

Predicting Student Performance in University Introductory Physics: The Role of Physics Concepts and Math Skills.



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**20 year continuing project to improve undergraduate education with contributions by:
Many faculty and graduate students of U of M Physics Department
In collaboration with U of M Physics Education Group**

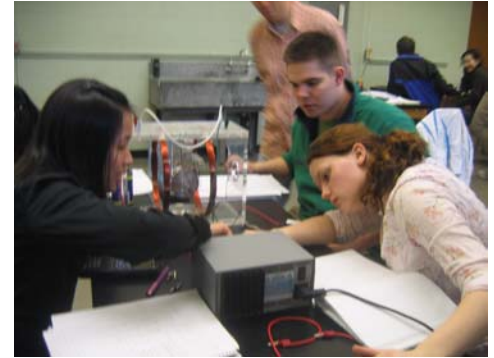
Details at <http://groups.physics.umn.edu/phased/>

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and the University of Minnesota**

Predicting Intro. Physics Performance?

A Guide for Discussion

1. **The Structure of the U of M Intro. Physics Course**
2. **Measuring Basic Physics Concepts.**
 - **The Force Concept Inventory (FCI)**
 - **Gender Differences?**
3. **Does the FCI Predict Success?**
 - **Gender Differences?**
4. **Does Math Skills Predict Success?**
 - **Gender Differences?**



U of M Physics Course Structure

LECTURES

Three hours each week, sometimes with informal cooperative groups. **Model** constructing knowledge, **model** problem solving framework.

DISCUSSION SECTION

One hour each Thursday -- groups practice using problem-solving framework to solve **context-rich problems** in **cooperative groups**. **Peer & instructor coaching**.

LABORATORY

Two hours each week -- **same** cooperative groups practice using framework to solve concrete experimental problems. **Same TA**. **Peer & instructor coaching**.

TESTS

Friday -- problem-solving quiz & conceptual questions (usually multiple choice) every three weeks.

Calculus-based Course for Engineering and Physical Science Students

Self Reported Student Majors (77% male class)

ALL	FEMALES	MALES	What is your intended major?
6.2%	14.4%	3.8%	Biological Science
4.4%	8.8%	3.1%	Chemistry
11.5%	6.2%	13.1%	Computer Science
59.6%	45.4%	63.7%	Engineering
2.7%	4.5%	2.2%	Mathematics
5.6%	11.8%	3.8%	Pre-medical
4.6%	4.2%	4.7%	Physics/Astrophysics
3.3%	3.0%	3.4%	Social Science
9.2%	10.9%	8.7%	Other
7.8%	7.9%	7.8%	Undecided

