Relationship between course grades in introductory physics and pre-instruction assessment scores

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Acknowledgments

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  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)
- Why do this? Perhaps ultimately we can offer special assistance to those students who need it most.

Sample Description

- 30 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

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?

(and, same questions for probabilities of getting a *low* grade)

*In this context, "high" and "low" mean "top quartile" and "bottom quartile"

Consistent result:

High scorers on the diagnostic pretests were much more likely to get ***high*** 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 2024	ASU-P	99	51%	8%	6.1
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)**	**(809)**	**44%**	**12%**	**3.8**

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AVERAGE	**(unweighted)**	**(809)**	**44%**	**12%**	**3.8**

High Course Grade vs. Mathematics Diagnostic Pretest Score

Campus	*N*	Top-quartile Math: % with top-quartile grades	Bottom-quartile Math: % with top-quartile grades	High-grade odds ratio
AVERAGE	(unweighted)	(809)	44%	12%	3.8

High scorers on math pretest were 3.8 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-2 2024	ASU-P	90	42%	5%	9.2
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)**	**(1620)**	**49%**	**9%**	**5.5**

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 scorers on the pretests were about *5 times* more likely to get a high grade than low scorers.

- Low scorers on the pretests were about *4 times* more likely to get a low grade than high scorers.

High and low grades for high and low scorers were compared for more than 2000 students in 30 distinct classes at 4 universities, yielding a total of 114 high/low comparisons.

➢ ***The quartile ratios were greater than 1.0 in 111 of the 114 cases (97%)***.

Relevant Questions

- Which, if any, of the diagnostic pretests is most predictive of students' performance?
- Does using multiple predictor variables offer greater predictive power than using just one of them?
- Can an "accurate" predictive model be created that incorporares multiple predictor variables?
- Does better performance on one pretest indicate that another pretest is more (or less) predictive? (This would be an "interaction" effect.)

Relevant Questions

- Which, if any, of the diagnostic pretests is most predictive of students' performance? *Varies with the course*

- Courses and instructors differ on the relative emphasis placed on conceptual problems, mathematical problem solving, and problems requiring significant reading and reasoning skills.
- There are also many possible ways to compare relative "predictability"
  - …for example, compare high/low grade ratios for different pretests

High Grade Odds Ratios

Course	Campus	*N* *(# classes)*	High-grade odds ratio, Math (average)	High-grade odds ratio, Lawson (average)	High-grade odds ratio, FCI (average)
Alg-1	ASU-P	6	5.0	3.0	3.6
Alg-1	CU	1	--	5.5	3.5
Alg-1	LMU	9	--	12.2	19.6
Alg-2	ASU-P	3	3.3	6.4	--
Calc-1	UWF	2	“∞”	--	1.7

High Grade Odds Ratios

Course	Campus	*N* *(# classes)*	High-grade odds ratio, Math (average)	High-grade odds ratio, Lawson (average)	High-grade odds ratio, FCI (average)
Alg-1	ASU-P	6	5.0	3.0	3.6
Alg-1	CU	1	--	5.5	3.5
Alg-1	LMU	9	--	12.2	19.6
Alg-2	ASU-P	3	3.3	6.4	--
Calc-1	UWF	2	“∞”	--	1.7

Low Grade Odds Ratios

Course	Campus	*N* *(# classes)*	Low-grade odds ratio, Math (average)	Low-grade odds ratio, Lawson (average)	Low-grade odds ratio, FCI (average)
Alg-1	ASU-P	6	2.8	3.9	3.2
Alg-1	CU	1	--	4.4	1.1
Alg-1	LMU	9	--	6.8	5.4
Alg-2	ASU-P	3	3.7	2.6	--
Calc-1	UWF	2	4.2	--	3.1

Another Approach: Multiple Regression

- Fit an equation including all predictor variables to the data using ordinary least squares, e.g.:

$$\text{Grades} = \beta_0 + \beta_1 * \text{Lawson Pretest} + \beta_2 * \text{Math Pretest} + \beta_3 * \text{FCI Pretest}$$

- Problem: most sample sizes too small to yield significant results, and too much between-class variation to combine samples
- Partial solution:
  - choose one very large sample (Alg-1 CU; *N* = 466) to compare Lawson and FCI
  - combine three very similar classes taught by same instructor (Alg-2 ASU-P, 2022-23-24; *N* = 216) to compare Lawson and Math

Reminder: Results for High Grade Odds Ratios for CU sample

Course	Campus	*N*	High-grade odds ratio, Math	High-grade odds ratio, Lawson	High-grade odds ratio, FCI
Alg-1	CU	466	--	5.5	3.5

Low Grade Odds Ratios

Course	Campus	*N*	Low-grade odds ratio, Math	Low-grade odds ratio, Lawson	Low-grade odds ratio, FCI
Alg-1	CU	466	--	4.4	1.1

Lawson pretest score seems to be more predictive than FCI pretest score

Alg-1 CU, *N* = 466

Results of Multiple Regression

Alg-1 CU, *N* = 466

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

Alg-1 CU, *N* = 466

Lawson more “influential”* than FCI

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

Both variables statistically significant

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

But correlation is quite low

**weighted more heavily when predicting grades*

(Interaction effect not significant)

High Grade Odds Ratios for Alg-2 ASU-P

Course	Campus	*N*	High-grade odds ratio, Math	High-grade odds ratio, Lawson	High-grade odds ratio, FCI
Alg-2	ASU-P, 2022-23-24	216	2.8	4.1	--

High Grade Odds Ratios for Alg-2 ASU-P

Course	Campus	*N*	High-grade odds ratio, Math	High-grade odds ratio, Lawson	High-grade odds ratio, FCI
Alg-2	ASU-P, 2022-23-24	216	2.8	4.1	--

High Grade Odds Ratios for Alg-2 ASU-P

Course	Campus	*N*	High-grade odds ratio, Math	High-grade odds ratio, Lawson	High-grade odds ratio, FCI
Alg-2	ASU-P, 2022-23-24	216	2.8	4.1	--

Low Grade Odds Ratios for Alg-2 ASU-P

Course	Campus	*N*	Low-grade odds ratio, Math	Low-grade odds ratio, Lawson	Low-grade odds ratio, FCI
Alg-2	ASU-P, 2022-23-24	216	4.8	2.4	--

No consistent “best” predictor

Alg-2 ASU-P, 2022-23-24, *N* = 216

Math more “influential” than Lawson?

Model: $\text{Grades} = 26.363 + 0.185 \cdot \text{Lawson Pretest} + 0.295 \cdot \text{Math Pretest}$

Predictor	Coefficient	Estimate	Standard Error	t-statistic	p-value
Constant	β_0	26.363	4.35	6.061	0
Lawson Pretest	β_1	0.185	0.067	2.775	0.006
Math Pretest	β_2	0.295	0.067	4.391	0

Both variables statistically significant

Summary of Overall Fit

R-Squared:	r^2 =0.154
Adjusted R-Squared:	r^2_{adj} =0.146
Residual Standard Error:	26.73 on 213 degrees of freedom.
Overall F-statistic:	19.427 on 2 and 213 degrees of freedom.
Overall p-value:	0

