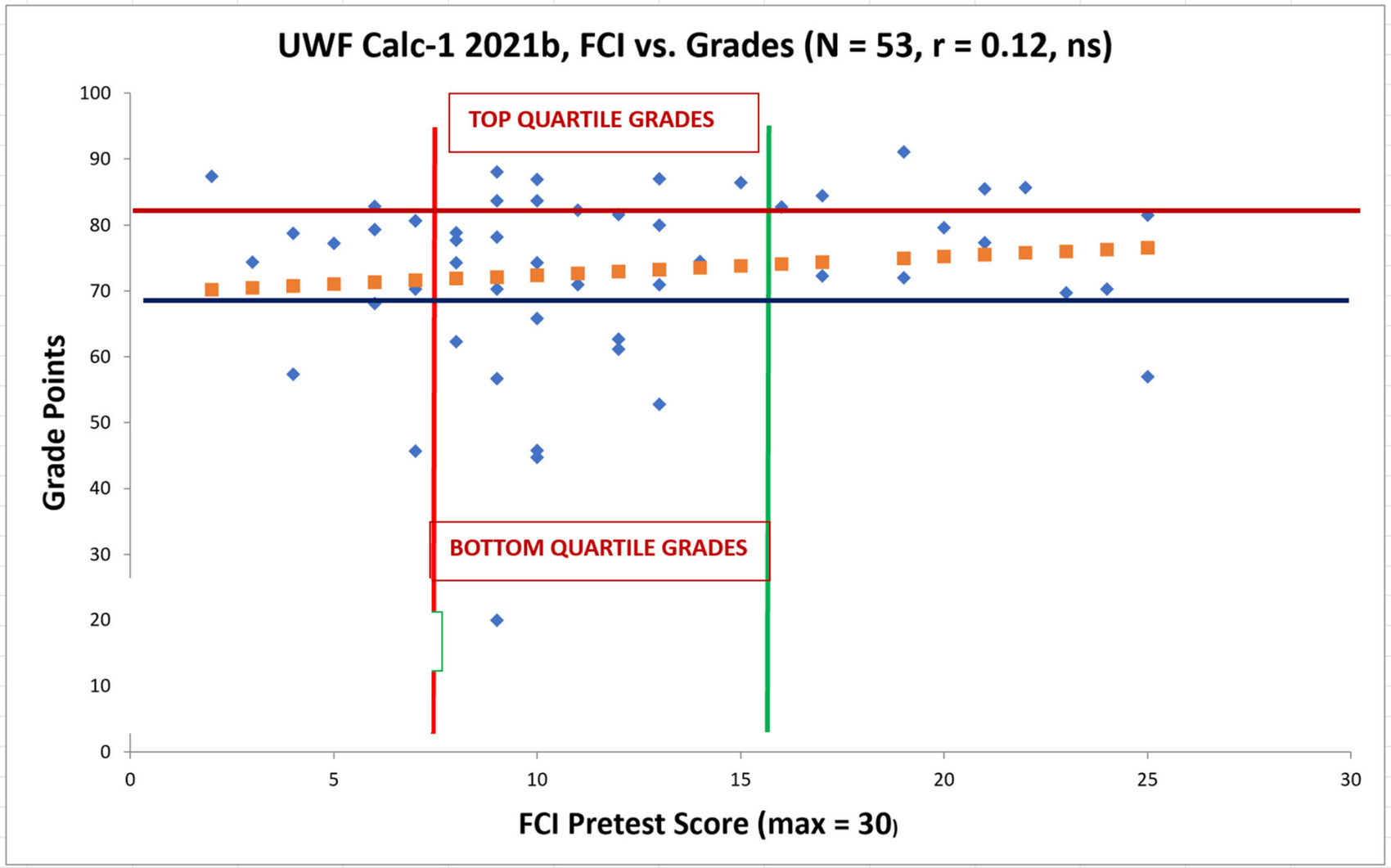
High and low grades for high and low scorers were compared in 12 classes for the math diagnostic, 20 classes for the Lawson pretest, and 23 classes for the FCI, a total of 110 high/low comparisons. ***The quartile ratios were greater than 1.0 in 107 of the 110 cases (97%)***.