Number of Students

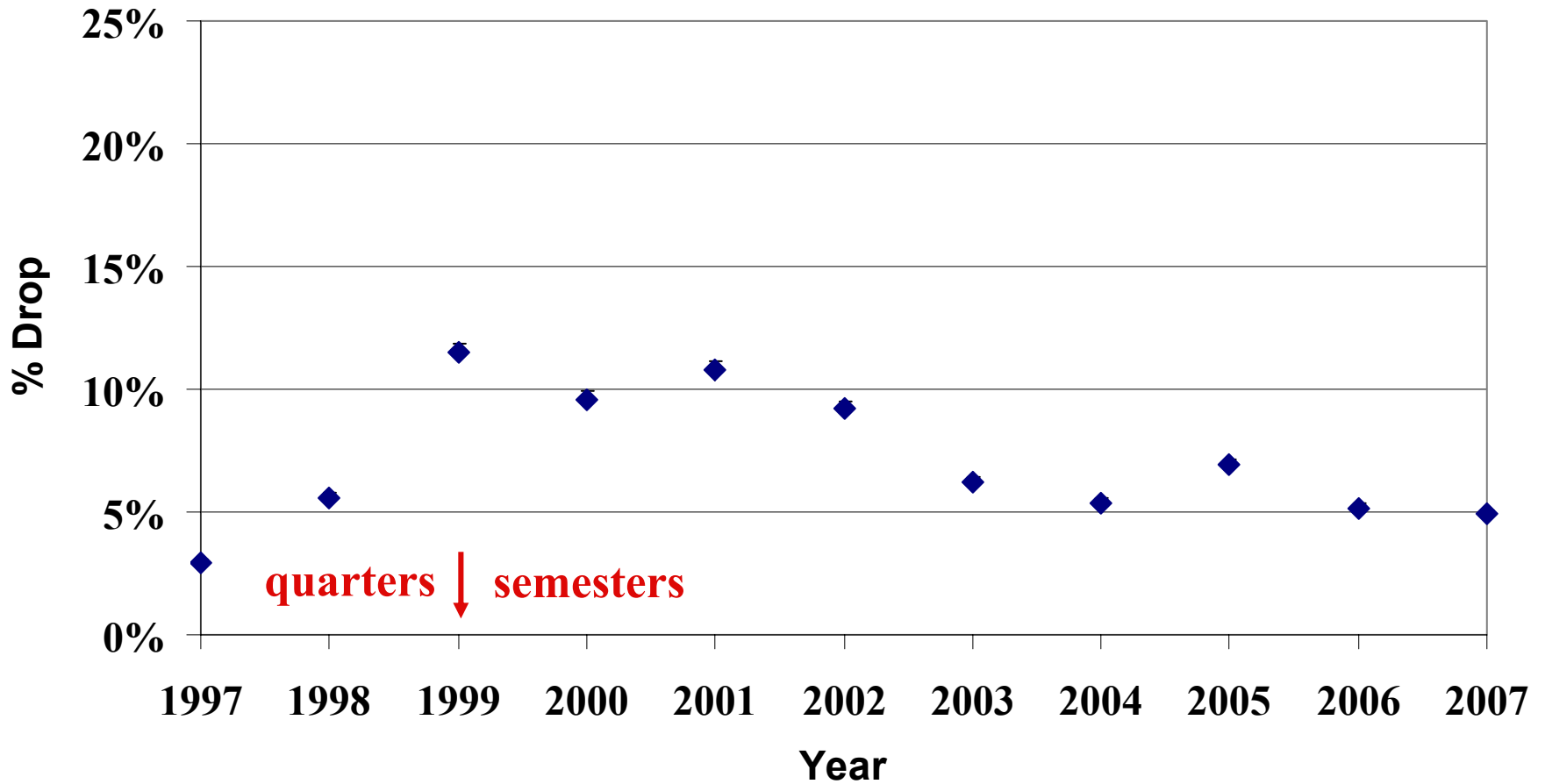
Lecture section = 250

Discussion section = 16

Lab section = 16

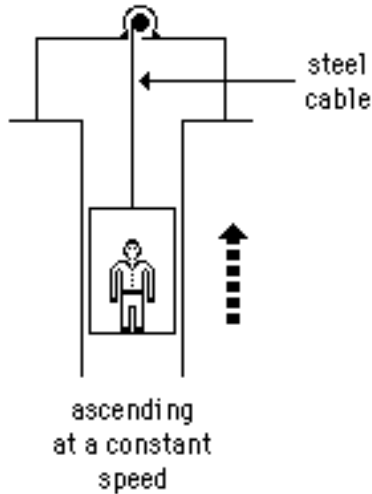
Retention

Drop % Physics 1301



Dropout rate to 6%, F/D rate to 3% in all classes

FCI Question 17

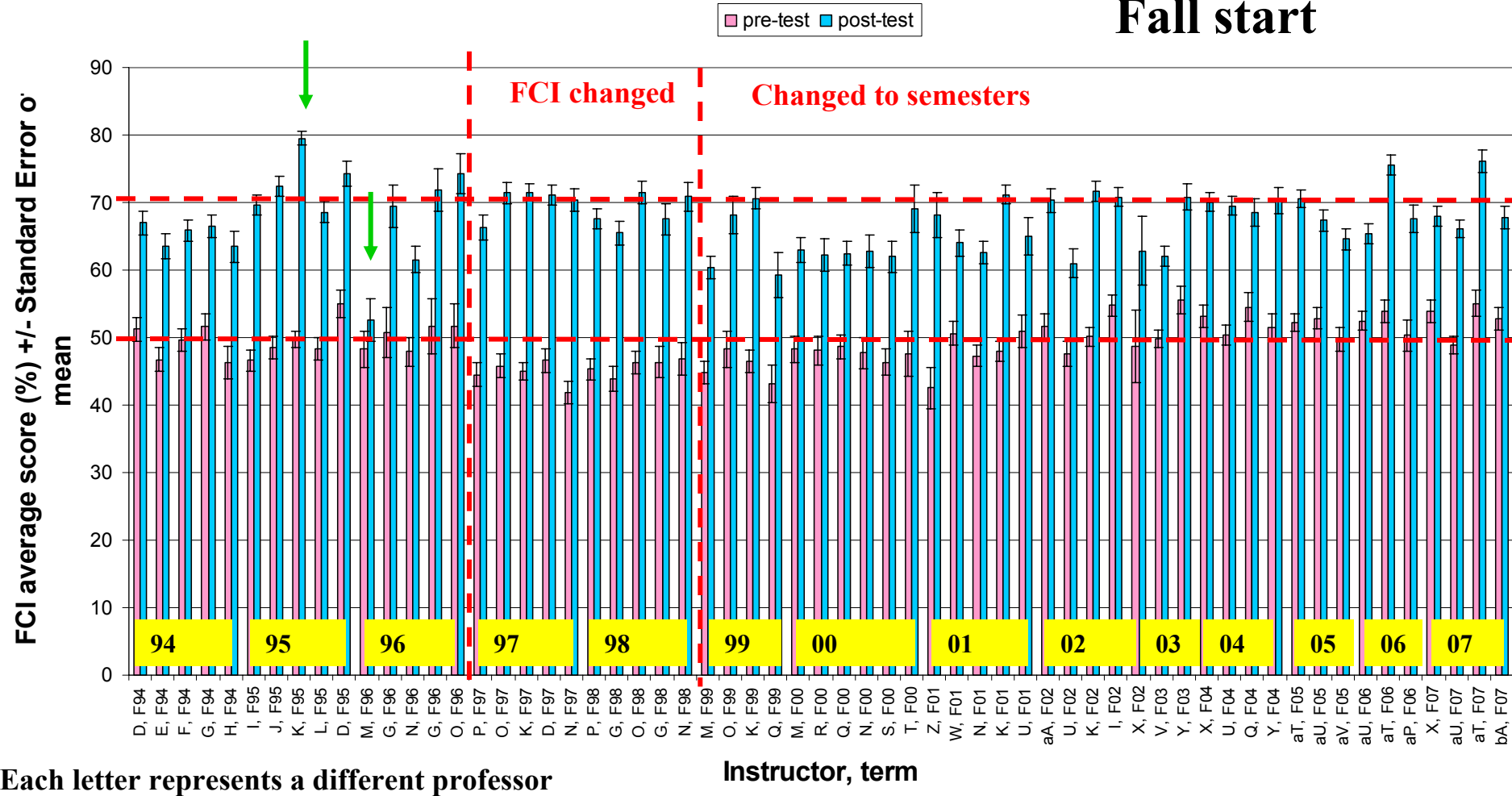


An elevator is being lifted up an elevator shaft at a constant speed by a steel cable, as shown in the figure. All frictional effects are negligible. In this situation, forces on the elevator are such that:

- | | <u>Pre</u> | <u>Post</u> |
|--|------------|-------------|
| (A) the upward force by the cable is greater than the downward force of gravity. | 64 | 36 |
| (B) the upward force by the cable is equal to the downward force of gravity. | 18 | 60 |
| (C) the upward force by the cable is smaller than the downward force of gravity. | 2 | 0 |
| (D) the upward force by the cable is greater than the sum of the downward force of gravity and a downward force due to the air. | 11 | 2 |
| (E) None of the above. (The elevator goes up because the cable is shortened, not because an upward force is exerted on the elevator by the cable). | 5 | 1 |

Introductory Physics for Physical Science and Engineering Students

Fall start

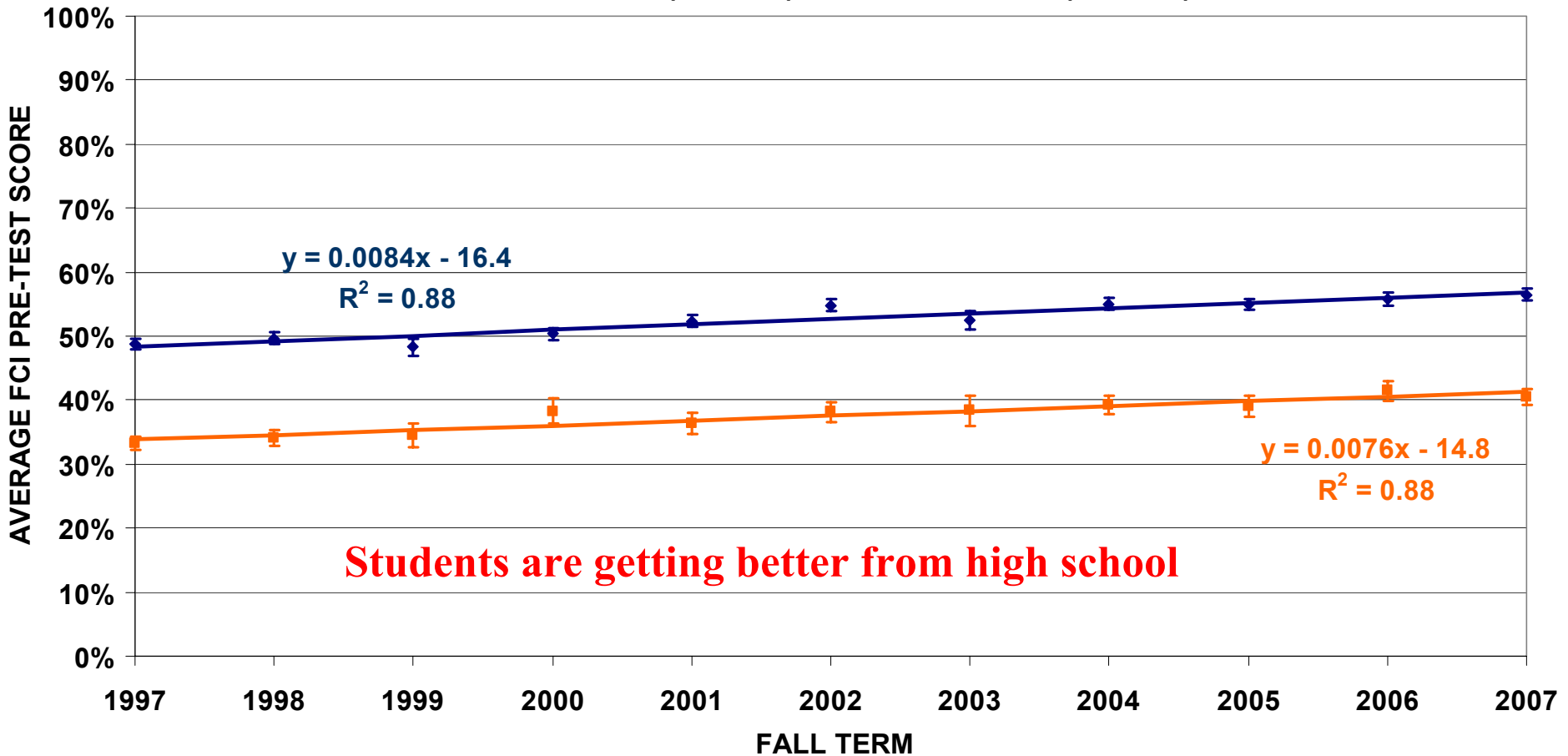


- Incoming student scores are slowly rising (better high school preparation)
- Our standard course (CGPS) achieves average FCI ~70%
- Our “best practices” course achieves average FCI ~80%
- Not executing any cooperative group procedures achieves average FCI ~50%