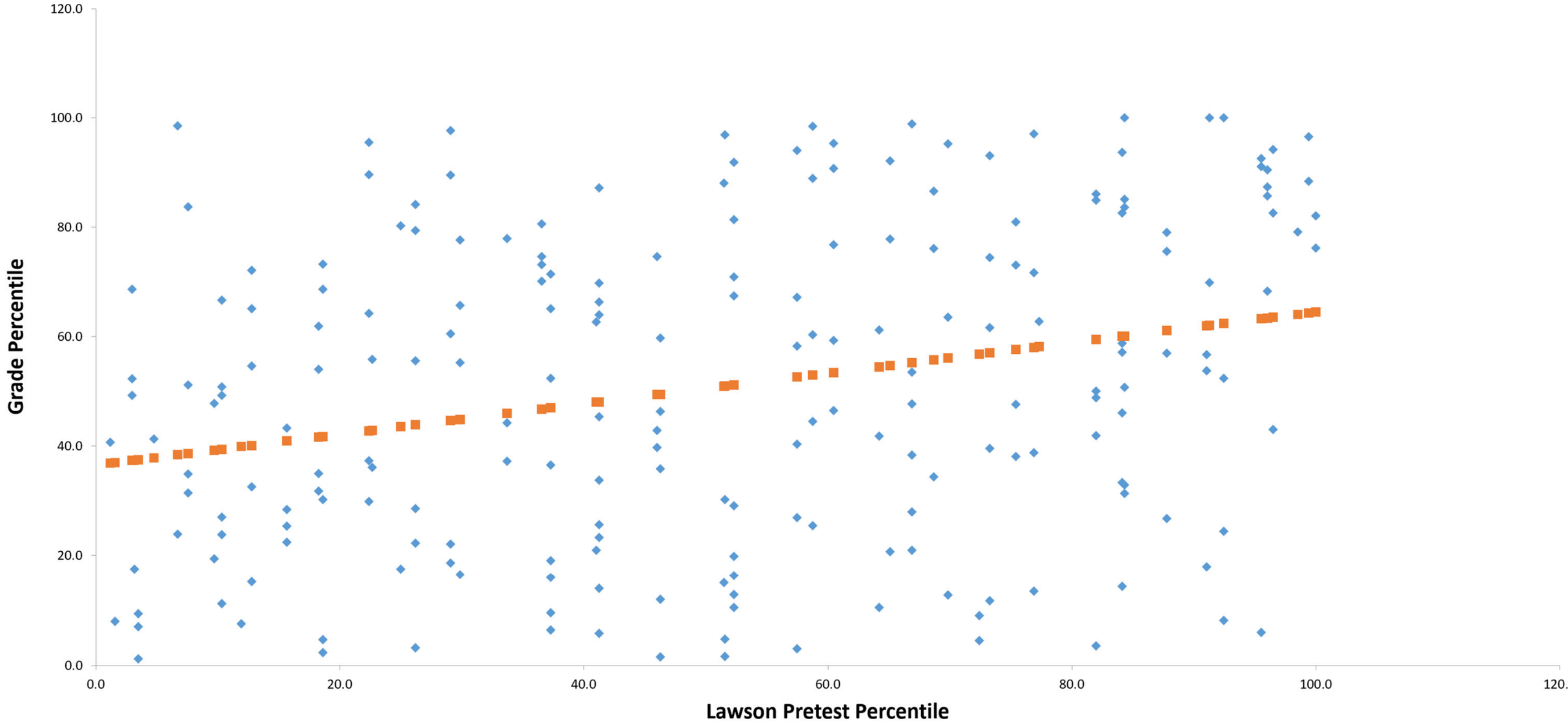
But correlation is still quite low

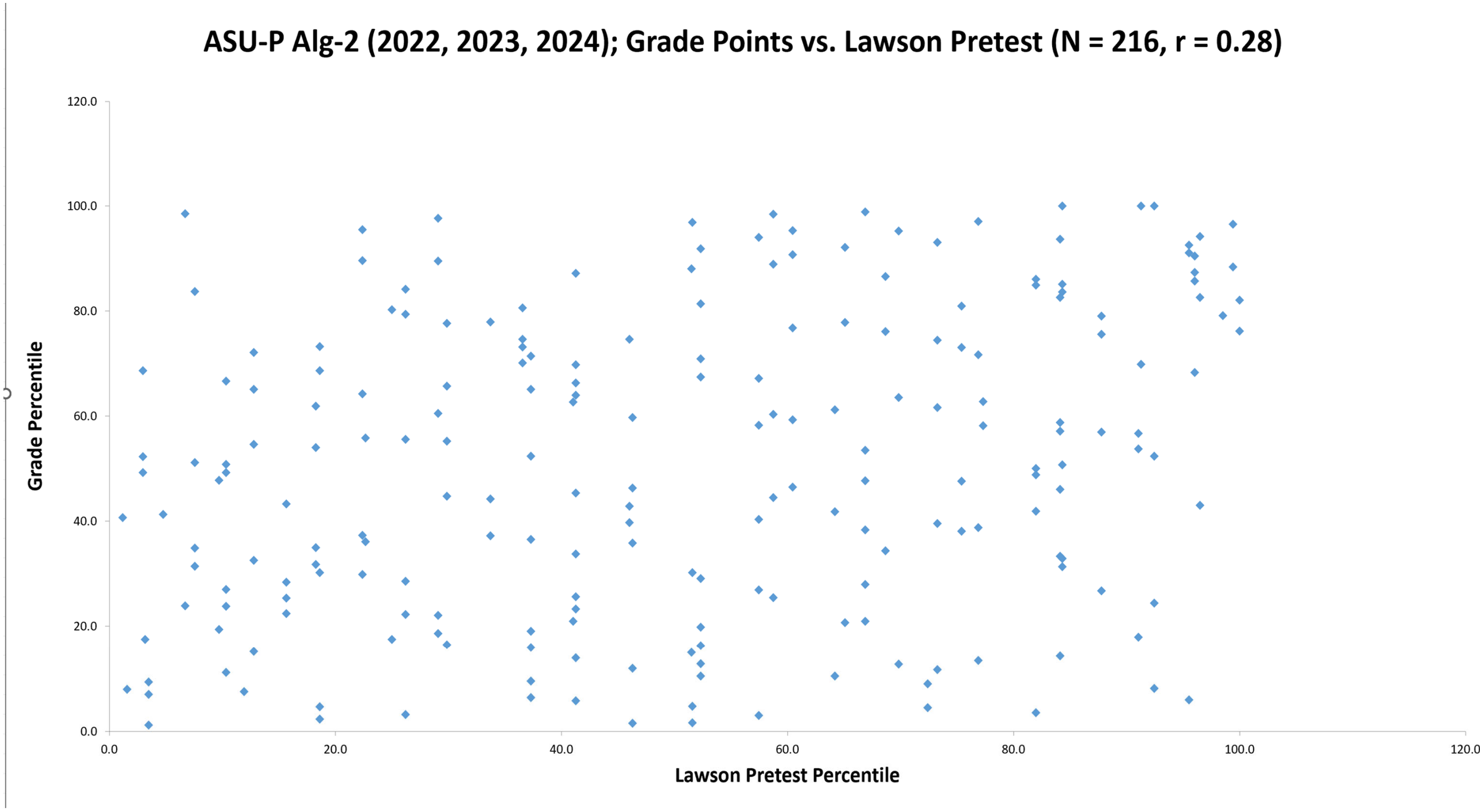
(Interaction effect not significant)

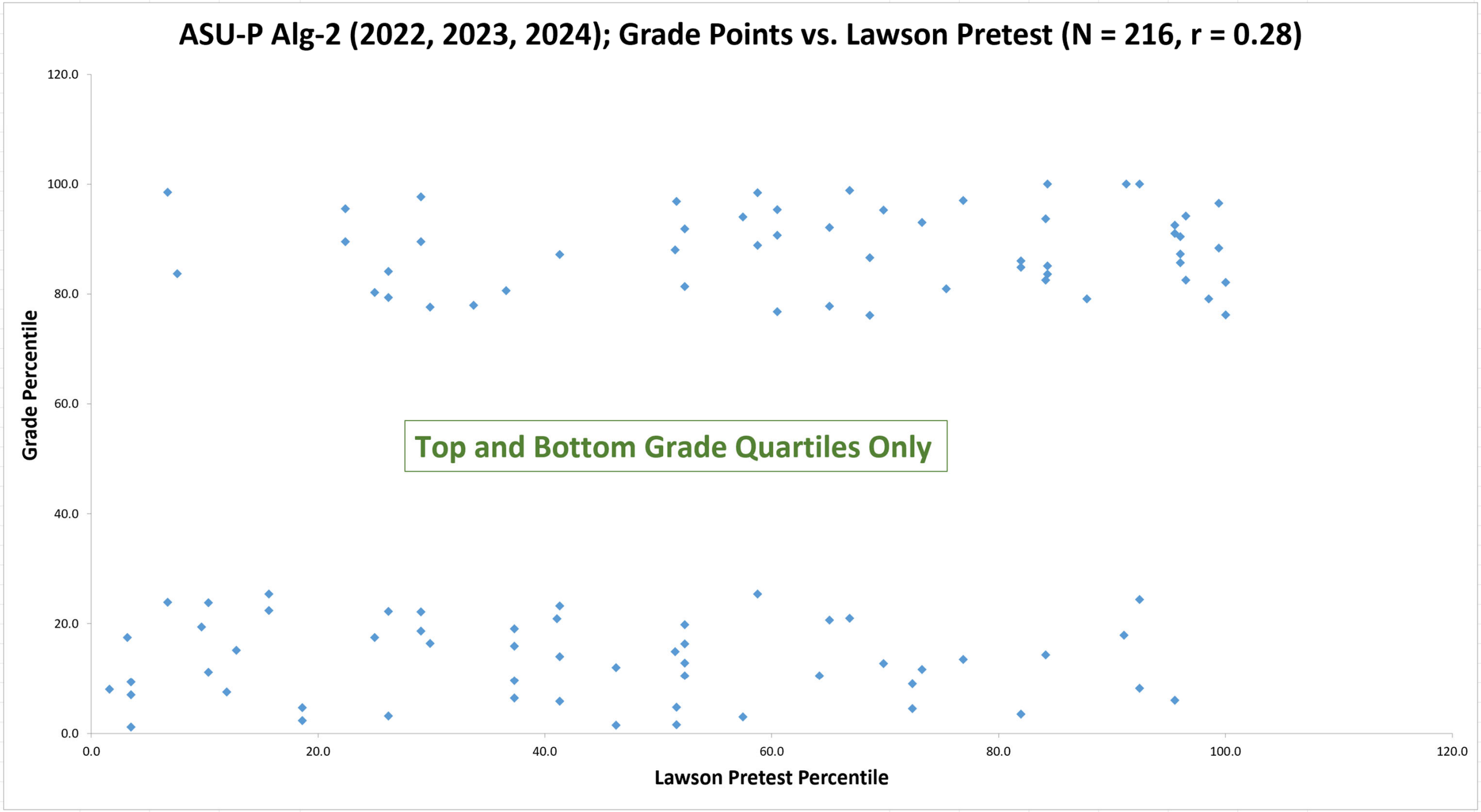
Regression analysis can be misleading

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

ASU-P Alg-2 (2022, 2023, 2024); Grade Points vs. Lawson Pretest (N = 216, r = 0.28)