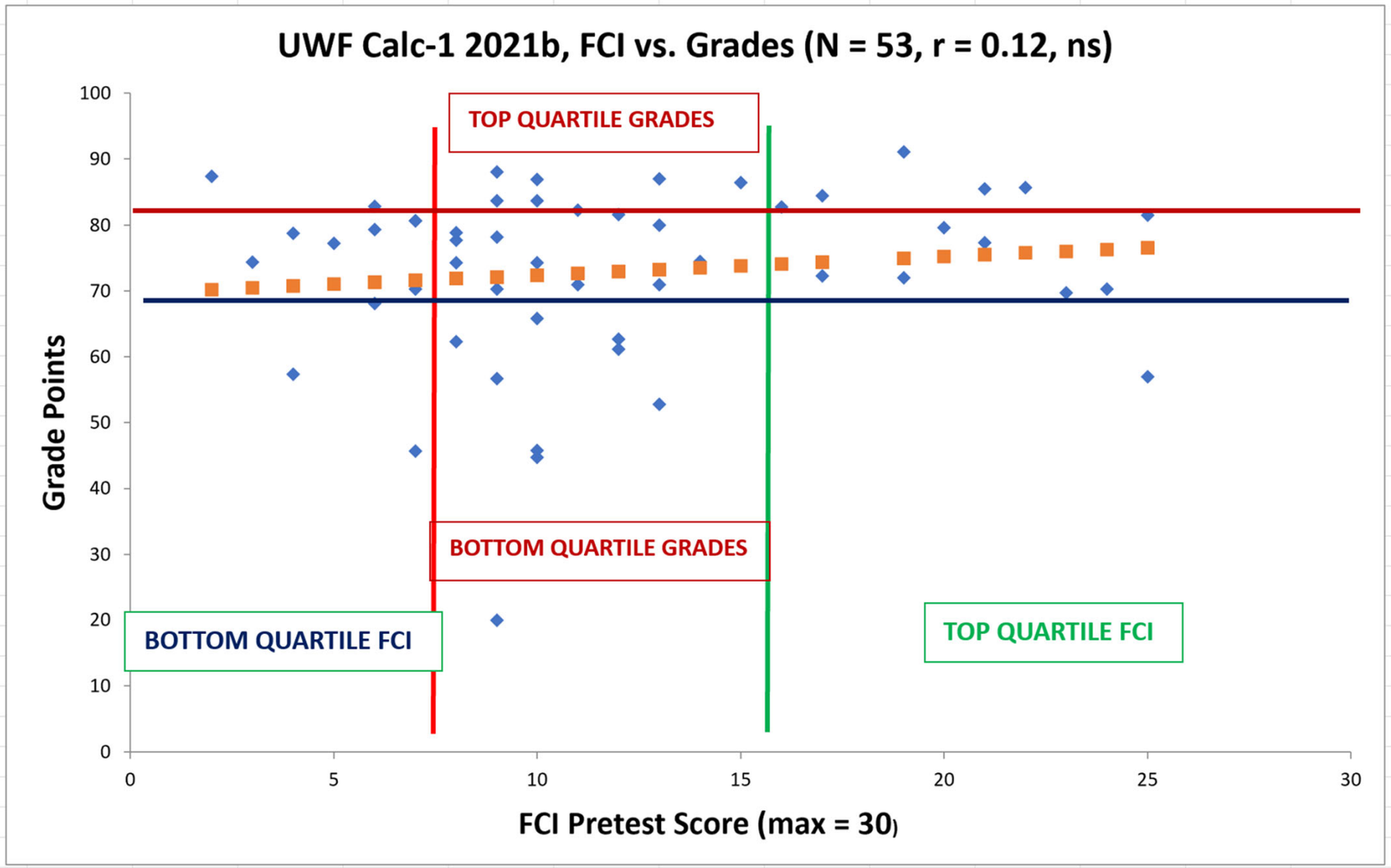
Regression analysis can be misleading

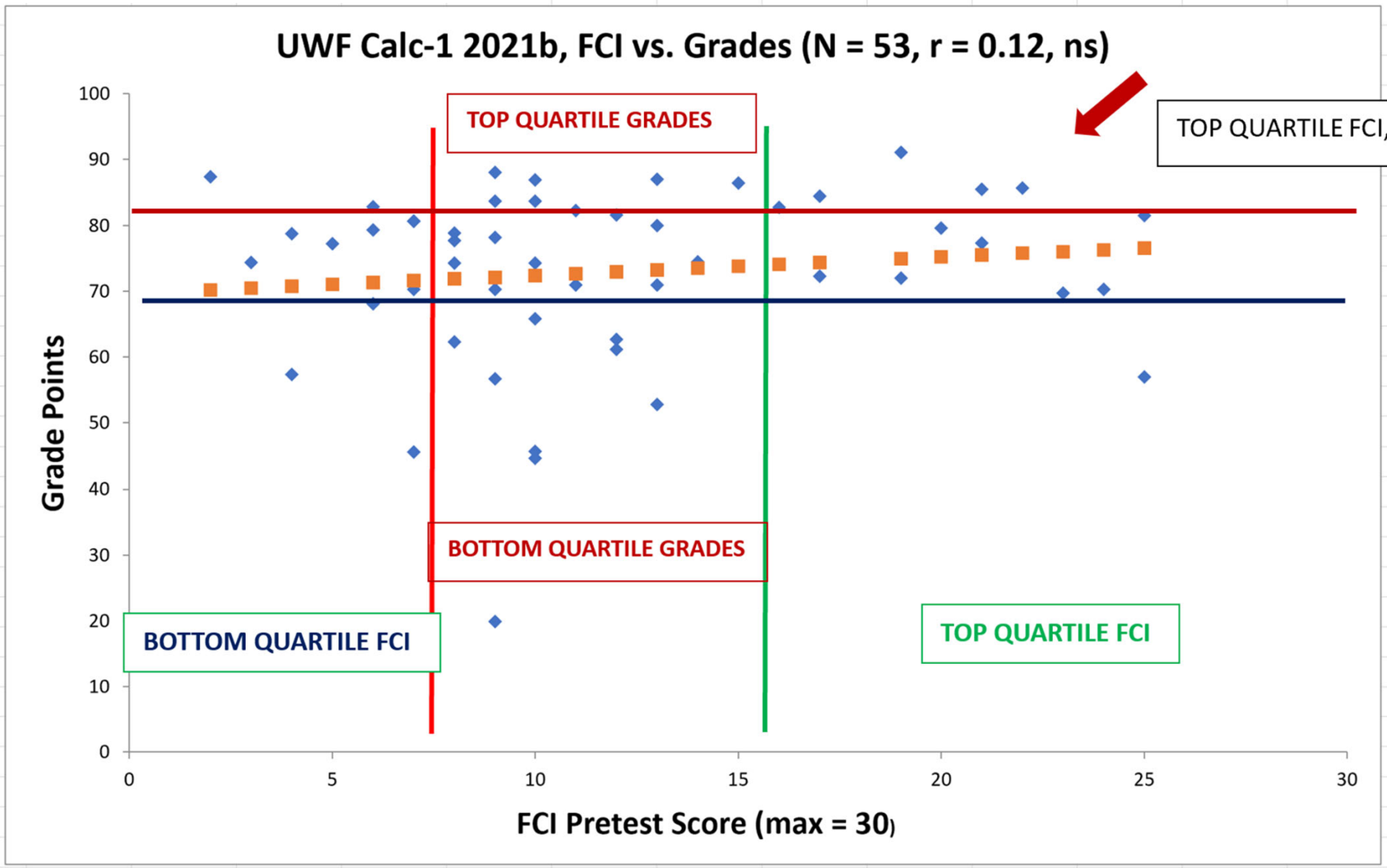
- High scatter in the data leads to relatively low correlation
- However, quartile comparison can reveal highly significant differences between low and high scorers


UWF Calc-1 2021b, FCI vs. Grades (N = 53, r = 0.12, ns)
Grade Points
100
90
80
70
60
50
40
30
20
10
0
0
5
10
15
20
25
30
FCI Pretest Score (max = 30)