AVERAGE FCI PRE-TEST SCORES BY GENDER & YEAR

CALCULUS-BASED PHYSICS FOR SCIENTISTS & ENGINEERS, FALL TERMS 1997-2007

◆ MALES (N=4375) ■ FEMALES (N=1261)

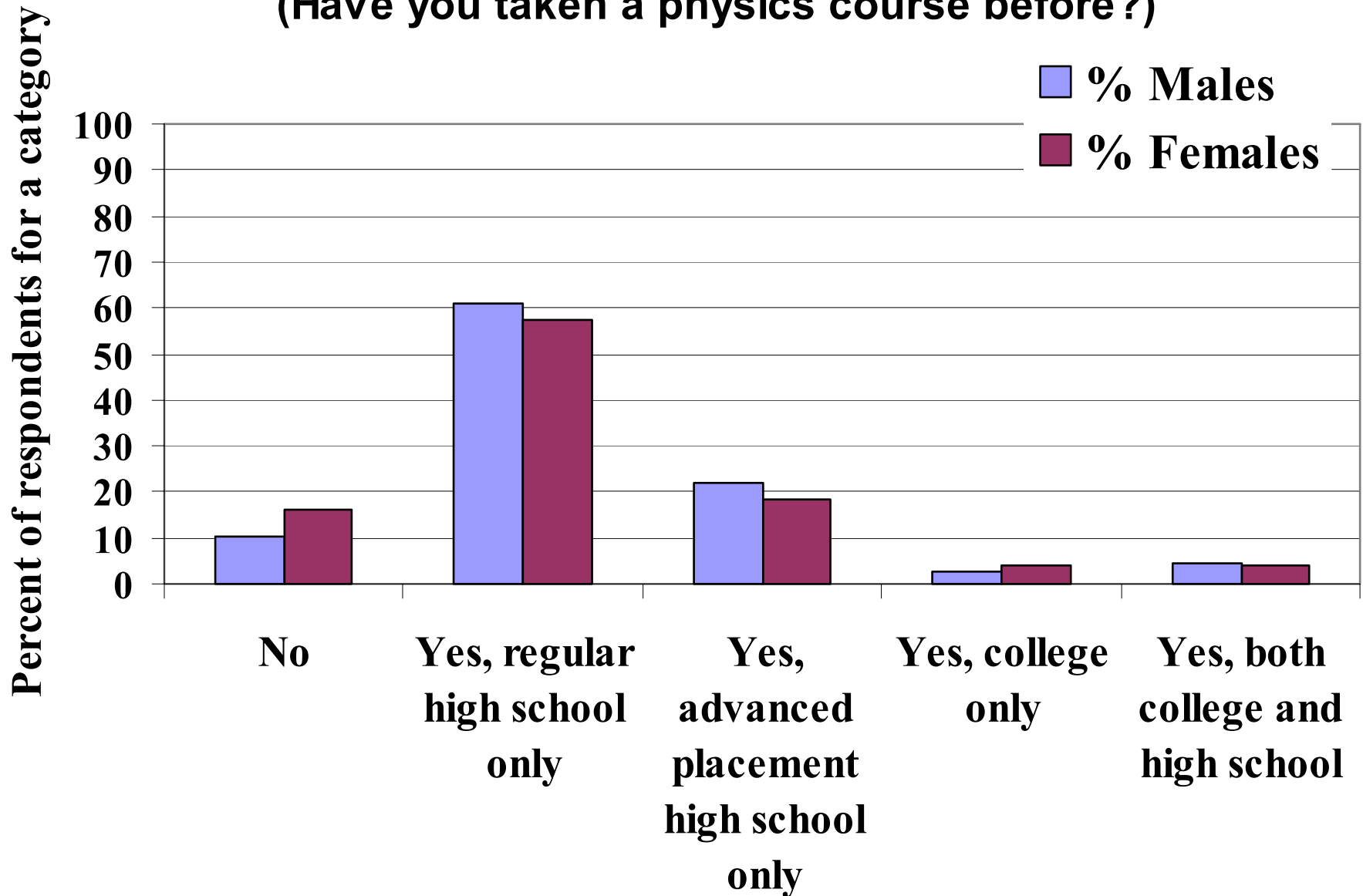


Students are getting better from high school

There is a gender gap in conceptual performance from high school

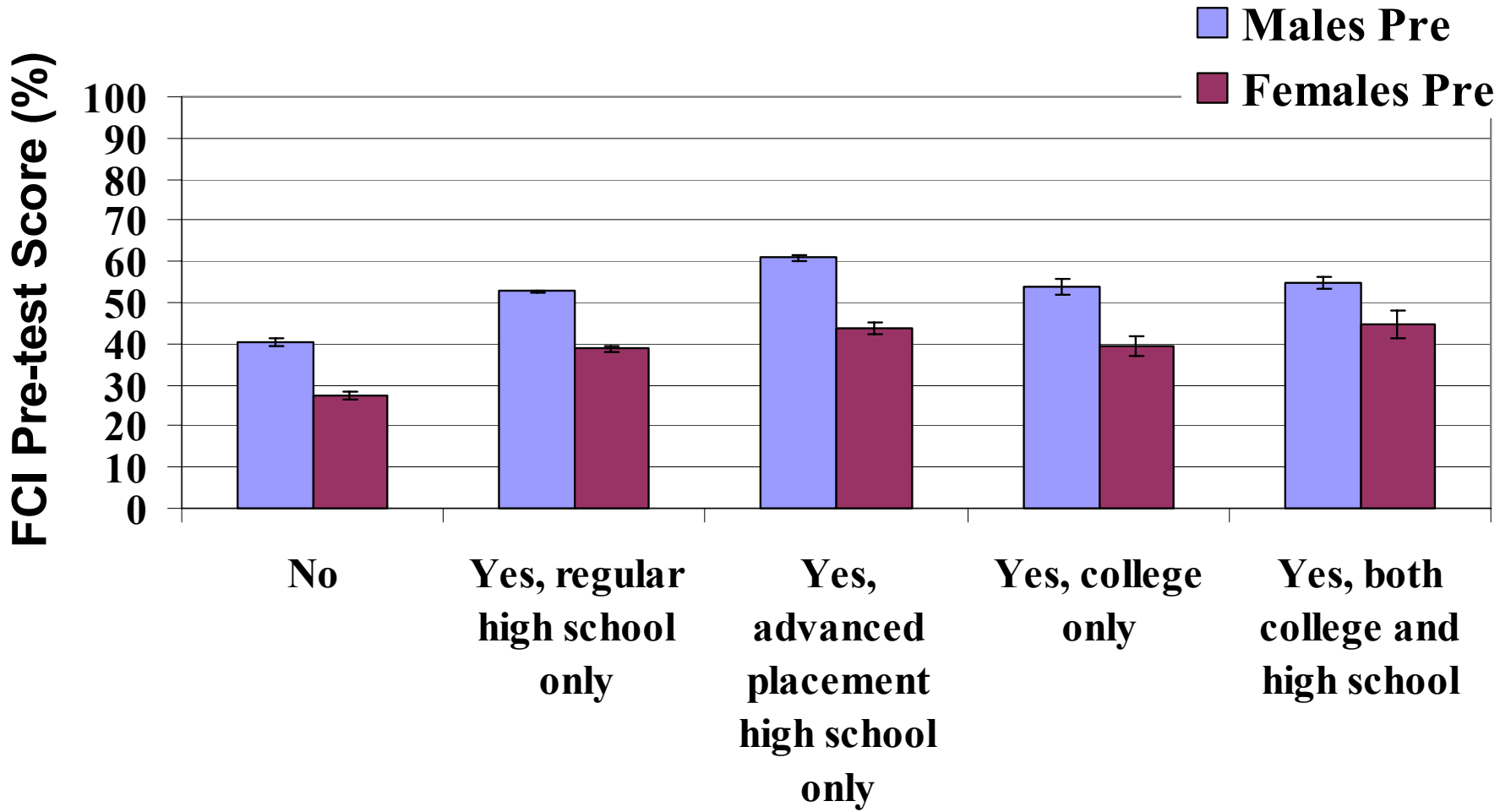
Males do better.