ASU-P Alg-2 (2022, 2023, 2024); Grade Points vs. Lawson Pretest (N = 216, r = 0.28)
Grade Percentile
120.0
100.0
80.0
60.0
40.0
20.0
0.0
0.0
20.0
40.0
60.0
80.0
100.0
120.0
Lawson Pretest Percentile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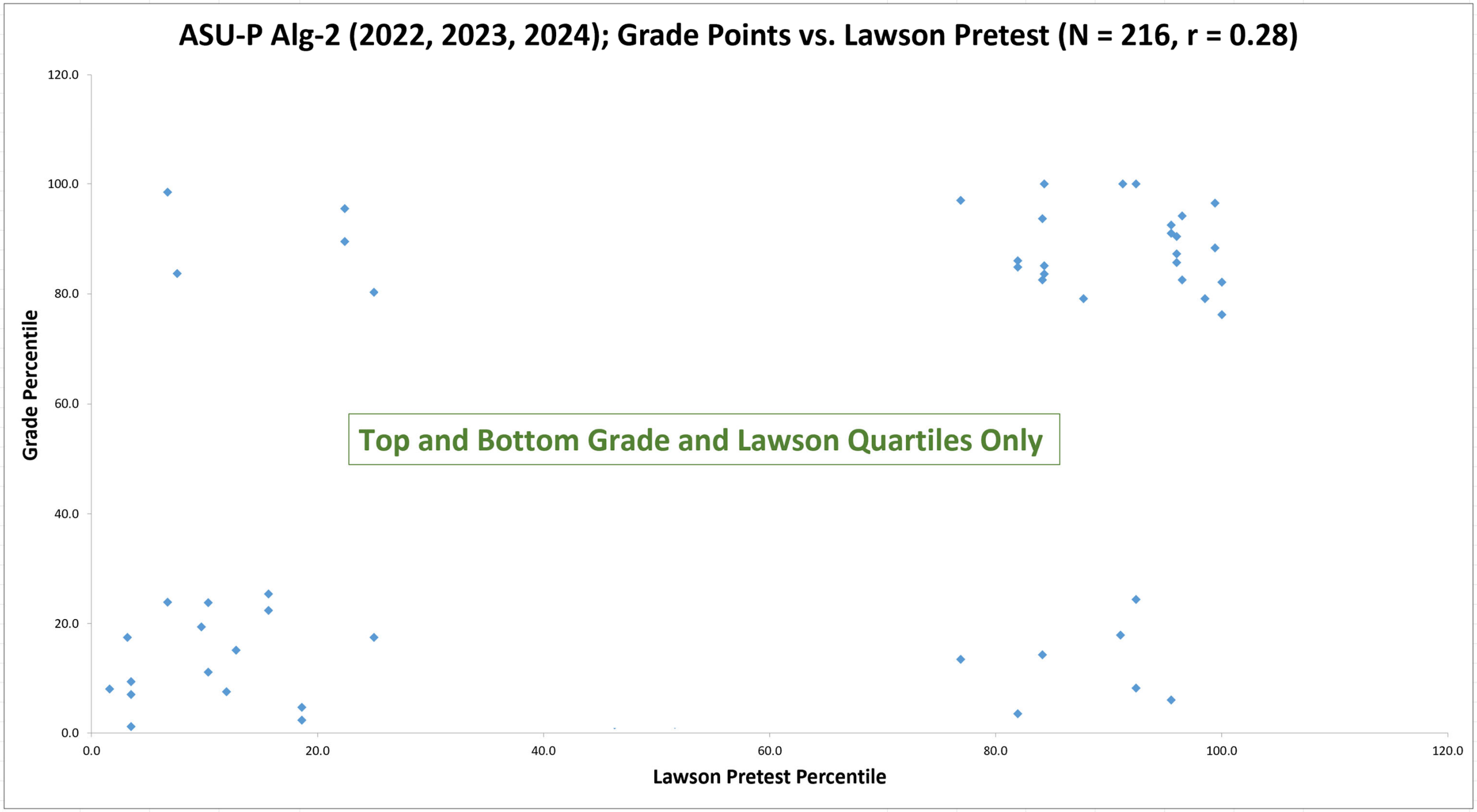
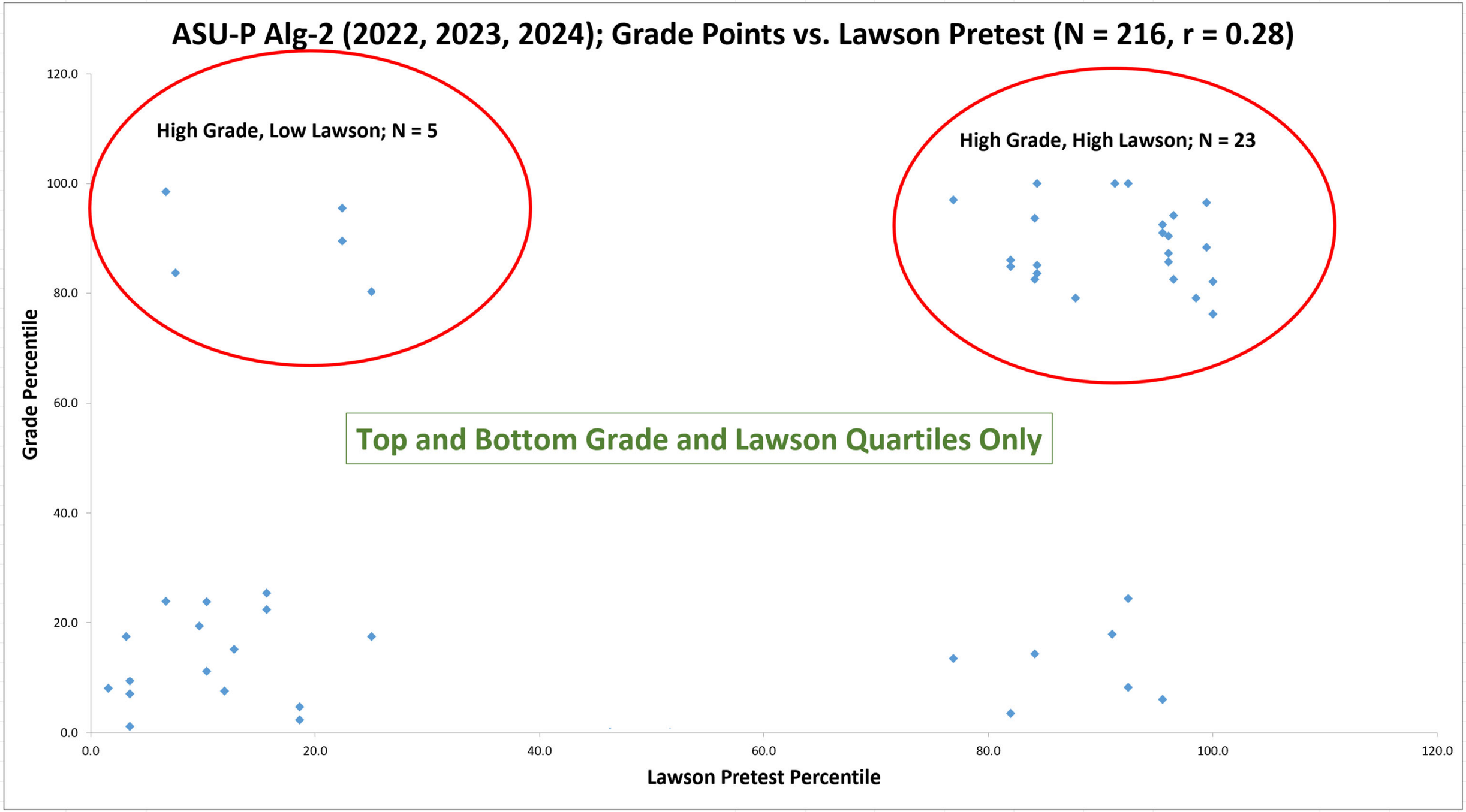
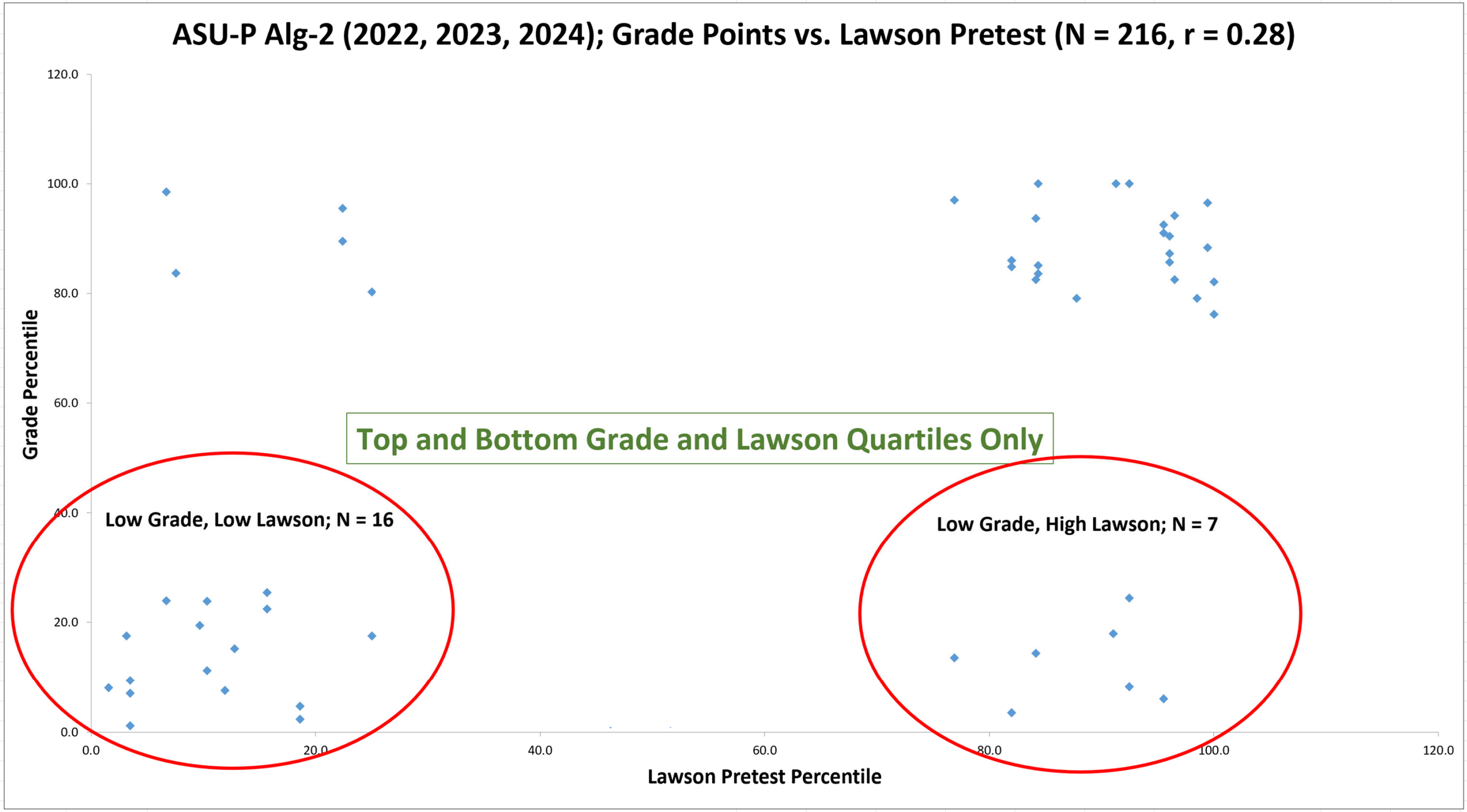
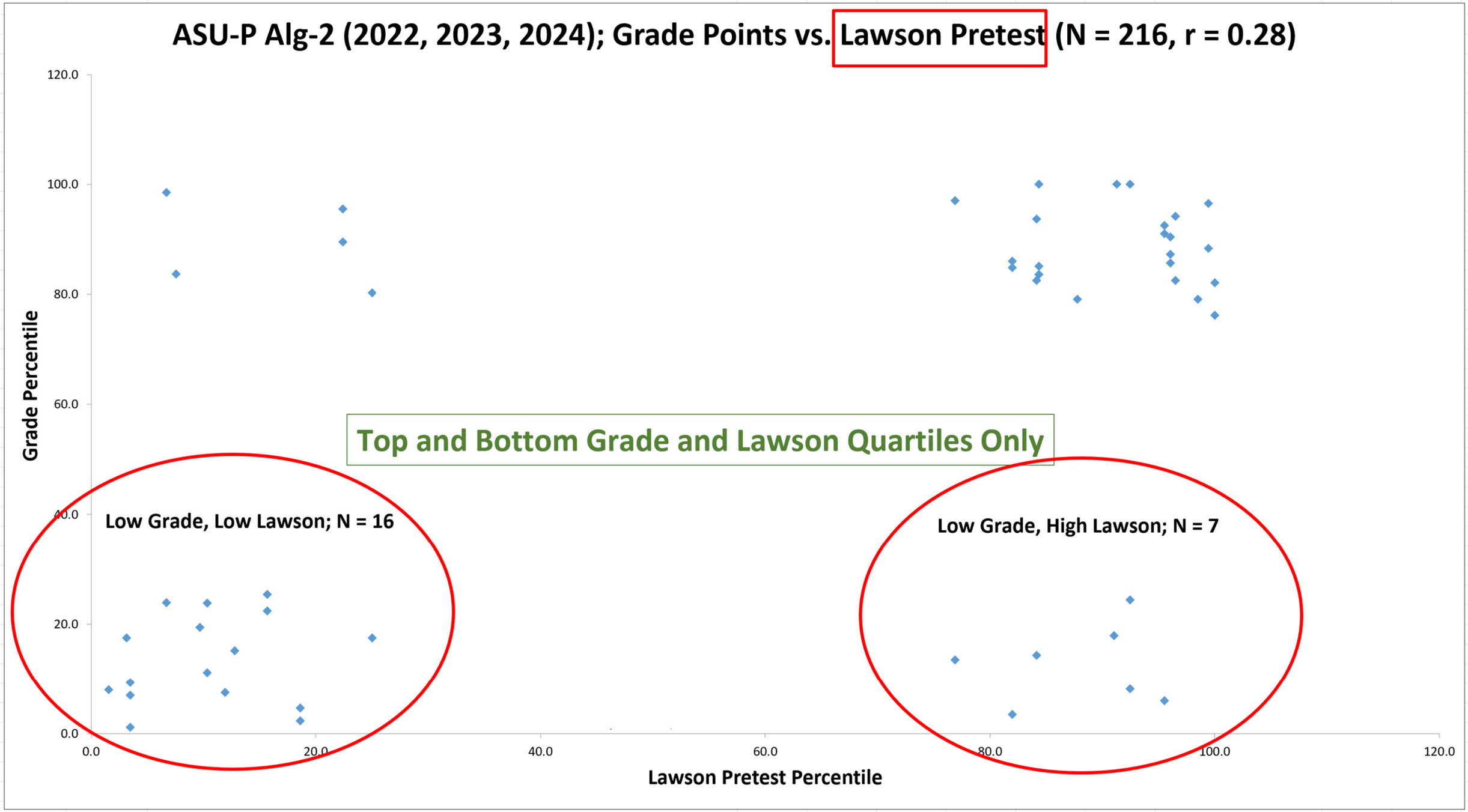
Grade Percentile
120.0
100.0
80.0
60.0
40.0
20.0
0.0
Top and Bottom Grade Quartiles Only
0.0
20.0
40.0
60.0
80.0
100.0
120.0
Lawson Pretest Percentile