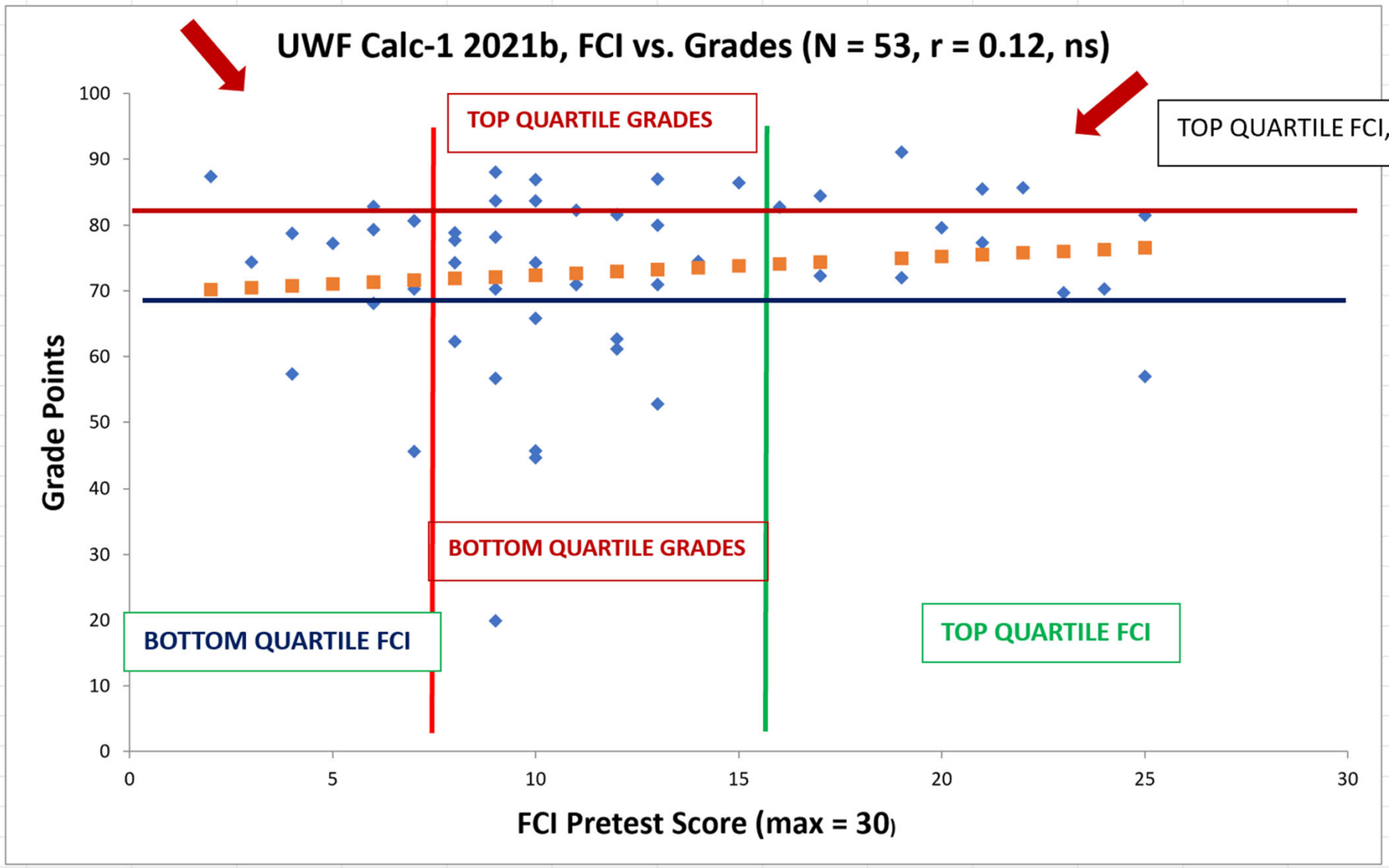

UWF Calc-1 2021b, FCI vs. Grades (N = 53, r = 0.12, ns)
Grade Points
100
90
80
70
60
50
40
30
20
10
0
0
5
10
15
20
25
30
FCI Pretest Score (max = 30)


UWF Calc-1 2021b, FCI vs. Grades (N = 53, r = 0.12, ns)
TOP QUARTILE GRADES
BOTTOM QUARTILE GRADES
Grade Points
FCI Pretest Score (max = 30)
0
10
20
30
40
50
60
70
80
90
100
0
5
10
15
20
25
30

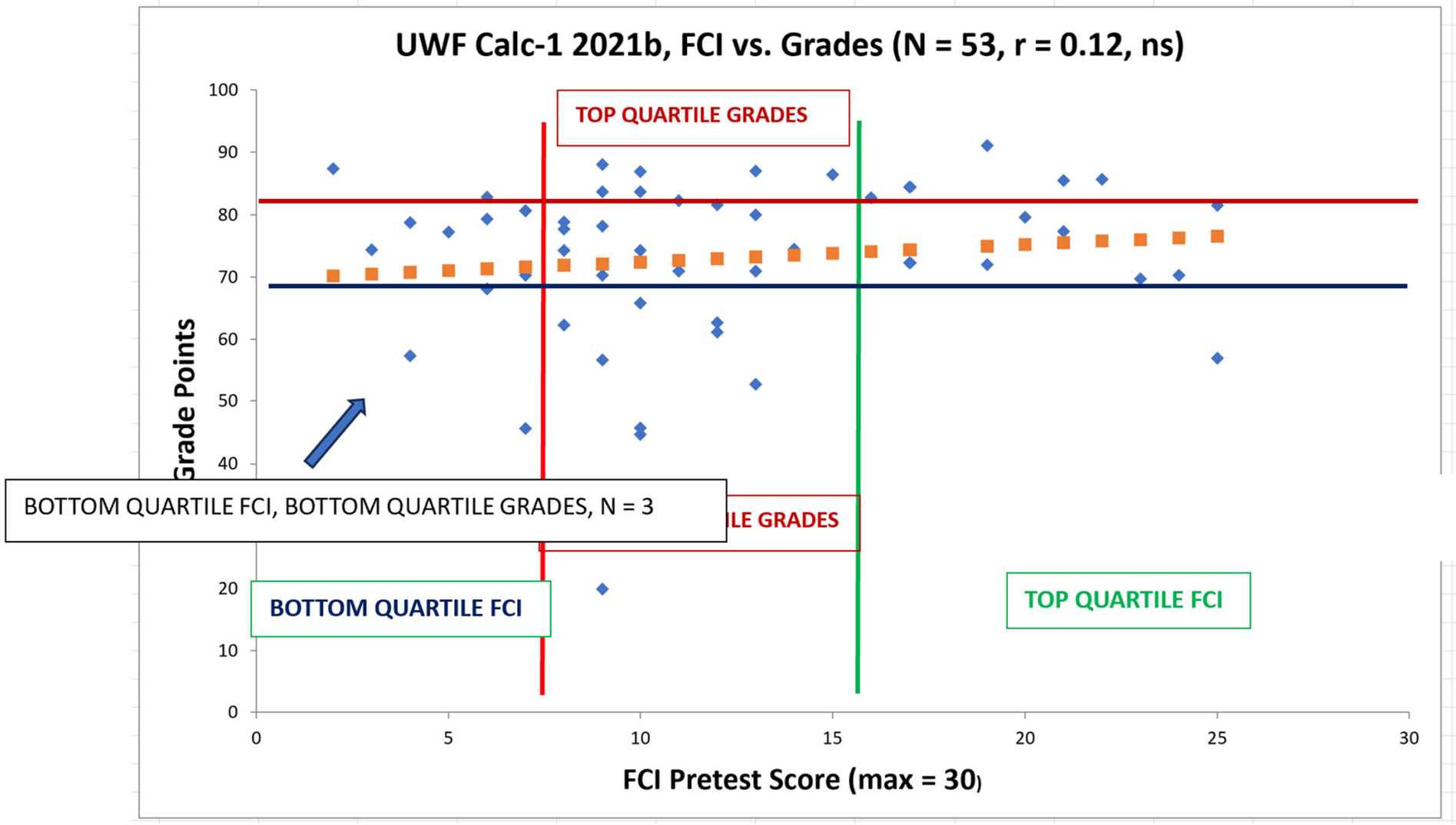

UWF Calc-1 2021b, FCI vs. Grades (N = 53, r = 0.12, ns)
TOP QUARTILE GRADES
BOTTOM QUARTILE GRADES
BOTTOM QUARTILE FCI
TOP QUARTILE FCI
Grade Points
FCI Pretest Score (max = 30)
0
10
20
30
40
50
60
70
80
90
100
0
5
10
15
20
25
30