Previous physics experience of males and females (Have you taken a physics course before?)



About 90% of males and 85% females have had at least high school physics

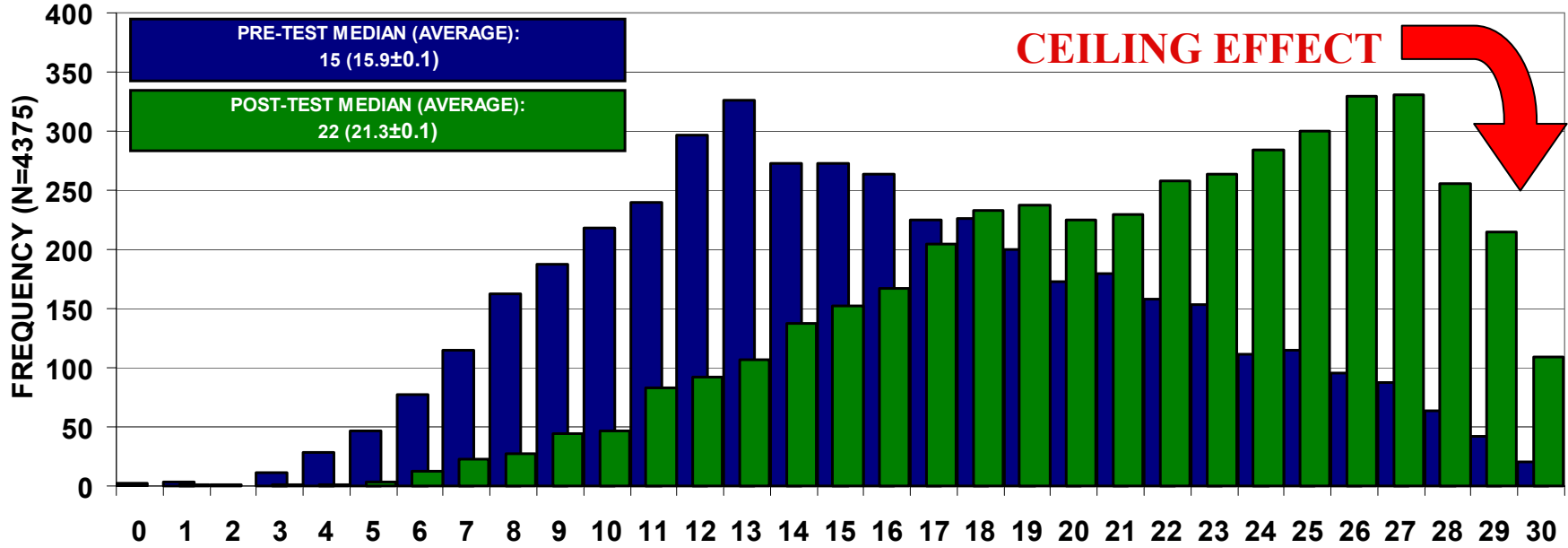
FCI Pretest scores by Previous Physics Experience (Have you taken a physics course before?)



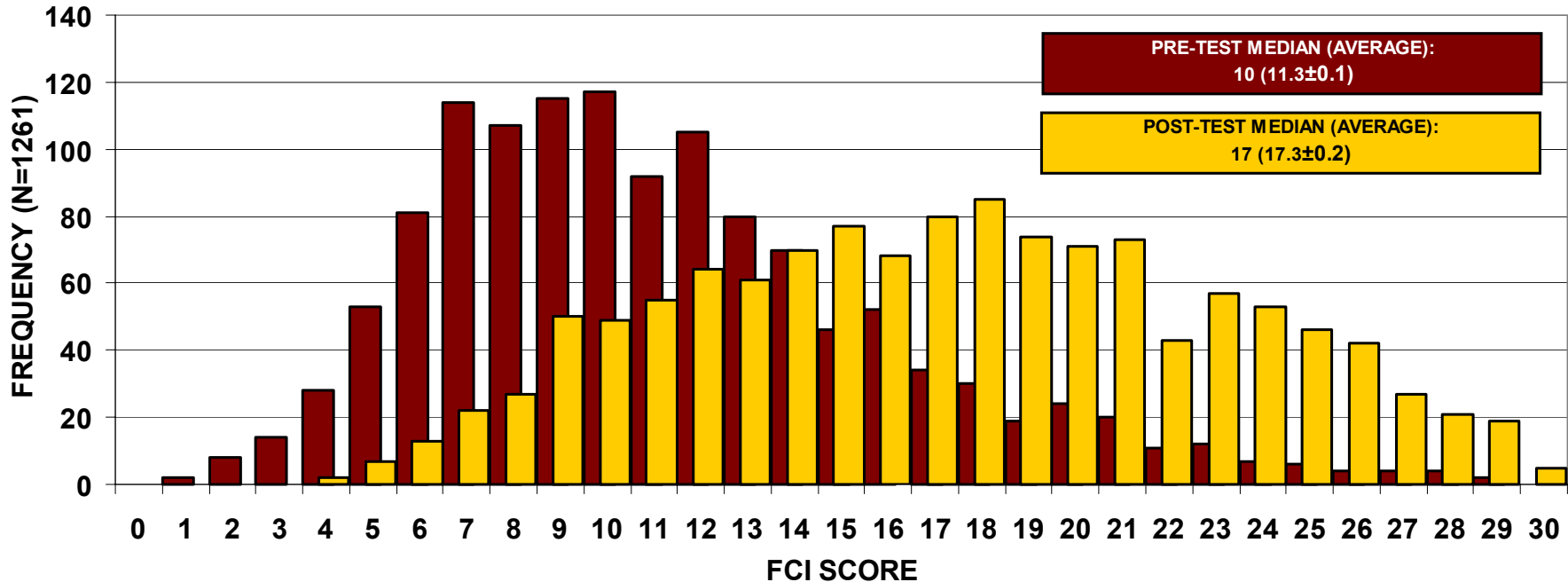
Gender gap is the same no matter what high school physics preparation.