ASU-P Alg-2 (2022, 2023, 2024); Grade Points vs. Lawson Pretest (N = 216, r = 0.28)
Grade Percentile
120.0
100.0
80.0
60.0
40.0
20.0
0.0
Top and Bottom Grade and Lawson Quartiles Only
0.0
20.0
40.0
60.0
80.0
100.0
120.0
Lawson Pretest Percentile


ASU-P Alg-2 (2022, 2023, 2024); Grade Points vs. Lawson Pretest (N = 216, r = 0.28)
High Grade, Low Lawson; N = 5
High Grade, High Lawson; N = 23
Top and Bottom Grade and Lawson Quartiles Only
Grade Percentile
Lawson Pretest Percentile
120.0
100.0
80.0
60.0
40.0
20.0
0.0
0.0
20.0
40.0
60.0
80.0
100.0
120.0


ASU-P Alg-2 (2022, 2023, 2024); Grade Points vs. Lawson Pretest (N = 216, r = 0.28)
Grade Percentile
120.0
100.0
80.0
60.0
40.0
20.0
0.0
0.0
20.0
40.0
60.0
80.0
100.0
120.0
Lawson Pretest Percentile
Top and Bottom Grade and Lawson Quartiles Only
Low Grade, Low Lawson; N = 16
Low Grade, High Lawson; N = 7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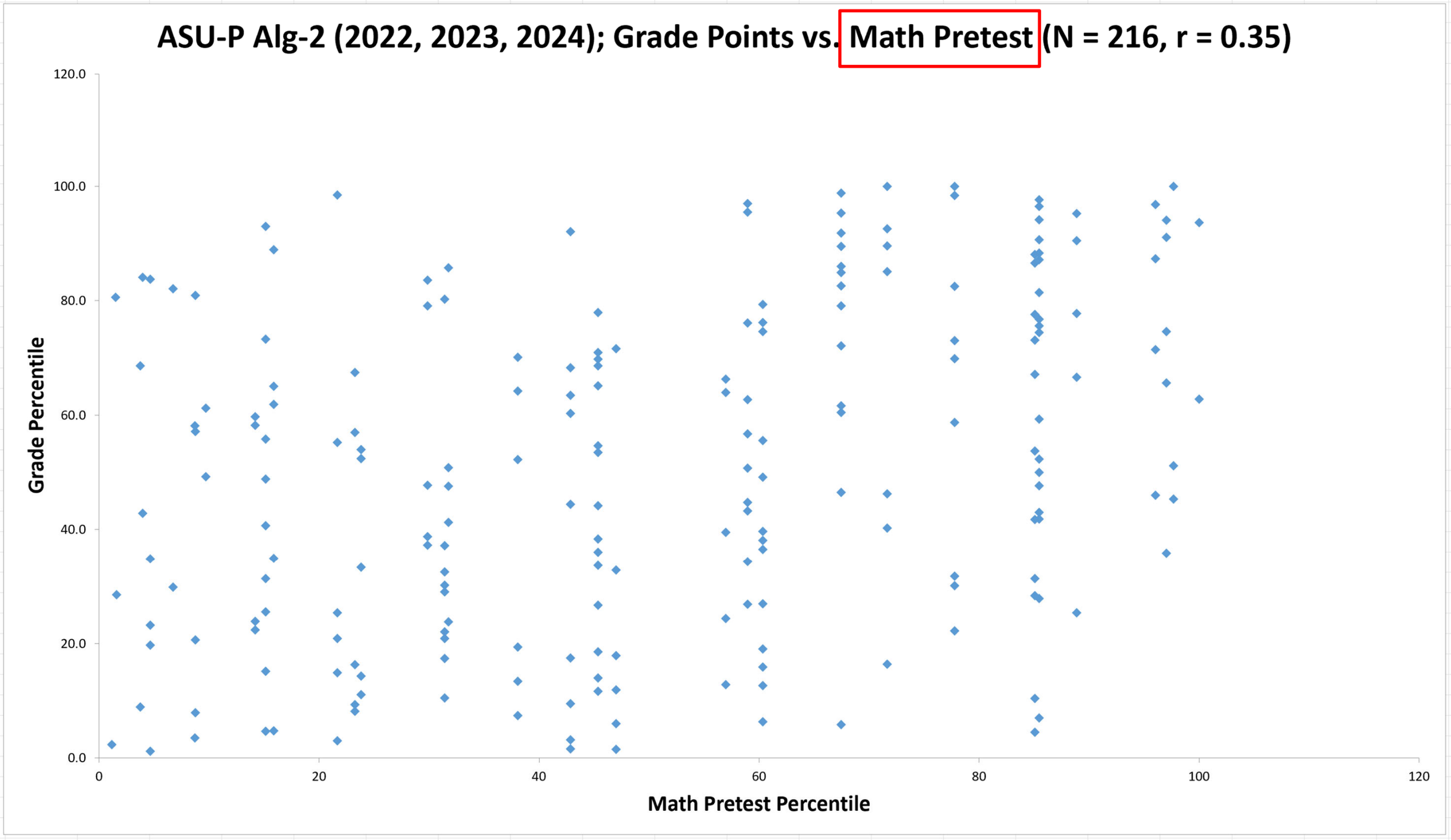
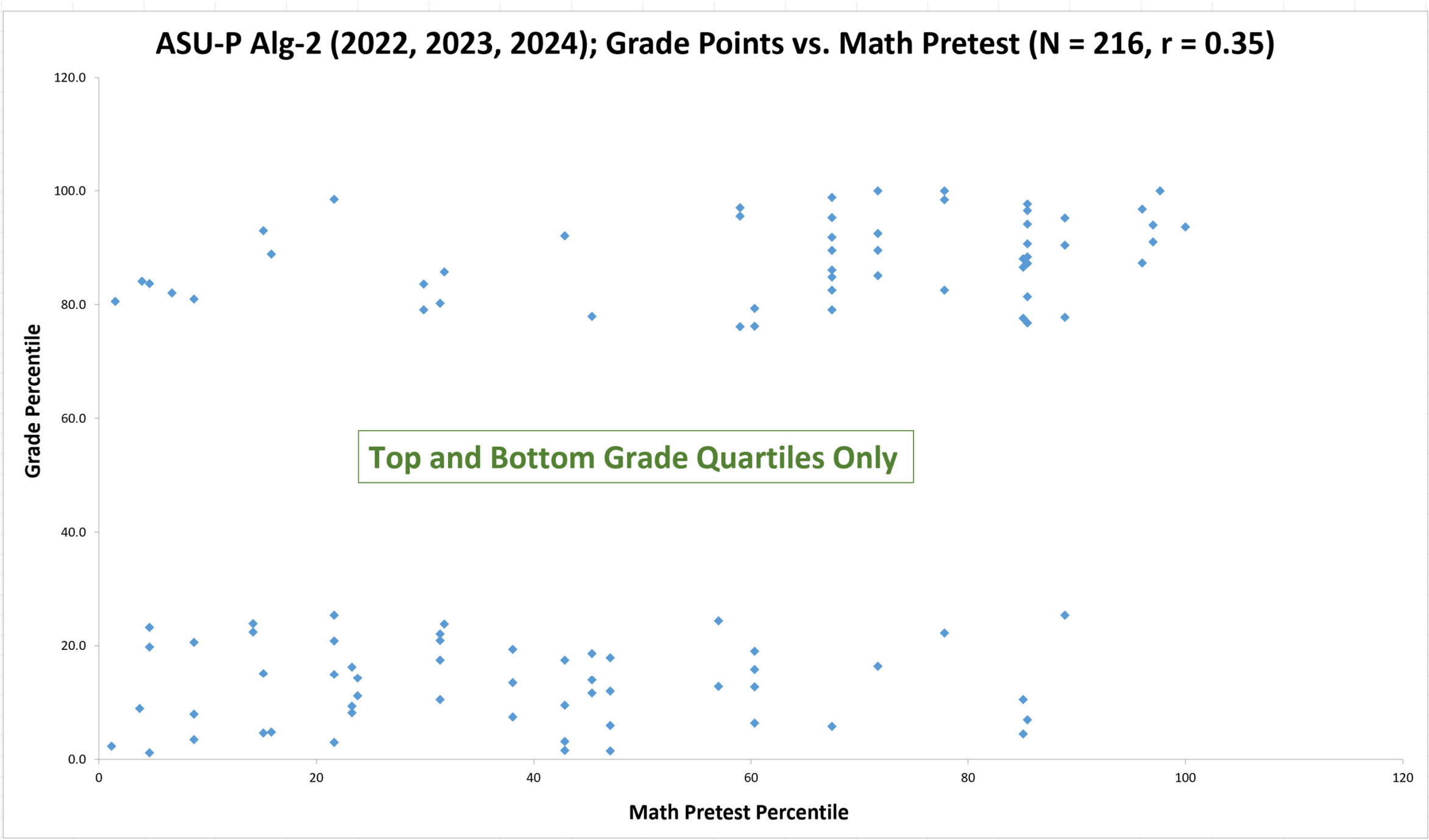
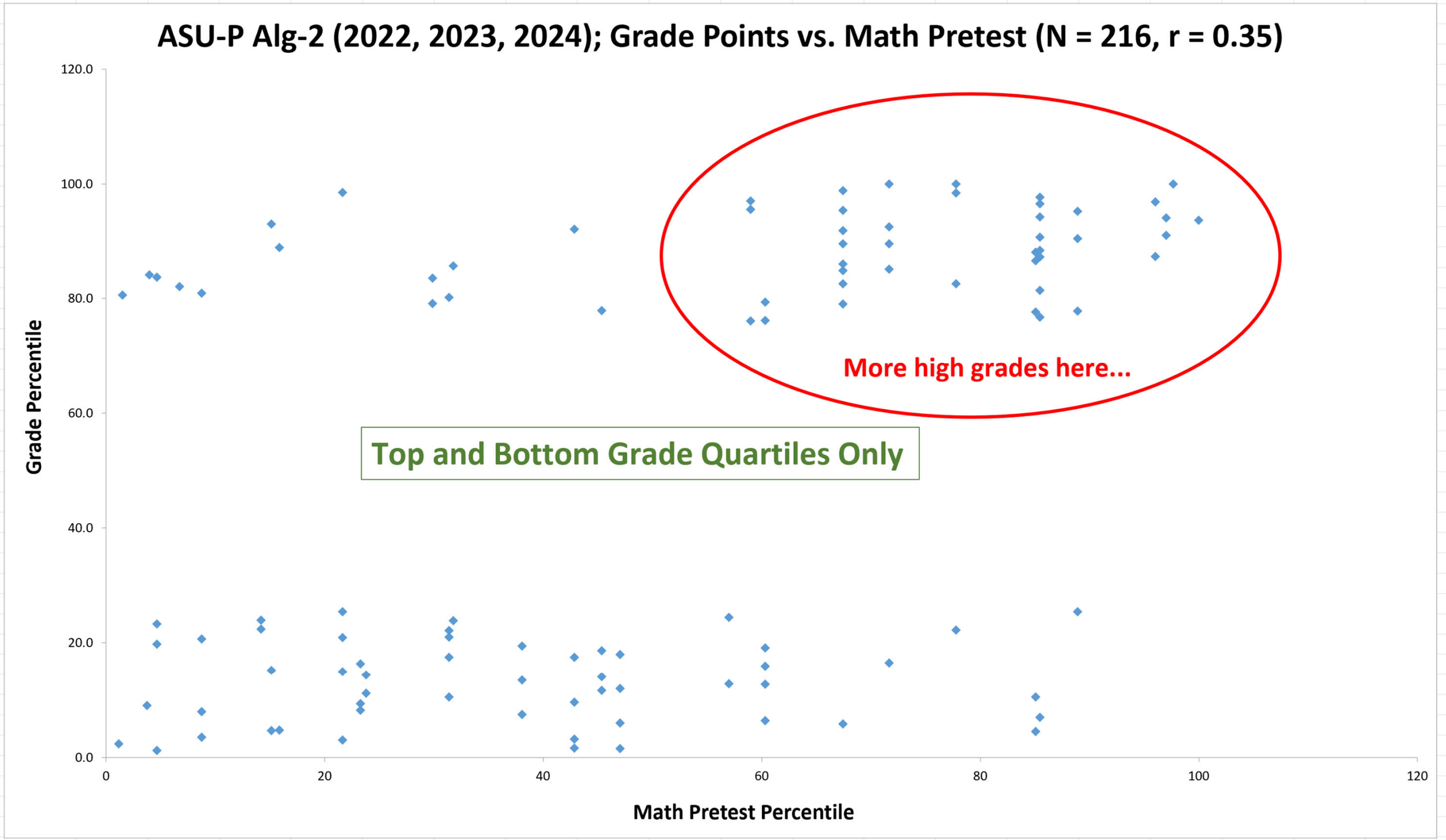
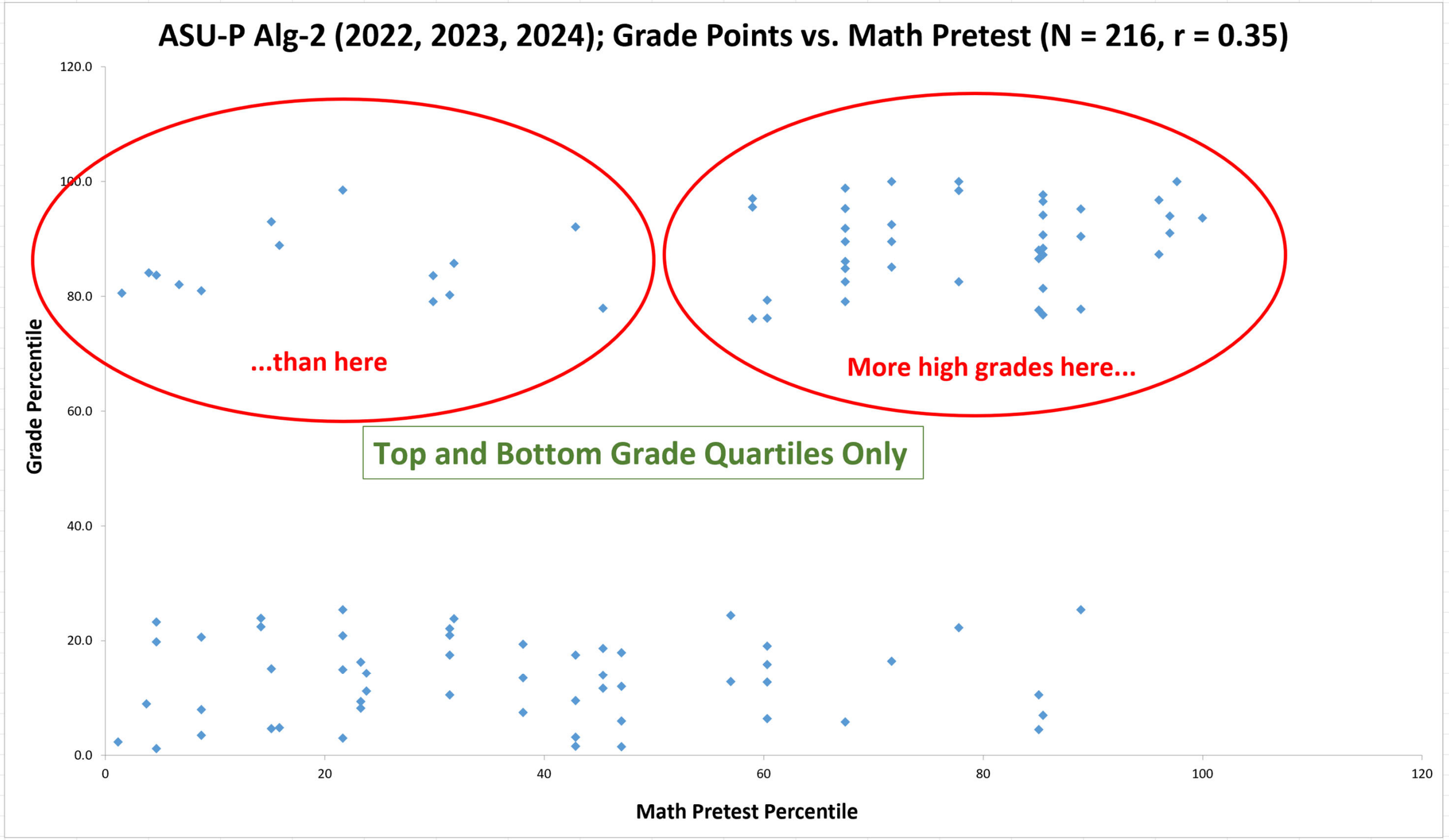
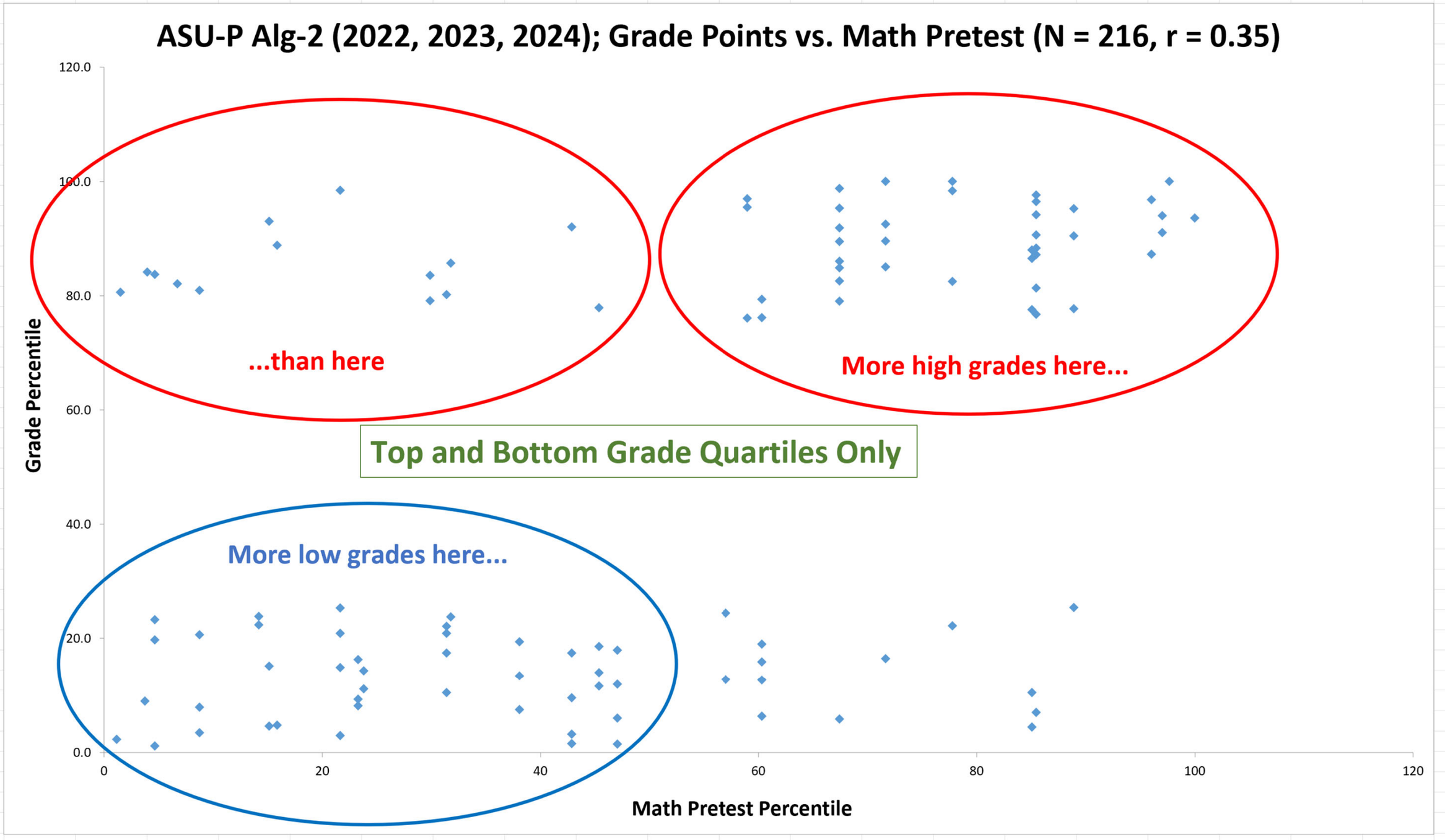
Grade Percentile
120.0
100.0
80.0
60.0
40.0
20.0
0.0
Top and Bottom Grade and Lawson Quartiles Only
Low Grade, Low Lawson; N = 16
Low Grade, High Lawson; N = 7
0.0
20.0
40.0
60.0
80.0
100.0
120.0
Lawson Pretest Percentile