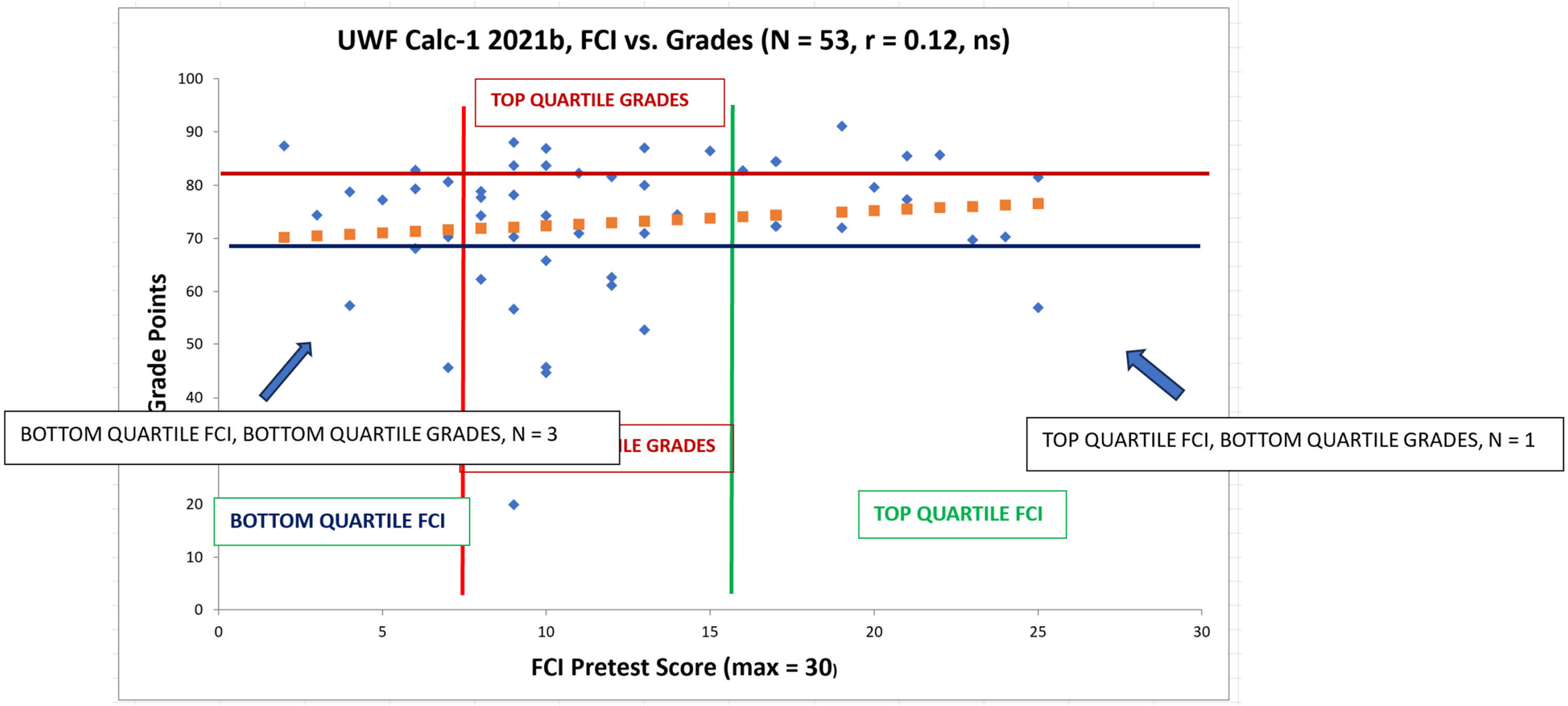

UWF Calc-1 2021b, FCI vs. Grades (N = 53, r = 0.12, ns)
TOP QUARTILE GRADES
BOTTOM QUARTILE GRADES
BOTTOM QUARTILE FCI
TOP QUARTILE FCI
TOP QUARTILE FCI, TOP QUARTILE GRADES, N = 5
Grade Points
FCI Pretest Score (max = 30)
0
10
20
30
40
50
60
70
80
90
100
0
5
10
15
20
25
30

BOTTOM QUARTILE FCI, TOP QUARTILE GRADES, N = 2



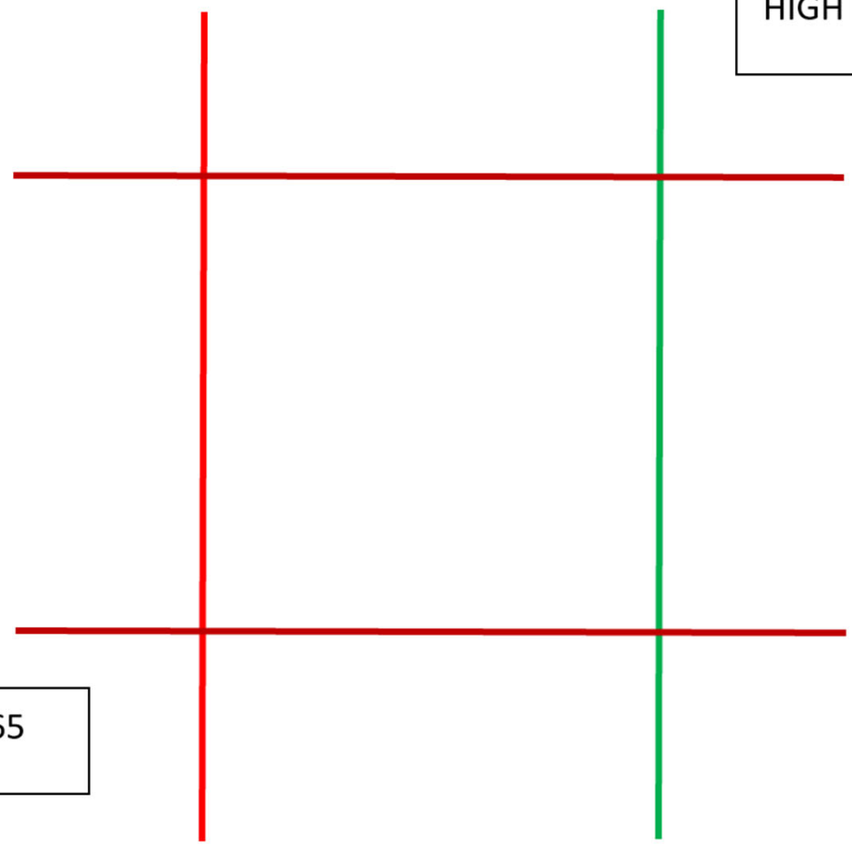
TOP QUARTILE FCI, TOP QUARTILE GRADES, N = 5