MALE FCI PRE-TEST & POST-TEST SCORES
 CALCULUS-BASED PHYSICS FOR SCIENTISTS & ENGINEERS, FALL TERMS 1997-2007

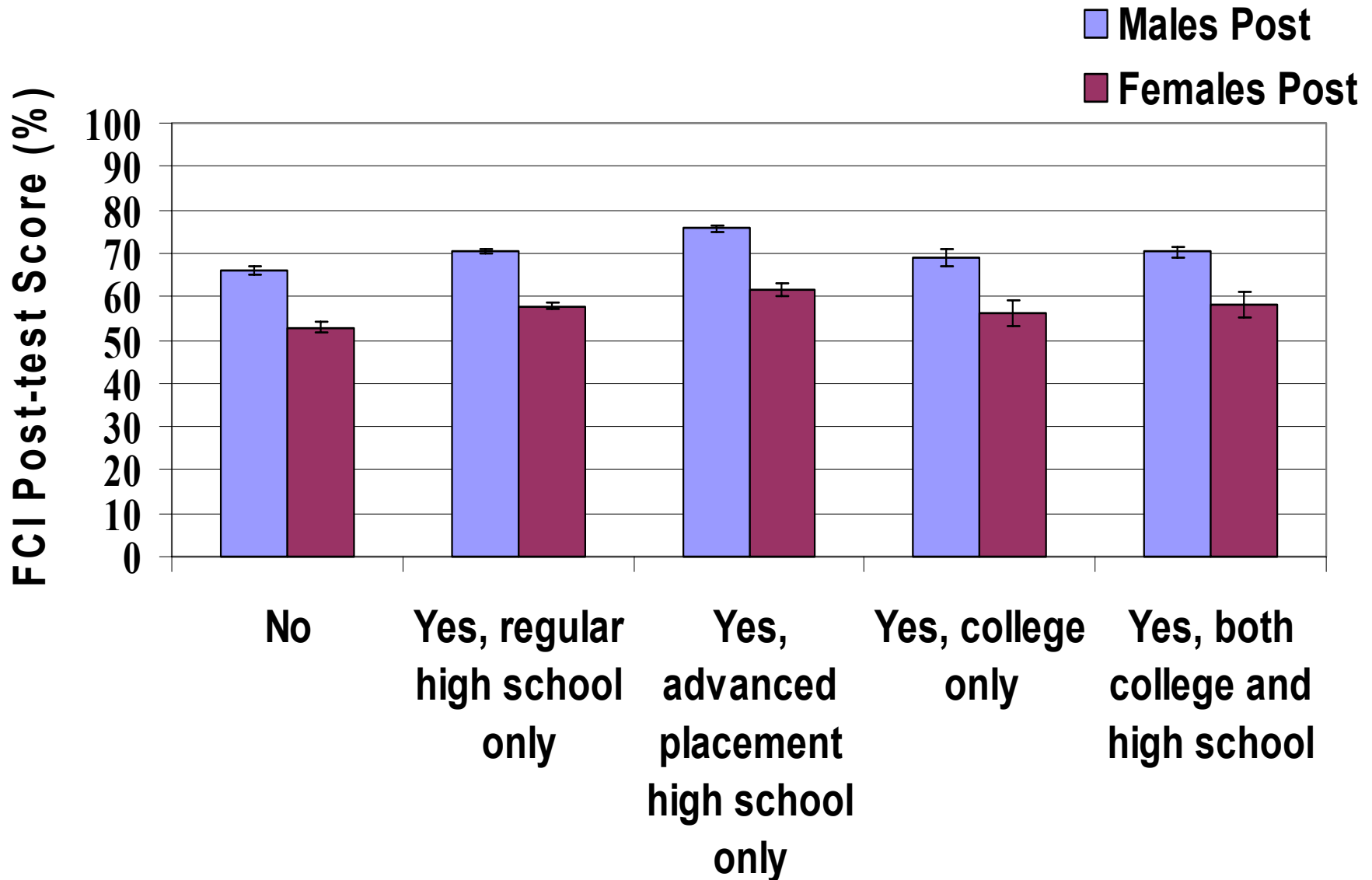
■ MALES PRE-TEST ■ MALES POST-TEST



■ FEMALES PRE-TEST ■ FEMALES POST-TEST



FCI Posttest scores by Previous Physics Experience (Have you taken a physics course before?)

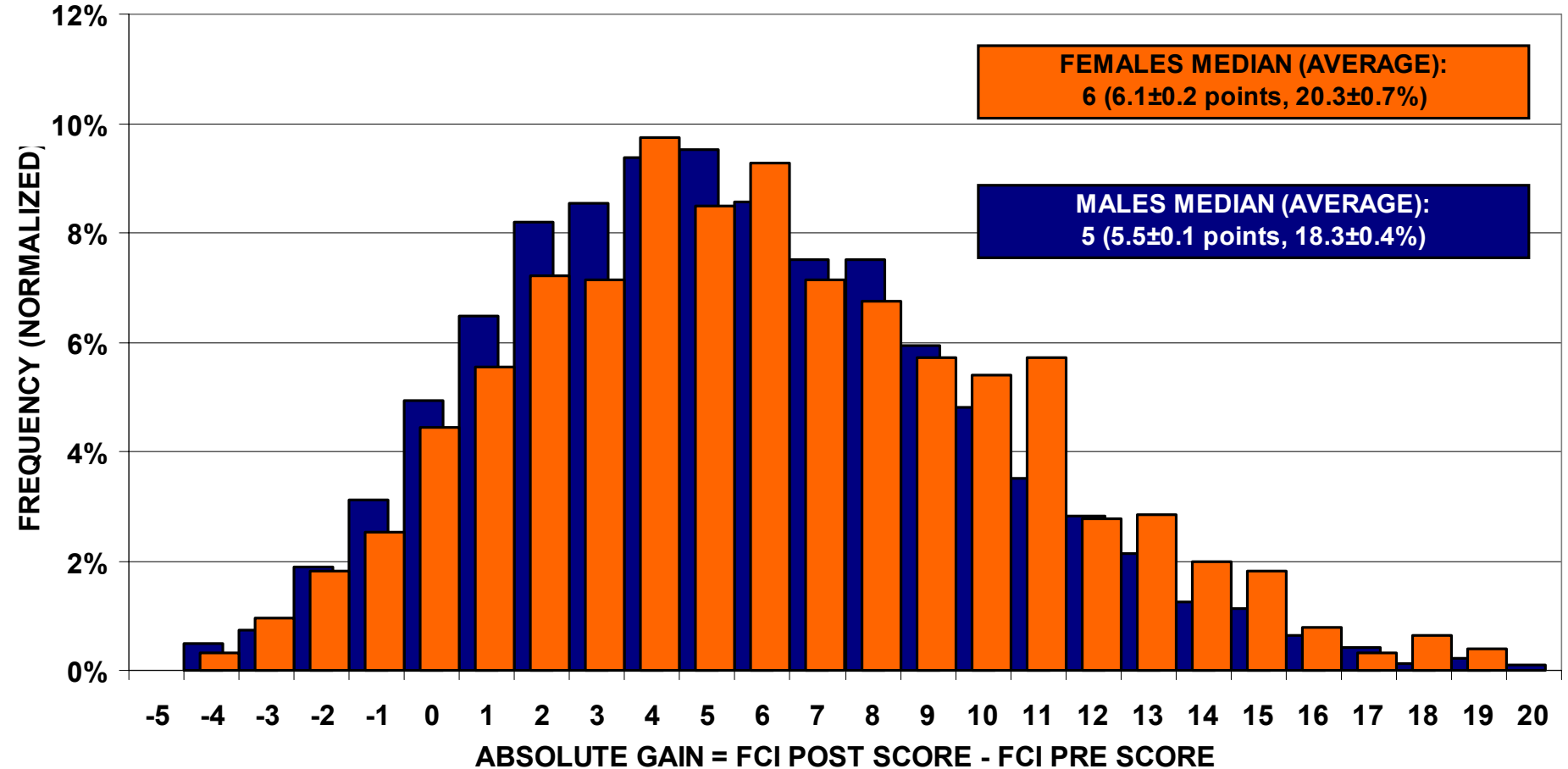


Gender gap persists no matter what high school physics preparation.