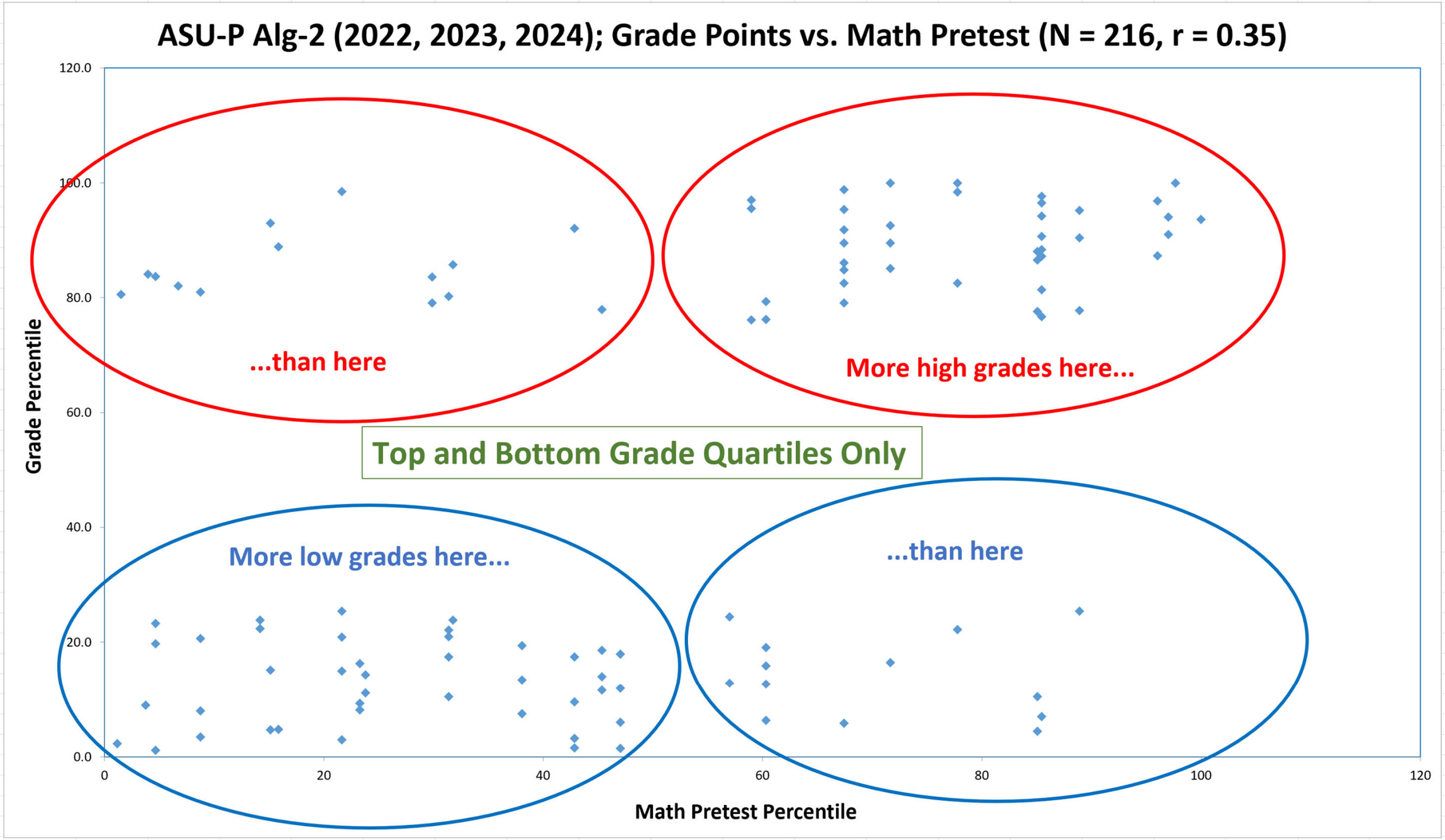

ASU-P Alg-2 (2022, 2023, 2024); Grade Points vs. Math Pretest (N = 216, r = 0.35)
Grade Percentile
Math Pretest Percentile
120.0
100.0
80.0
60.0
40.0
20.0
0.0
0
20
40
60
80
100
120


ASU-P Alg-2 (2022, 2023, 2024); Grade Points vs. Math Pretest (N = 216, r = 0.35)
Grade Percentile
120.0
100.0
80.0
60.0
40.0
20.0
0.0
0
20
40
60
80
100
120
Math Pretest Percentile
Top and Bottom Grade Quartiles Only


ASU-P Alg-2 (2022, 2023, 2024); Grade Points vs. Math Pretest (N = 216, r = 0.35)
Grade Percentile
120.0
100.0
80.0
60.0
40.0
20.0
0.0
0
20
40
60
80
100
120
Math Pretest Percentile
More high grades here...
Top and Bottom Grade Quartiles Only


ASU-P Alg-2 (2022, 2023, 2024); Grade Points vs. Math Pretest (N = 216, r = 0.35)
Grade Percentile
120.0
100.0
80.0
60.0
40.0
20.0
0.0
0
20
40
60
80
100
120
Math Pretest Percentile
...than here
More high grades here...
Top and Bottom Grade Quartiles Only


ASU-P Alg-2 (2022, 2023, 2024); Grade Points vs. Math Pretest (N = 216, r = 0.35)
Grade Percentile
120.0
100.0
80.0
60.0
40.0
20.0
0.0
0
20
40
60
80
100
120
Math Pretest Percentile
...than here
More high grades here...
Top and Bottom Grade Quartiles Only
More low grades here...


ASU-P Alg-2 (2022, 2023, 2024); Grade Points vs. Math Pretest (N = 216, r = 0.35)
Grade Percentile
120.0
100.0
80.0
60.0
40.0
20.0
0.0
0
20
40
60
80
100
120
Math Pretest Percentile
...than here
More high grades here...
Top and Bottom Grade Quartiles Only
More low grades here...
...than here

Relevant Questions

- Can an “accurate” predictive model be created that incorporares multiple predictor variables? *No, but better than random*

Alg-2 ASU-P, 2022-23-24, *N* = 216

Model: $\text{Grades} = 26.363 + 0.185 \cdot \text{Lawson Pretest} + 0.295 \cdot \text{Math Pretest}$

Q: How accurately can this model predict students' grades?

A: If we randomly guess in which grade quartile each student will end up, we'd be right 25% of the time.

If instead we had applied this model to each *actual** student's Lawson and Math pretest scores, we would have correctly predicted whether they ended up with top- or bottom-quartile grades 45% of the time.

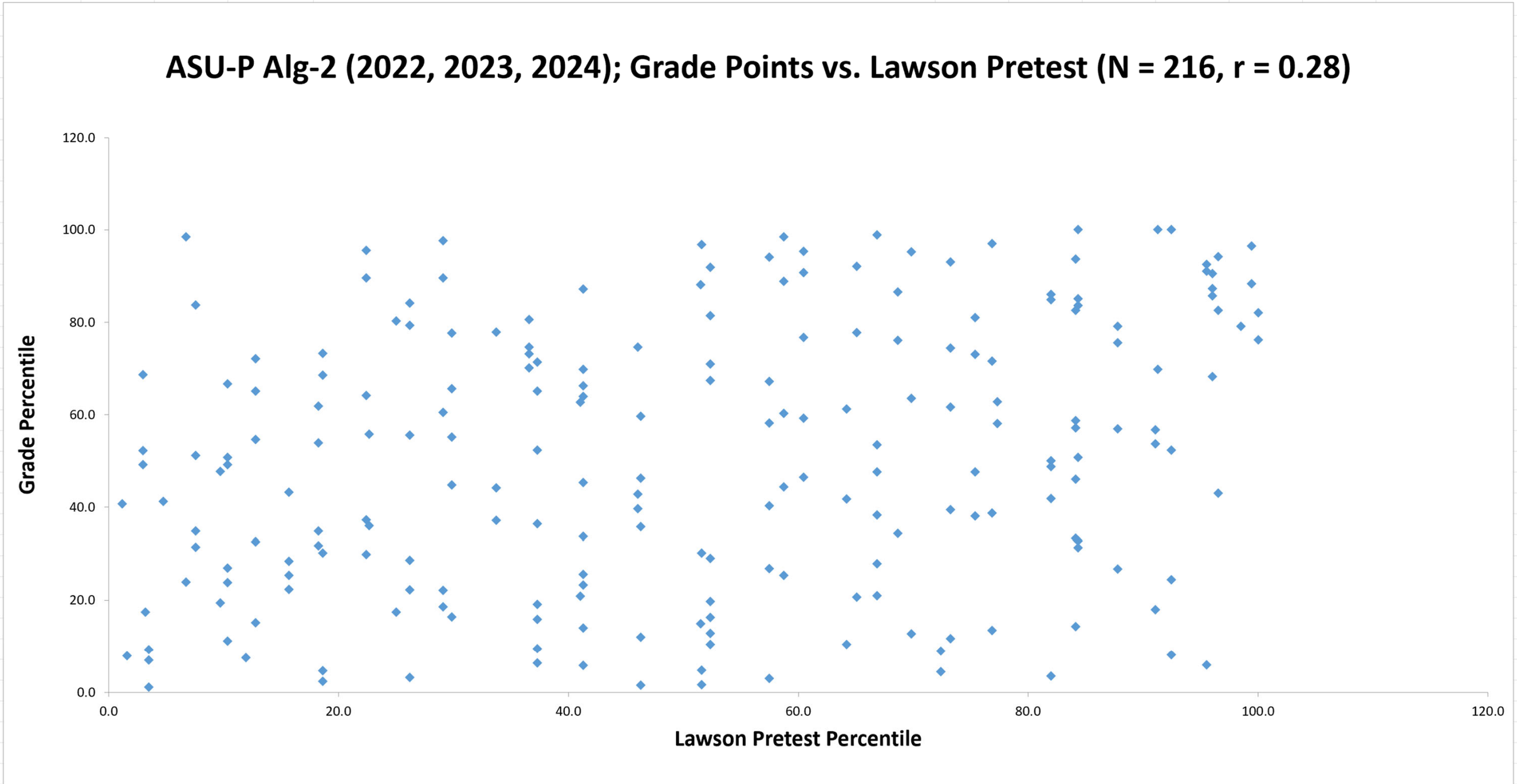
**that is, the students in Alg-2 ASU-P 2022-23-24*