UWF Calc-1 2021b, FCI vs. Grades (N = 53, r = 0.12, ns)
TOP QUARTILE GRADES
BOTTOM QUARTILE FCI, BOTTOM QUARTILE GRADES, N = 3
BOTTOM QUARTILE FCI
TOP QUARTILE FCI
Grade Points
FCI Pretest Score (max = 30)
100
90
80
70
60
50
40
20
10
0
0
5
10
15
20
25
30


UWF Calc-1 2021b, FCI vs. Grades (N = 53, r = 0.12, ns)
TOP QUARTILE GRADES
ILE GRADES
BOTTOM QUARTILE FCI
TOP QUARTILE FCI
BOTTOM QUARTILE FCI, BOTTOM QUARTILE GRADES, N = 3
TOP QUARTILE FCI, BOTTOM QUARTILE GRADES, N = 1
Grade Points
FCI Pretest Score (max = 30)
0
10
20
30
40
50
60
70
80
90
100
0
5
10
15
20
25
30

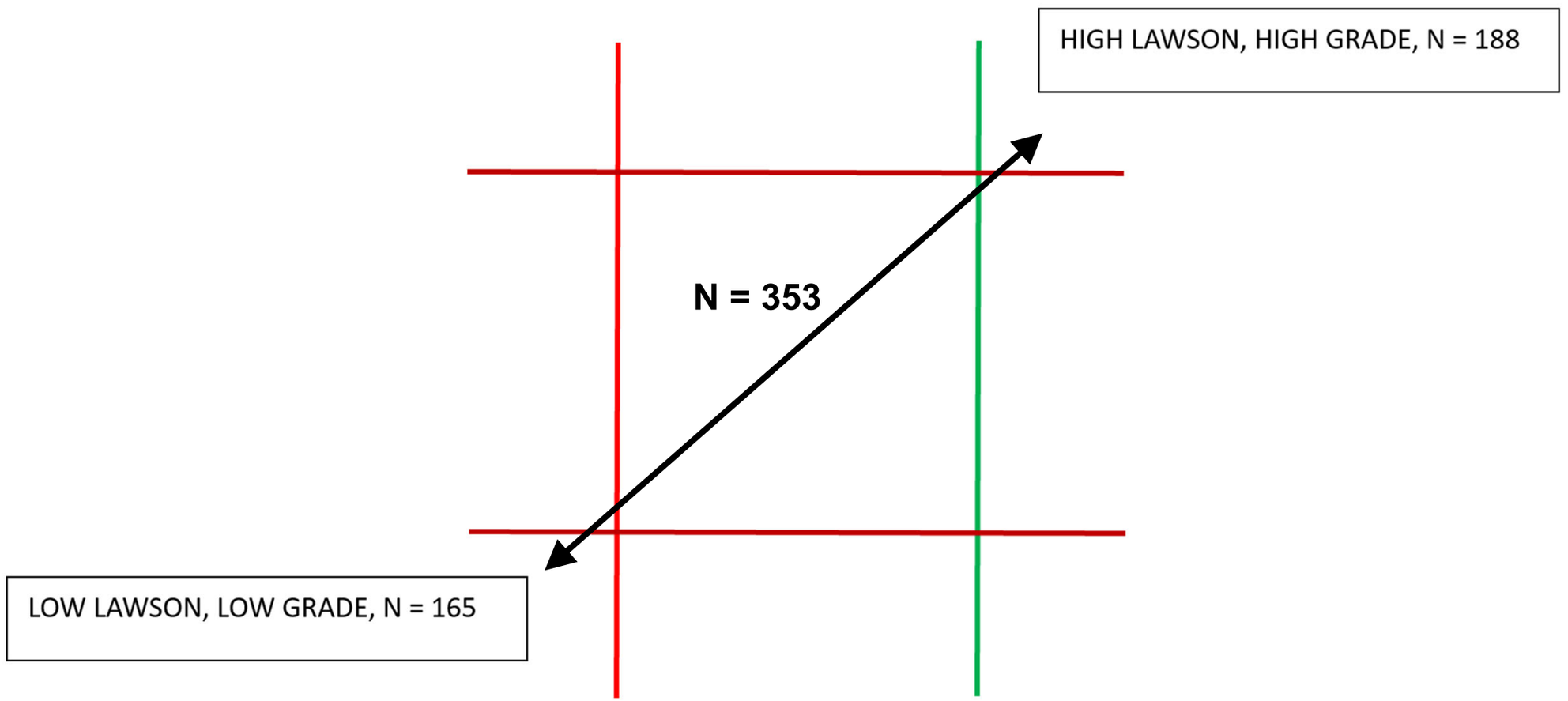
LAWSON PRETEST VS. GRADES, 20 CLASSES COMBINED

HIGH LAWSON, HIGH GRADE, N = 188



LOW LAWSON, LOW GRADE, N = 165

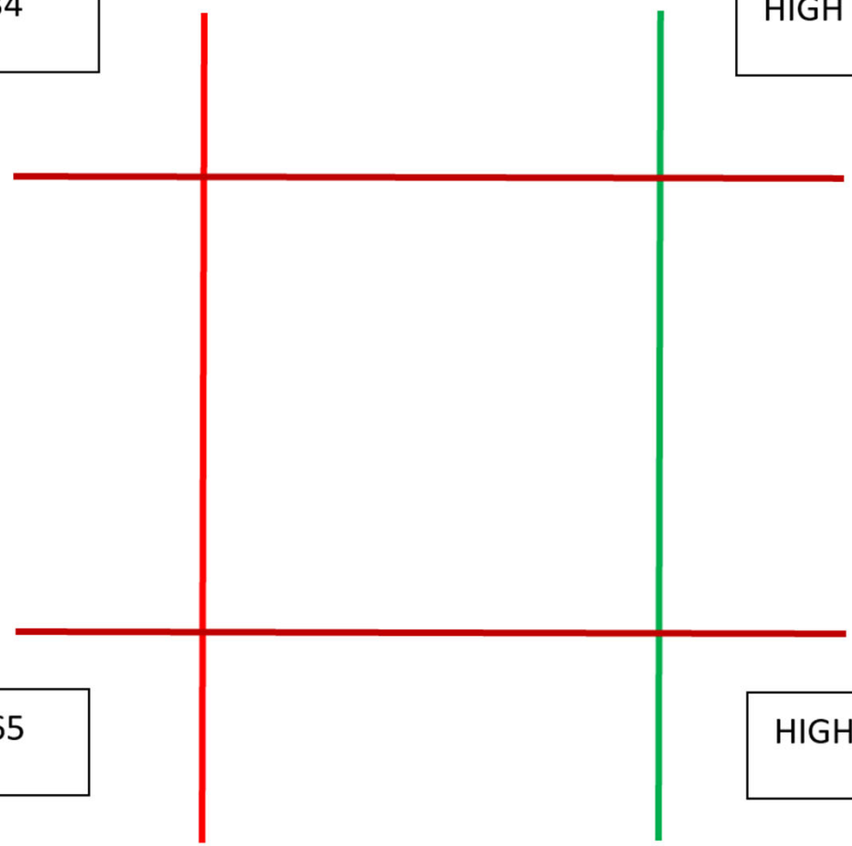
LAWSON PRETEST VS. GRADES, 20 CLASSES COMBINED