FCI ABSOLUTE GAIN BY GENDER

CALCULUS-BASED PHYSICS FOR SCIENTISTS & ENGINEERS, FALL TERMS 1997-2007

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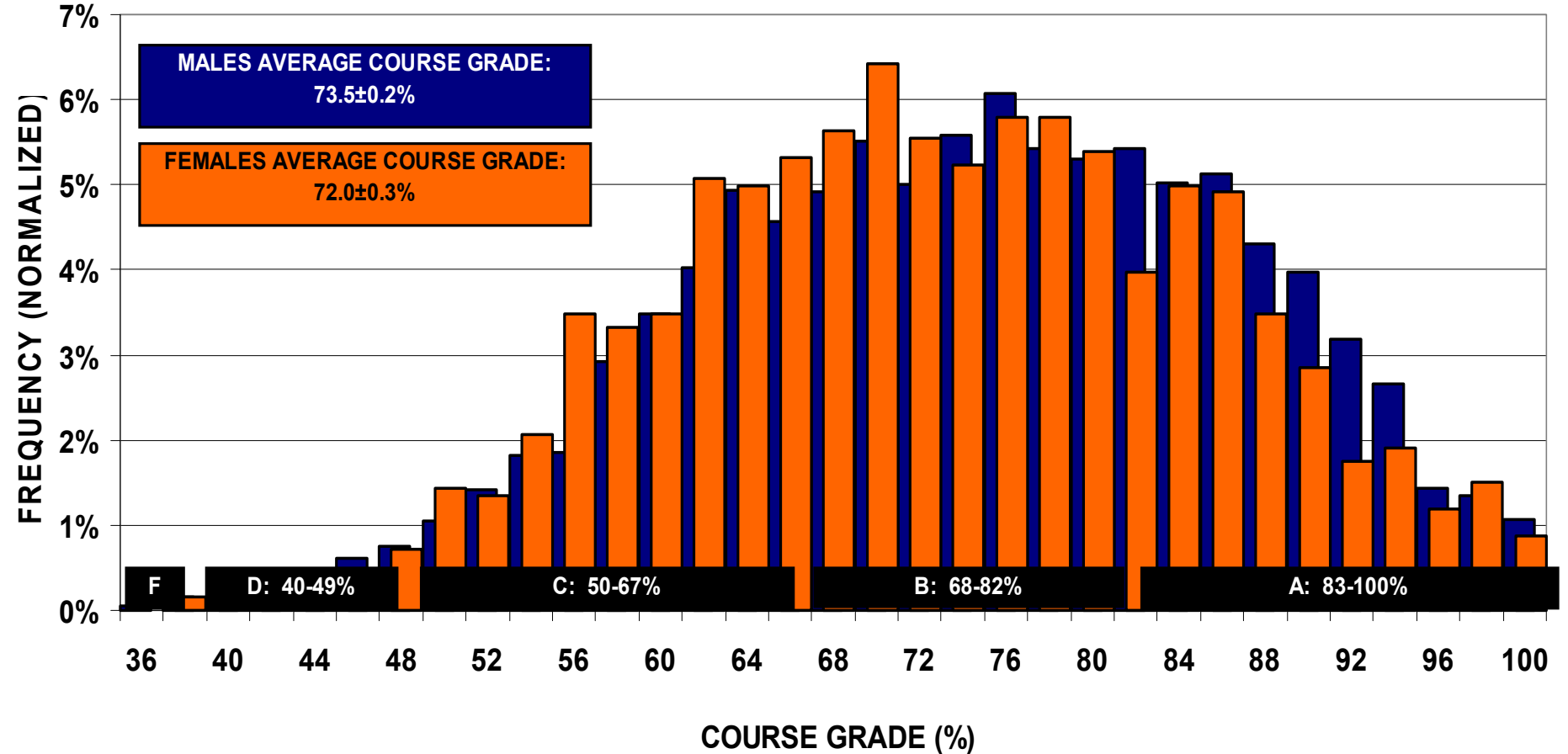


Males and females gain the same amount from the class.

COURSE GRADES BY GENDER

CALCULUS-BASED PHYSICS FOR SCIENTISTS & ENGINEERS, FALL TERMS 1997-2007

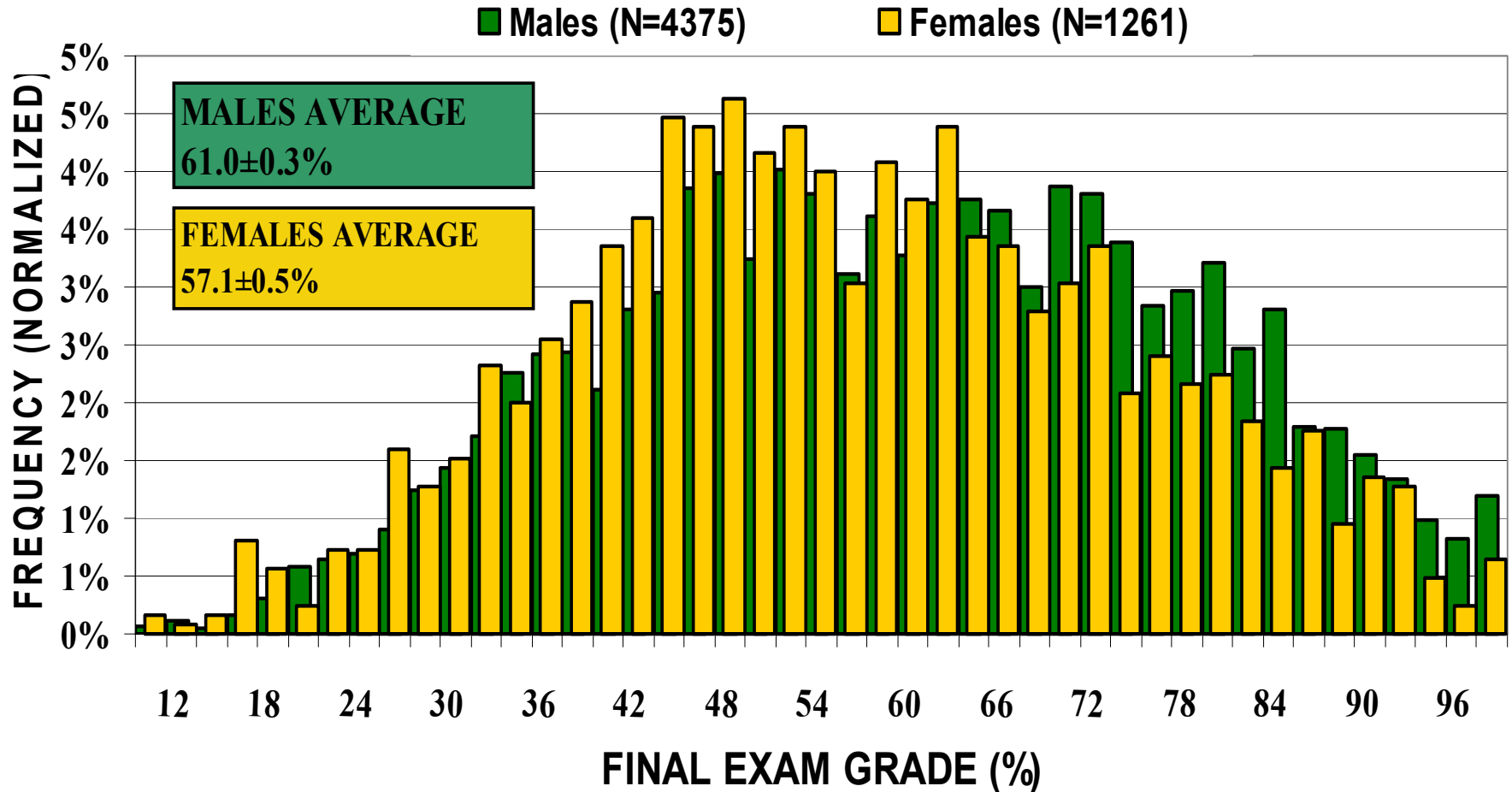
■ MALES (N=4375) ■ FEMALES (N=1261)