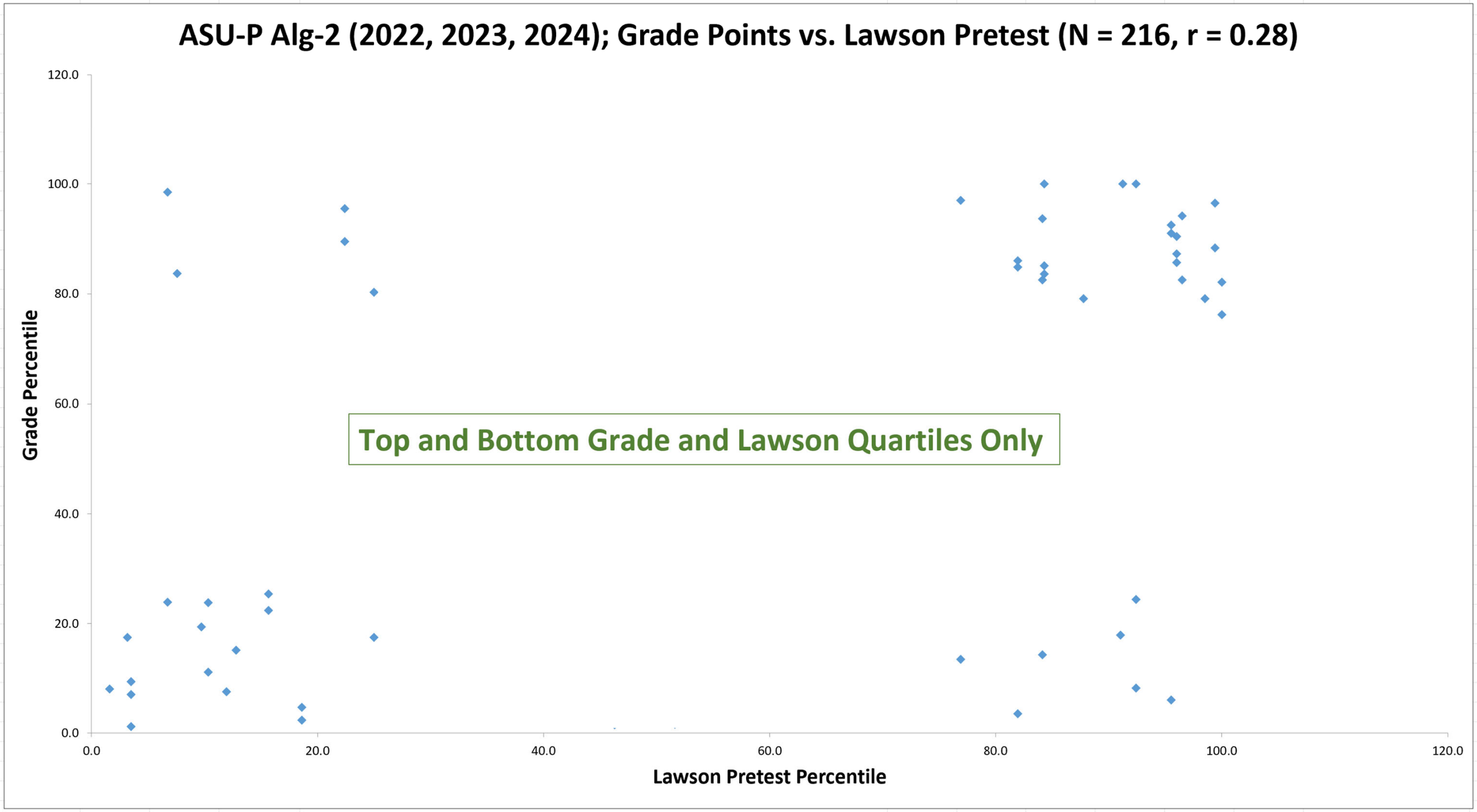
Relevant Questions

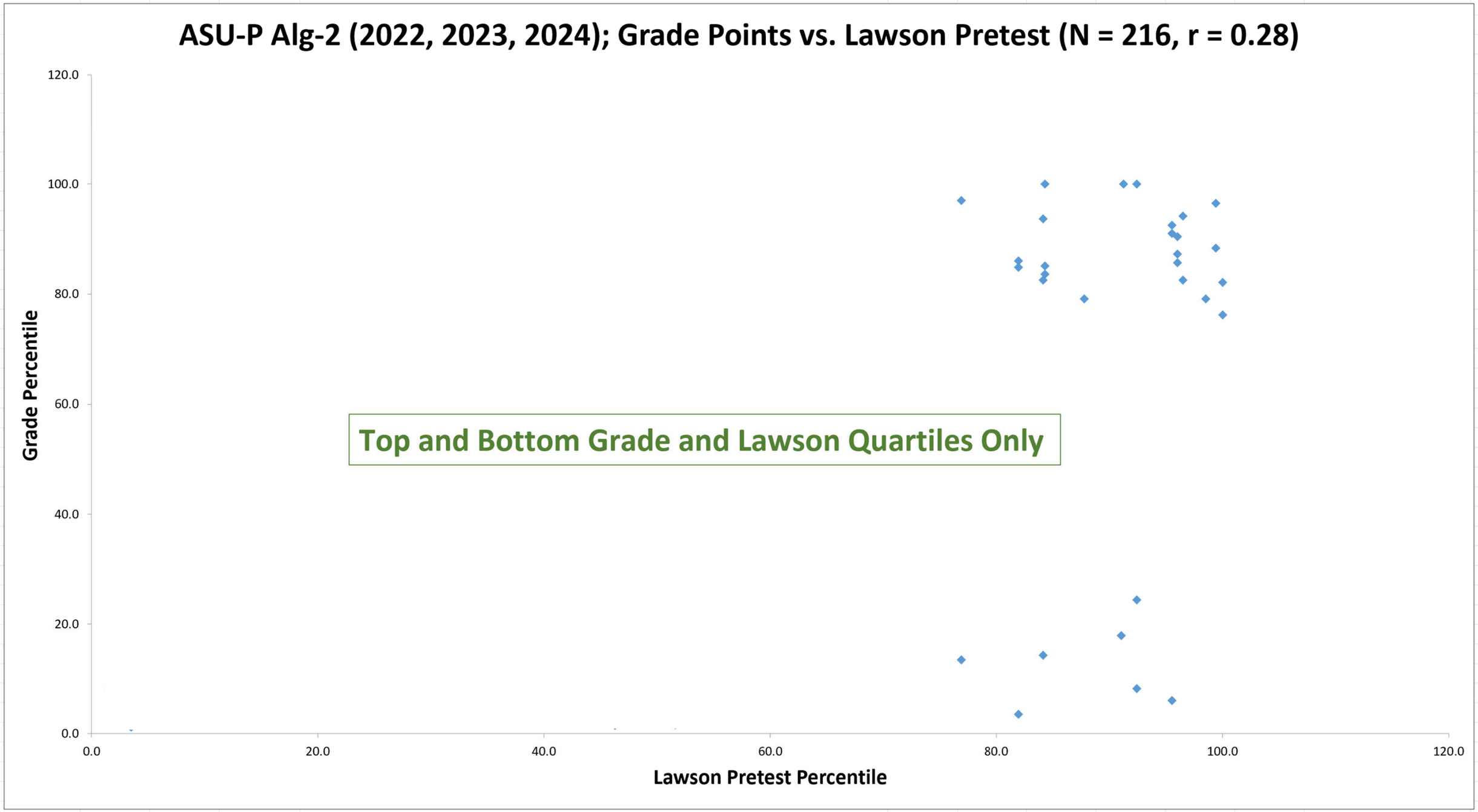
- Does using multiple predictor variables offer greater predictive power than using just one of them? *Yes*

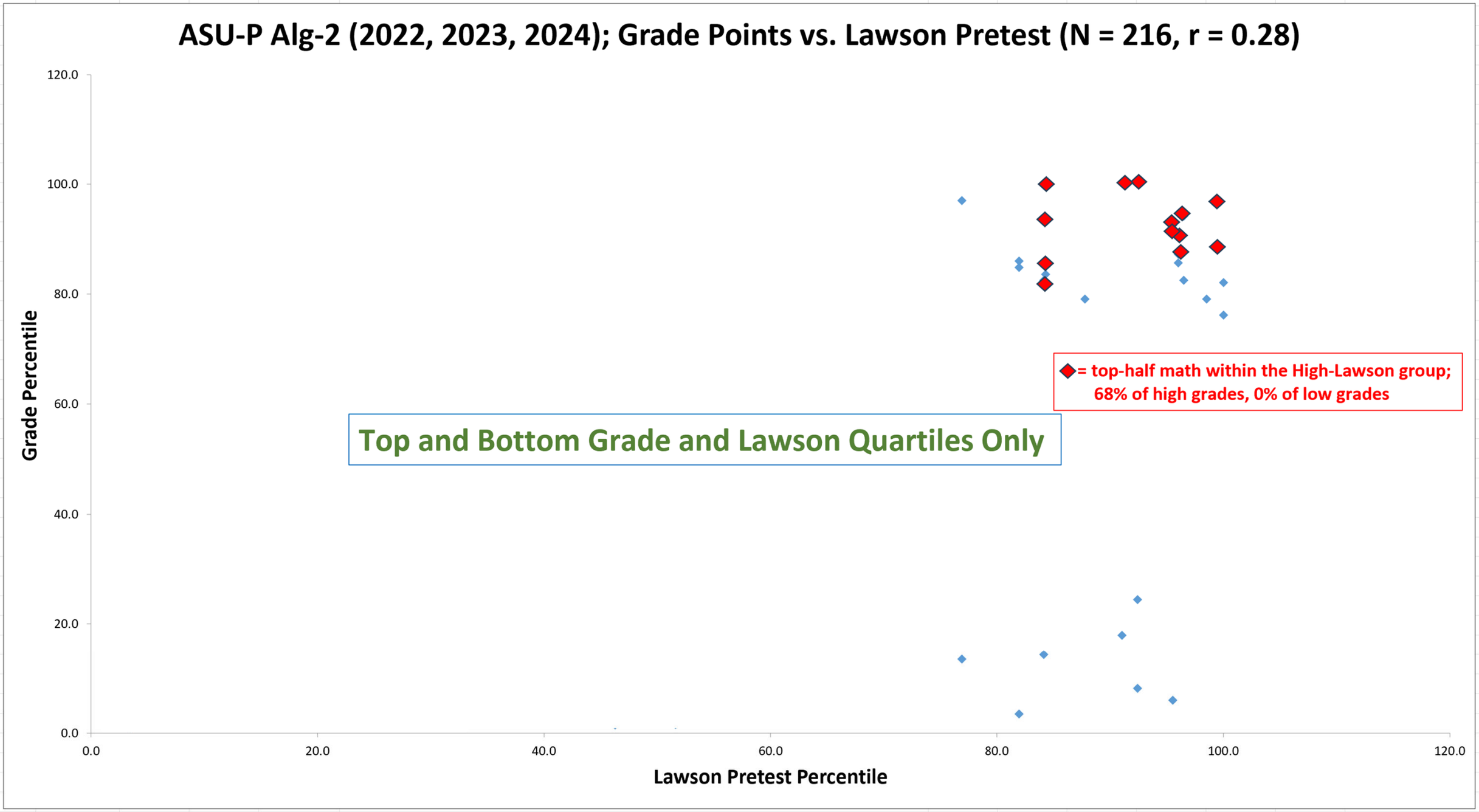
Further Analysis of Alg-2 ASU-P sample (*N* = 216)