LAWSON PRETEST VS. GRADES, 20 CLASSES COMBINED

LOW LAWSON, HIGH GRADE, N = 34

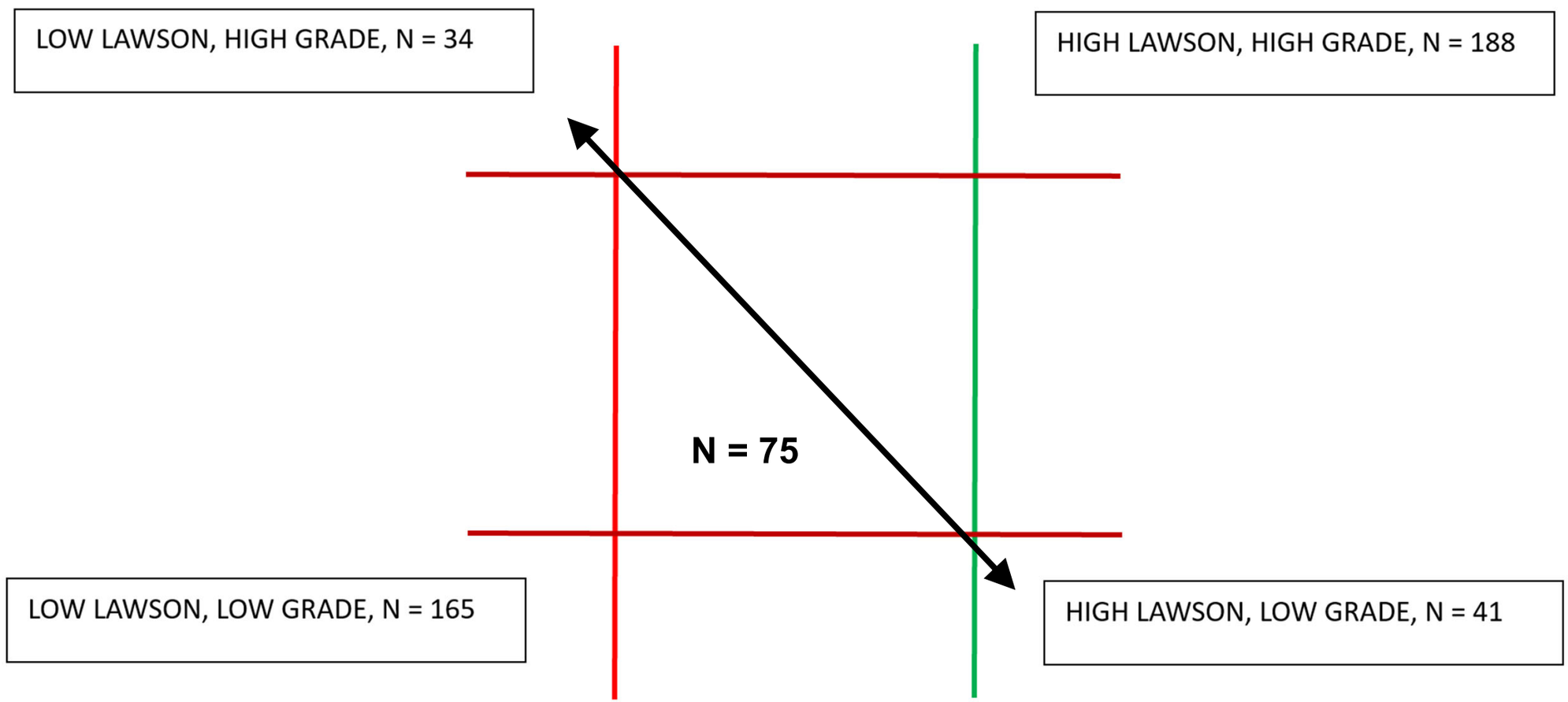
HIGH LAWSON, HIGH GRADE, N = 188



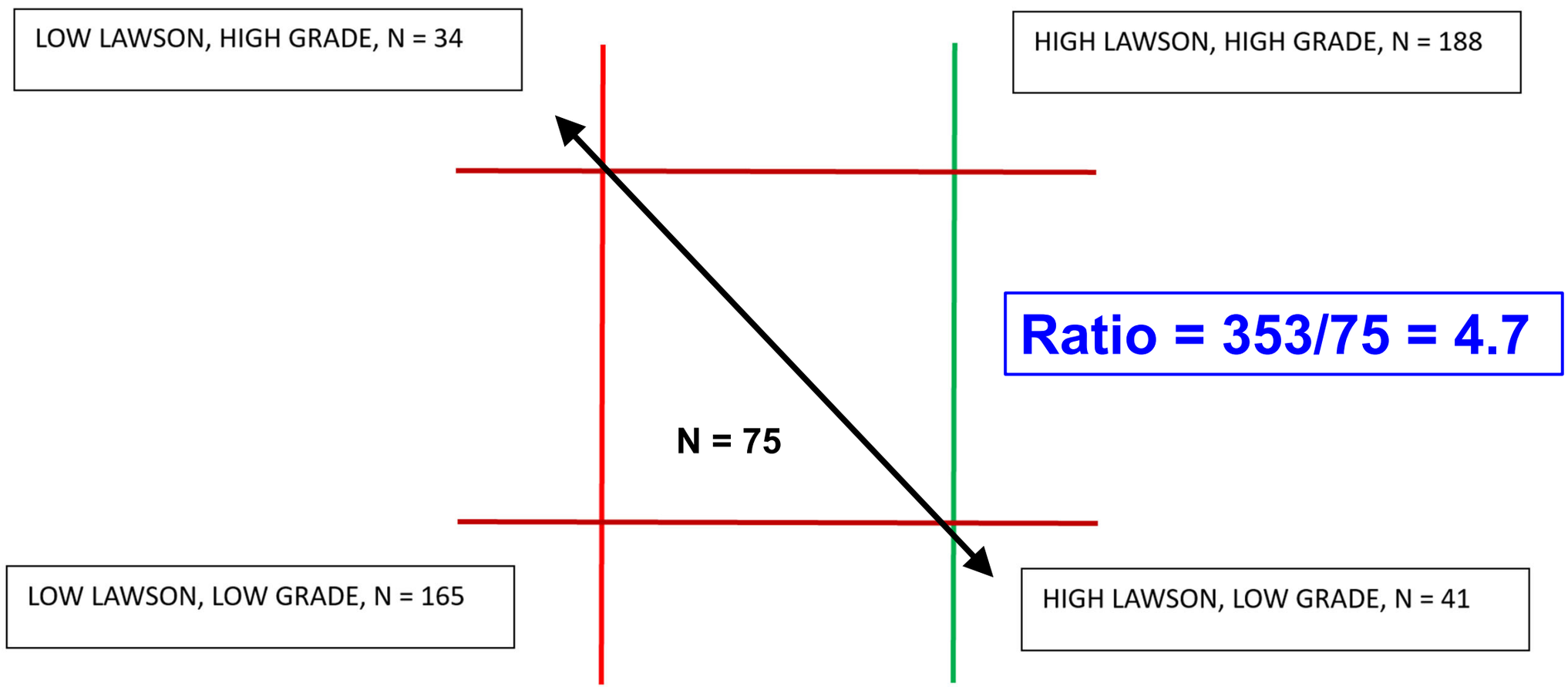
LOW LAWSON, LOW GRADE, N = 165

HIGH LAWSON, LOW GRADE, N = 41

LAWSON PRETEST VS. GRADES, 20 CLASSES COMBINED



LAWSON PRETEST VS. GRADES, 20 CLASSES COMBINED



Alternative to Regression Analysis

- Stratify sample into “high” and “low” scorers on pretest measure #1 (e.g, FCI), then separate each group further into high and low scorers on pretest measure #2 (e.g, Lawson test).
  - We already know that the measure #1 groups differ in grade probabilities
- Compare high/low grade probabilities to see whether pretest measure #2 offers *additional* predictive power regarding grade probabilities

Further Analysis of Alg-1 CU sample (*N* = 466)

		Probability of top-quartile grade	Probability of bottom-quartile grade
Top-Quartile on FCI Pretest	Top-half on Lawson pretest	60%	15%
	Bottom-half on Lawson pretest	26%	26%
	Ratio	2.3	1.8
Bottom-Quartile on FCI Pretest	Top-half on Lawson pretest	23%	15%
	Bottom-half on Lawson pretest	0%	26%
	Ratio	--	1.8

Even within a sample separated into high and low FCI pretest scores, Lawson pretest score was an additional reliable predictor of high/low grades.

Model: $\text{Grades} = 54.6109 + 0.2635 \cdot \text{Lawson pre} + 0.0814 \cdot \text{FCI pre}$

Predictor	Coefficient	Estimate	Standard Error	t-statistic	p-value
Constant	β_0	54.6109	2.3996	22.7587	0
Lawson pre	β_1	0.2635	0.0344	7.6579	0
FCI pre	β_2	0.0814	0.0353	2.3046	0.0216

Summary of Overall Fit

R-Squared:	r^2 =0.1632
Adjusted R-Squared:	r^2_{adj} =0.1596
Residual Standard Error:	10.7314 on 463 degrees of freedom.
Overall F-statistic:	45.1624 on 2 and 463 degrees of freedom.
Overall p-value:	0

Model: $\text{grade} = 39.7737 + 0.4092 \cdot \text{Lawson} + 0.1569 \cdot \text{FCI}$

Predictor	Coefficient	Estimate	Standard Error	t-statistic	p-value
Constant	β_0	39.7737	3.9295	10.1219	0
Lawson	β_1	0.4092	0.0576	7.11	0
FCI	β_2	0.1569	0.0634	2.4722	0.0141

Summary of Overall Fit

R-Squared:	r^2 =0.2794
Adjusted R-Squared:	r^2_{adj} =0.2732
Residual Standard Error:	13.5281 on 231 degrees of freedom.