Males and females do about as well in the course.

FINAL EXAM GRADES BY GENDER

CALCULUS-BASED PHYSICS FOR SCIENTISTS & ENGINEERS, FALL TERMS 1997-2007



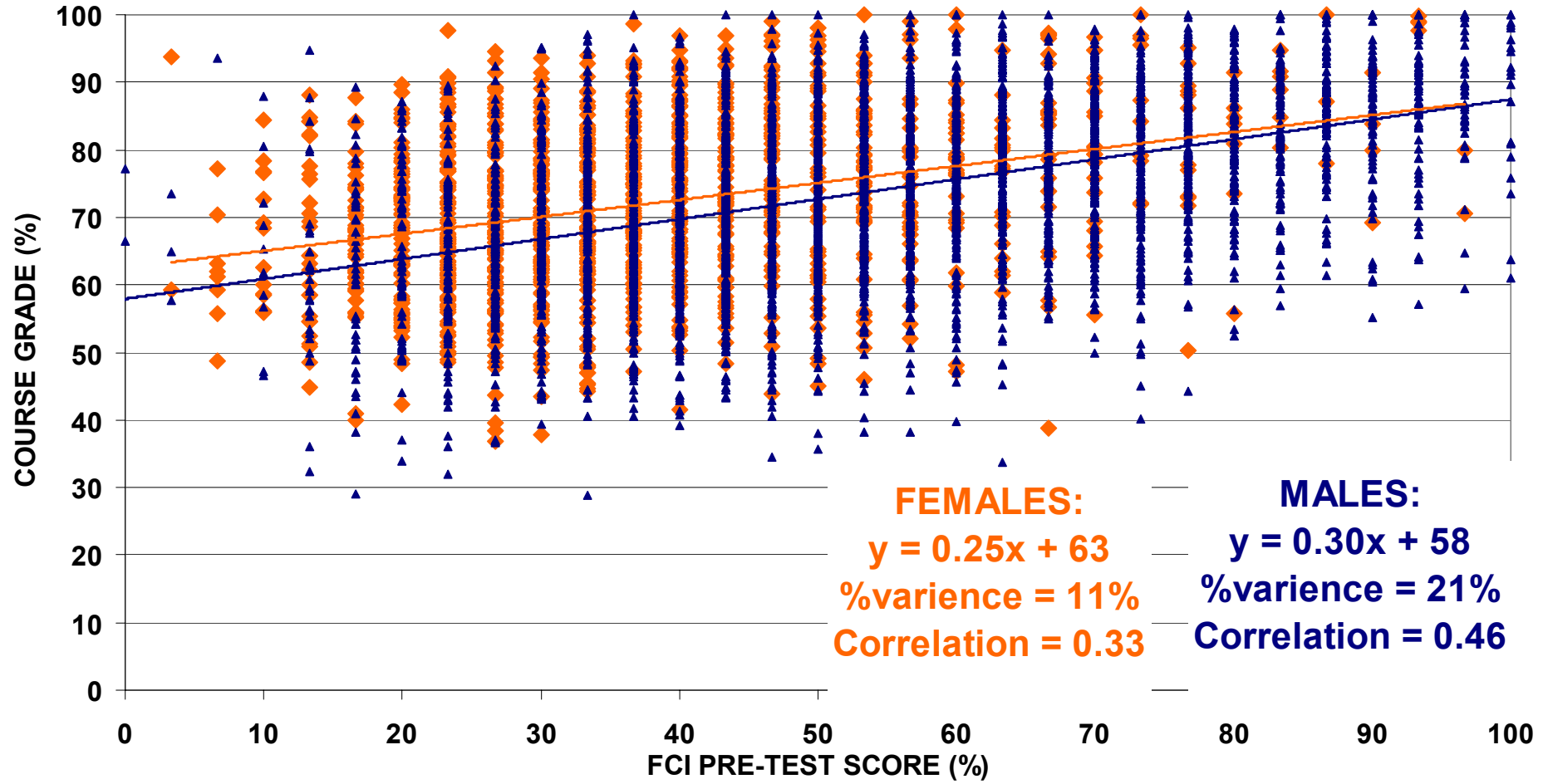
Males do slightly better in the course final exam problems.

Can the FCI be used as a placement test?

COURSE GRADE VS. FCI PRE-TEST SCORE

CALCULUS-BASED PHYSICS FOR SCIENTISTS & ENGINEERS, FALL TERMS 1997-2007

◆ FEMALES (N=1261) ▲ MALES (N=4375)