		Probability of top-quartile grade	Probability of bottom-quartile grade
Top-Quartile on Lawson Pretest	Top-half on Math pretest	54%	0%
	Bottom-half on Math pretest	24%	28%
	Ratio	2.3	“∞”


ASU-P Alg-2 (2022, 2023, 2024); Grade Points vs. Lawson Pretest (N = 216, r = 0.28)
Grade Percentile
120.0
100.0
80.0
60.0
40.0
20.0
0.0
0.0
20.0
40.0
60.0
80.0
100.0
120.0
Lawson Pretest Percentile

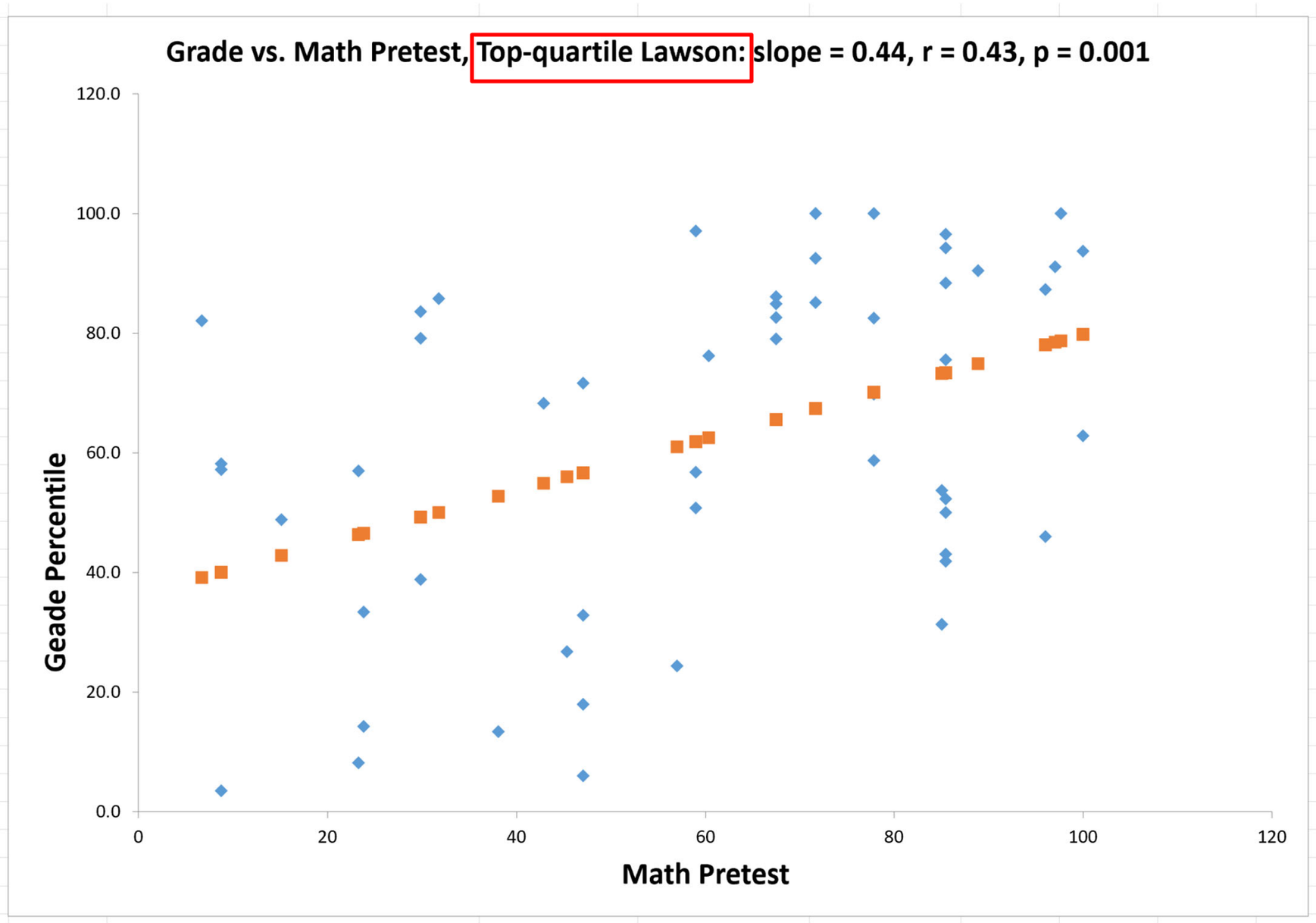

ASU-P Alg-2 (2022, 2023, 2024); Grade Points vs. Lawson Pretest (N = 216, r = 0.28)
Grade Percentile
120.0
100.0
80.0
60.0
40.0
20.0
0.0
Top and Bottom Grade and Lawson Quartiles Only
0.0
20.0
40.0
60.0
80.0
100.0
120.0
Lawson Pretest Percentile

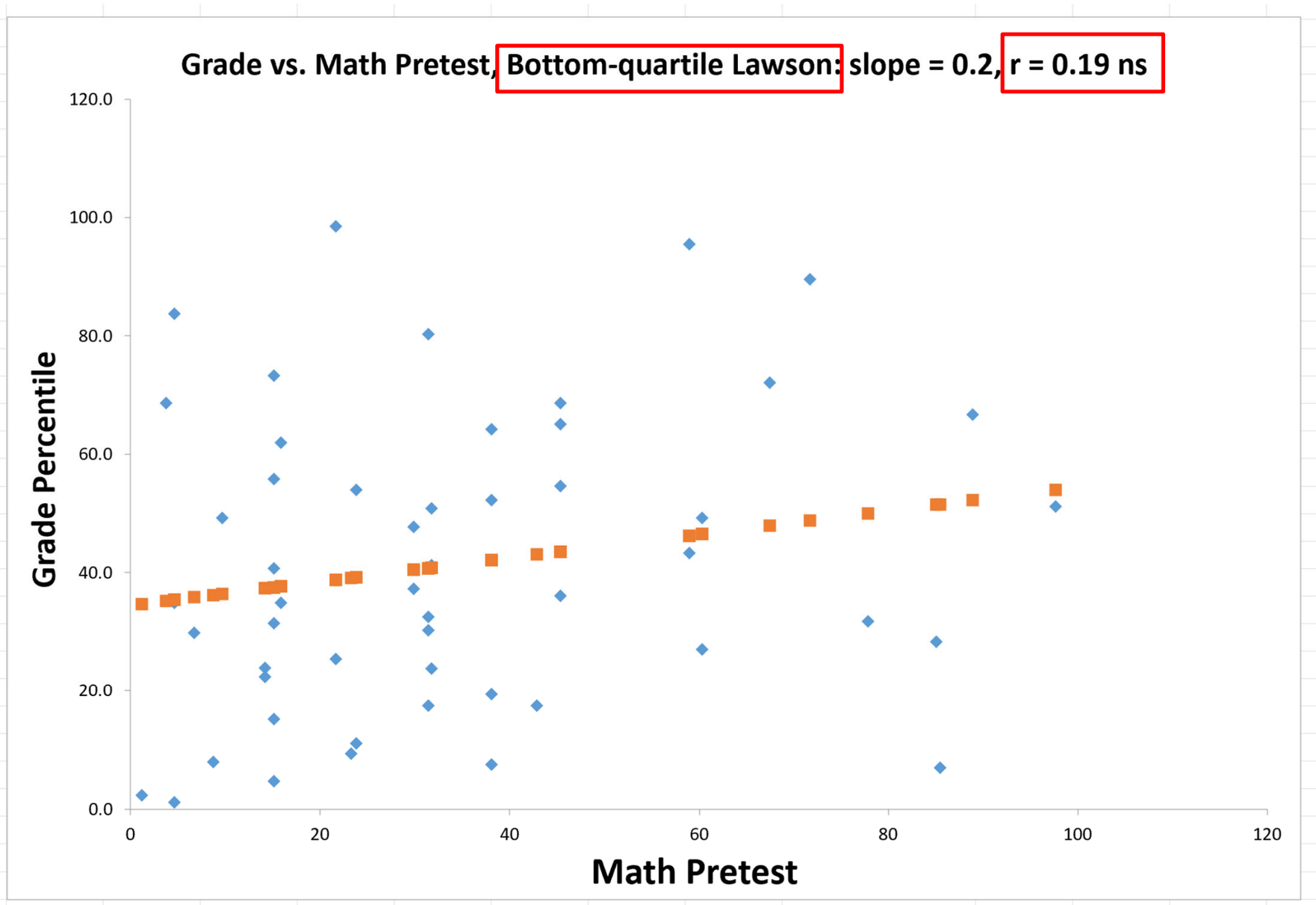

ASU-P Alg-2 (2022, 2023, 2024); Grade Points vs. Lawson Pretest (N = 216, r = 0.28)
Grade Percentile
120.0
100.0
80.0
60.0
40.0
20.0
0.0
0.0
20.0
40.0
60.0
80.0
100.0
120.0
Lawson Pretest Percentile
Top and Bottom Grade and Lawson Quartiles Only


ASU-P Alg-2 (2022, 2023, 2024); Grade Points vs. Lawson Pretest (N = 216, r = 0.28)
Grade Percentile
120.0
100.0
80.0
60.0
40.0
20.0
0.0
0.0
20.0
40.0
60.0
80.0
100.0
120.0
Lawson Pretest Percentile
= top-half math within the High-Lawson group;
68% of high grades, 0% of low grades
Top and Bottom Grade and Lawson Quartiles Only

Relevant Questions

- Does better performance on one pretest indicate that another pretest is more (or less) predictive? (This would be an "interaction" effect.) *Maybe*


Grade vs. Math Pretest, Top-quartile Lawson: slope = 0.44, r = 0.43, p = 0.001
Geade Percentile
120.0
100.0
80.0
60.0
40.0
20.0
0.0
0
20
40
60
80
100
120
Math Pretest


Grade vs. Math Pretest, Bottom-quartile Lawson: slope = 0.2, r = 0.19 ns
Grade Percentile
120.0
100.0
80.0
60.0
40.0
20.0
0.0
0
20
40
60
80
100
120
Math Pretest

Important Note

- Anecdotal evidence shows:
  - Students with low pretest scores but high grades are often highly engaged and regular participants in class activity
  - High scores but low grades are often associated with missing many classes and assignments

Summary

- High and low pretest scores on diagnostic tests are consistently predictive of students' probability of attaining high or low grades
- High pre-instruction scores on a math diagnostic, a test of scientific reasoning, and the FCI are all *independently* associated with higher probability of getting high grades (and avoiding low 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)