Overall F-statistic:	44.7913 on 2 and 231 degrees of freedom.
Overall p-value:	0

Model: $\text{Grades} = 63.1281 + 0.1521 \cdot \text{Lawson pre} - 0.2008 \cdot \text{FCI pre} + 0.0036 \cdot \text{Lawson pre} * \text{FCI pre}$

Predictor	Coefficient	Estimate	Standard Error	t-statistic	p-value
Constant	β_0	63.1281	5.9074	10.6863	0
Lawson pre	β_1	0.1521	0.0785	1.9371	0.0533
FCI pre	β_2	-0.2008	0.1823	-1.1012	0.2714
$\text{Lawson pre} * \text{FCI pre}$	$\beta_{1,2}$	0.0036	0.0023	1.5773	0.1154

Summary of Overall Fit

R-Squared:	r^2 =0.1677
Adjusted R-Squared:	r^2_{adj} =0.1623
Residual Standard Error:	10.7142 on 462 degrees of freedom.
Overall F-statistic:	31.0344 on 3 and 462 degrees of freedom.
Overall p-value:	0

Model: $\text{grade} = 37.0054 + 0.444 \cdot \text{Lawson} + 0.2444 \cdot \text{FCI} - 0.0011 \cdot \text{Lawson} * \text{FCI}$

Predictor	Coefficient	Estimate	Standard Error	t-statistic	p-value
Constant	β_0	37.0054	10.8237	3.4189	0.0007
Lawson	β_1	0.444	0.1393	3.1884	0.0016
FCI	β_2	0.2444	0.3252	0.7517	0.453
$\text{Lawson} * \text{FCI}$	$\beta_{1,2}$	-0.0011	0.0039	-0.2746	0.7839

Summary of Overall Fit

R-Squared:	r^2 =0.2797
Adjusted R-Squared:	r^2_{adj} =0.2703
Residual Standard Error:	13.5552 on 230 degrees of freedom.
Overall F-statistic:	29.7665 on 3 and 230 degrees of freedom.
Overall p-value:	0

Lawson Pre %	Math Pre %	FCI Pre %	Grade Points %
83	100	63	102.55
25	81	20	98.17
75	94	43	97.87
71	31	17	95.92
46	81	57	94.16
71	75	17	93.19
58	94	47	93.06
92	69	13	92.00
54	81	40	91.99
42	63	37	91.81
62	**77**	**35**	**95**
50	50	17	74.59
38	19	27	72.20
42	63	10	71.27
21	50	3	66.22
29	25	10	63.28
42	56	17	62.07
12	56	10	50.68
17	63	23	47.12
12	69	20	46.87
58	44	17	42.26
32	**49**	**15**	**60**

Model: $\text{Grades} = 53.3545 + 0.2712 \cdot \text{Lawson} + 0.1178 \cdot \text{Math} + 0.2921 \cdot \text{FCI}$

Predictor	Coefficient	Estimate	Standard Error	t-statistic	p-value
Constant	β_0	53.3545	6.7143	7.9464	0
Lawson	β_1	0.2712	0.0973	2.7878	0.0085
Math	β_2	0.1178	0.1211	0.9729	0.3373
FCI	β_3	0.2921	0.1722	1.6961	0.0987

Summary of Overall Fit

R-Squared:	r^2 =0.4125
Adjusted R-Squared:	r^2_{adj} =0.3621
Residual Standard Error:	11.8971 on 35 degrees of freedom.

Model: $\text{Grades} = 54.4256 + 0.3871 \cdot \text{Lawson} - 0.12 \cdot \text{Math} + 0.5701 \cdot \text{FCI} + 0.0029 \cdot \text{Lawson} * \text{Math} - 0.0135 \cdot \text{Lawson} * \text{FCI} + 0.0056 \cdot \text{Math} * \text{FCI}$

Predictor	Coefficient	Estimate	Standard Error	t-statistic	p-value
Constant	β_0	54.4256	21.0039	2.5912	0.0143
Lawson	β_1	0.3871	0.4382	0.8835	0.3836
Math	β_2	-0.12	0.4142	-0.2898	0.7738
FCI	β_3	0.5701	0.6212	0.9177	0.3656
$\text{Lawson} * \text{Math}$	$\beta_{1,2}$	0.0029	0.0076	0.3863	0.7019
$\text{Lawson} * \text{FCI}$	$\beta_{1,3}$	-0.0135	0.0104	-1.2951	0.2045
$\text{Math} * \text{FCI}$	$\beta_{2,3}$	0.0056	0.01	0.5621	0.578

Summary of Overall Fit

R-Squared:	r^2 =0.445
Adjusted R-Squared:	r^2_{adj} =0.3409
Residual Standard Error:	12.0935 on 32 degrees of freedom.
Overall F-statistic:	4.2756 on 6 and 32 degrees of freedom.
Overall p-value:	0.0028

Analysis of Variance Table

Source	df	SS	MS	F-statistic	p-value
Regression	6	3751.972	625.3287	4.2756	0.0028
Residual Error	32	4680.1119	146.2535		
Total	38	8432.0839	221.8969		

Model: $\text{Grades} = 39.3403 + 0.4245 \cdot \text{Lawson Pretest} + 0.1633 \cdot \text{Math Pretest} + 0.3069 \cdot \text{FCI Pretest}$

Predictor	Coefficient	Estimate	Standard Error	t-statistic	p-value
Constant	β_0	39.3403	10.7565	3.6574	0.0021
Lawson Pretest	β_1	0.4245	0.1532	2.7712	0.0136
Math Pretest	β_2	0.1633	0.1933	0.8447	0.4107
FCI Pretest	β_3	0.3069	0.2674	1.1476	0.268

Summary of Overall Fit

R-Squared:	r^2 =0.5658
Adjusted R-Squared:	r^2_{adj} =0.4843
Residual Standard Error:	14.423 on 16 degrees of freedom.

Model: $\text{Grades} = 17.0099 + 0.7348 \cdot \text{Lawson Pretest} + 0.5341 \cdot \text{Math Pretest} + 0.5494 \cdot \text{FCI Pretest} - 0.0055 \cdot \text{Lawson Pretest} * \text{Math Pretest} + 0.003 \cdot \text{Lawson Pretest} *$

Predictor	Coefficient	Estimate	Standard Error	t-statistic	p-value
Constant	β_0	17.0099	39.6595	0.4289	0.675
Lawson Pretest	β_1	0.7348	0.7043	1.0433	0.3158
Math Pretest	β_2	0.5341	0.8032	0.6649	0.5177
FCI Pretest	β_3	0.5494	1.2591	0.4363	0.6698
$\text{Lawson Pretest} * \text{Math Pretest}$	$\beta_{1,2}$	-0.0055	0.0123	-0.4471	0.6622
$\text{Lawson Pretest} * \text{FCI Pretest}$	$\beta_{1,3}$	0.003	0.0218	0.1373	0.8929
$\text{Math Pretest} * \text{FCI Pretest}$	$\beta_{2,3}$	-0.0047	0.0237	-0.1982	0.8459

Summary of Overall Fit

R-Squared:	r^2 =0.5796
Adjusted R-Squared:	r^2_{adj} =0.3856
Residual Standard Error:	15.7439 on 13 degrees of freedom.
Overall F-statistic:	2.987 on 6 and 13 degrees of freedom.
Overall p-value:	0.0464

Model: $\text{Grades} = 39.3505 + 0.4244 \cdot \text{Lawson} + 0.1633 \cdot \text{Math} + 0.3066 \cdot \text{FCI}$

Predictor	Coefficient	Estimate	Standard Error	t-statistic	p-value
Constant	β_0	39.3505	10.7577	3.6579	0.0021
Lawson	β_1	0.4244	0.1532	2.7703	0.0137
Math	β_2	0.1633	0.1934	0.8445	0.4109
FCI	β_3	0.3066	0.2674	1.1464	0.2685

Summary of Overall Fit

R-Squared:	r^2 =0.5655
Adjusted R-Squared:	r^2_{adj} =0.484
Residual Standard Error:	14.4247 on 16 degrees of freedom.
Overall F-statistic:	6.9415 on 3 and 16 degrees of freedom.
Overall p-value:	0.0033

Model: $\text{Grades} = 17.0041 + 0.735 \cdot \text{Lawson} + 0.5339 \cdot \text{Math} + 0.5502 \cdot \text{FCI} - 0.0055 \cdot \text{Lawson} * \text{Math} + 0.003 \cdot \text{Lawson} * \text{FCI} - 0.0047 \cdot \text{Math} * \text{FCI}$

Predictor	Coefficient	Estimate	Standard Error	t-statistic	p-value
Constant	β_0	17.0041	39.6619	0.4287	0.6751
Lawson	β_1	0.735	0.7043	1.0436	0.3157
Math	β_2	0.5339	0.8033	0.6646	0.5179
FCI	β_3	0.5502	1.2592	0.437	0.6693
$\text{Lawson} * \text{Math}$	$\beta_{1,2}$	-0.0055	0.0123	-0.4468	0.6623
$\text{Lawson} * \text{FCI}$	$\beta_{1,3}$	0.003	0.0218	0.136	0.8939
$\text{Math} * \text{FCI}$	$\beta_{2,3}$	-0.0047	0.0237	-0.198	0.8461

Summary of Overall Fit

R-Squared:	r^2 =0.5794
Adjusted R-Squared:	r^2_{adj} =0.3853
Residual Standard Error:	15.7449 on 13 degrees of freedom.
Overall F-statistic:	2.9847 on 6 and 13 degrees of freedom.
Overall p-value:	0.0465

Important Note

- Motivational factors can also be highly influential, in some cases overcoming the “disadvantages” revealed by low pretest scores.

Summary

- Numerous factors influence students' physics course performance
- Previous preparation in calculational skill, reasoning, and physics concept knowledge are significant predictors of course grades
- 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)