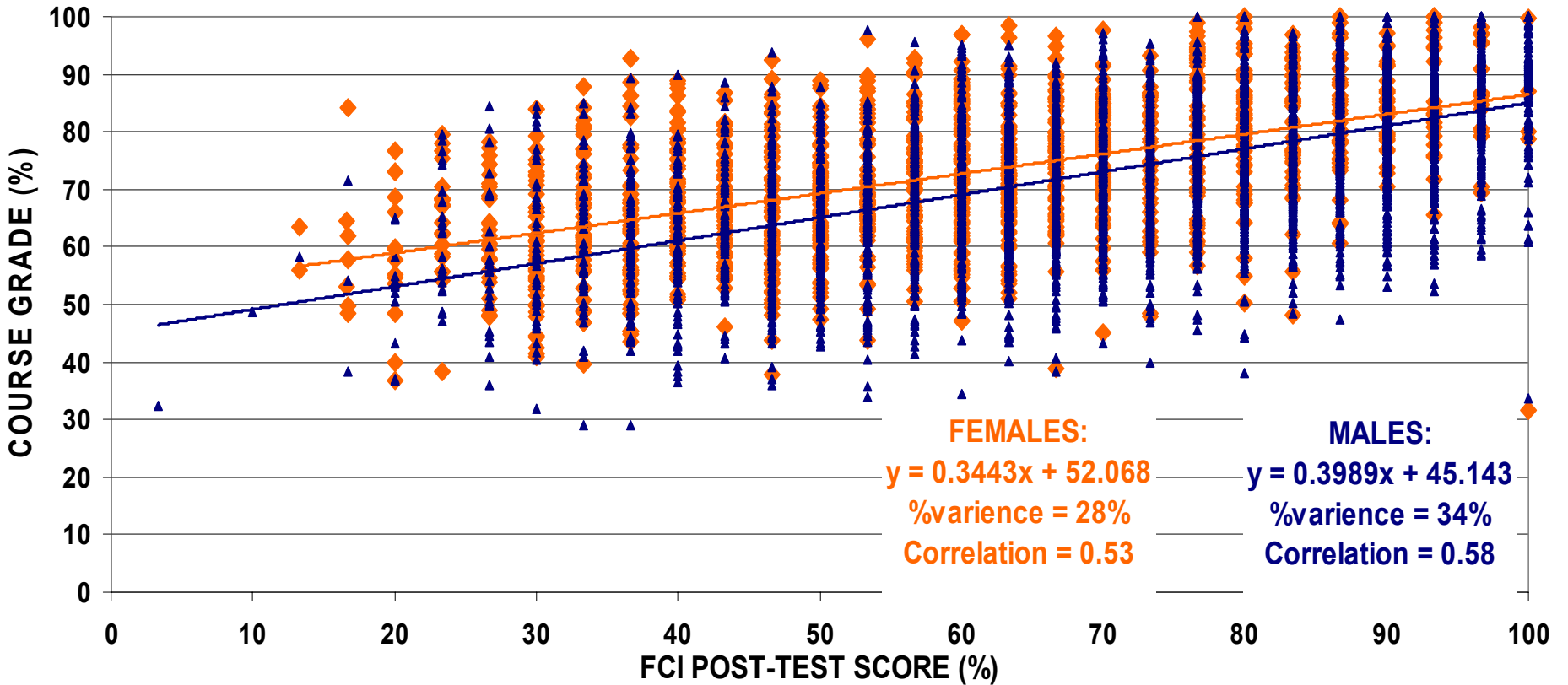
The FCI is not a good predictor of performance.

COURSE GRADE VS. FCI POST-TEST SCORE

CALCULUS-BASED PHYSICS FOR SCIENTISTS & ENGINEERS, FALL TERMS 1997-2007

◆ FEMALES (N=1261)

▲ MALES (N=4375)



Can a Math Skills Test be used as a placement test?

Algebra

Solve for **a** in the equation $a^2x + cy = t$

- (a) $\pm\sqrt{t - cy - x}$ (b) $\pm\sqrt{\frac{t - cy}{x}}$ [95-99%] (c) $\pm\frac{1}{a}\sqrt{t - cy}$
(d) $\frac{t - cy}{2x}$ (e) $(cy - t)(cy + t)$

Solve for **y** in the equation $\frac{ax + b}{cy + d} = f$

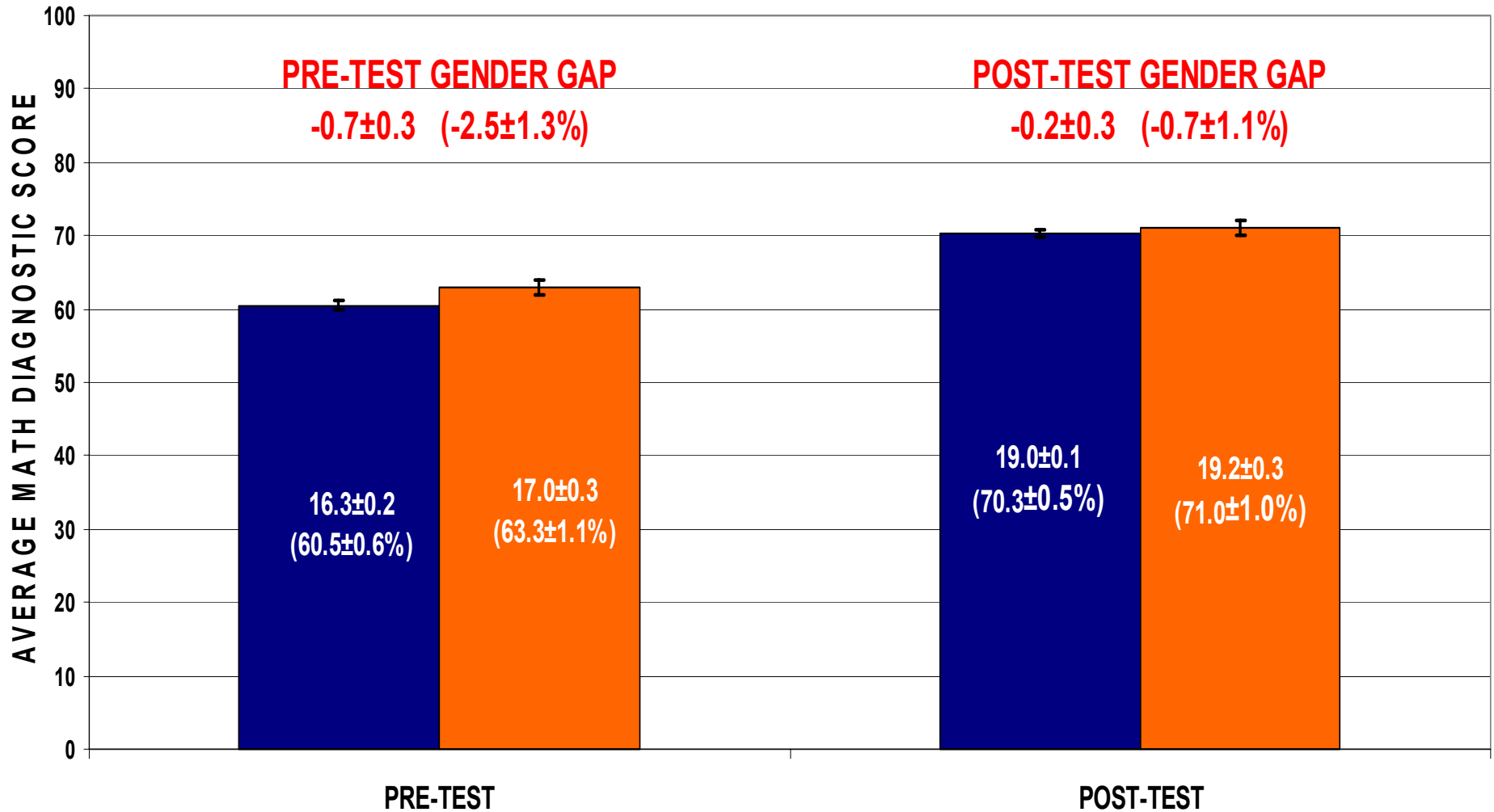
- (a) $\frac{ax + b - df}{cf} = y$ [49-72%] (b) $\frac{ax + b}{f + d}$ (c) $\frac{ax + b}{d} \left(\frac{1}{cf} \right)$
(d) $\frac{ax + b}{cf + d}$ (e) $\frac{1}{c} \left(\frac{f}{ax + b} - d \right)$ [15-34%]

AVERAGE MATH PRE-TEST & POST-TEST SCORES BY GENDER

CALCULUS-BASED PHYSICS FOR SCIENTISTS & ENGINEERS, FALL TERMS 2005-2007

■ MALES (N=845)

■ FEMALES (N=266)

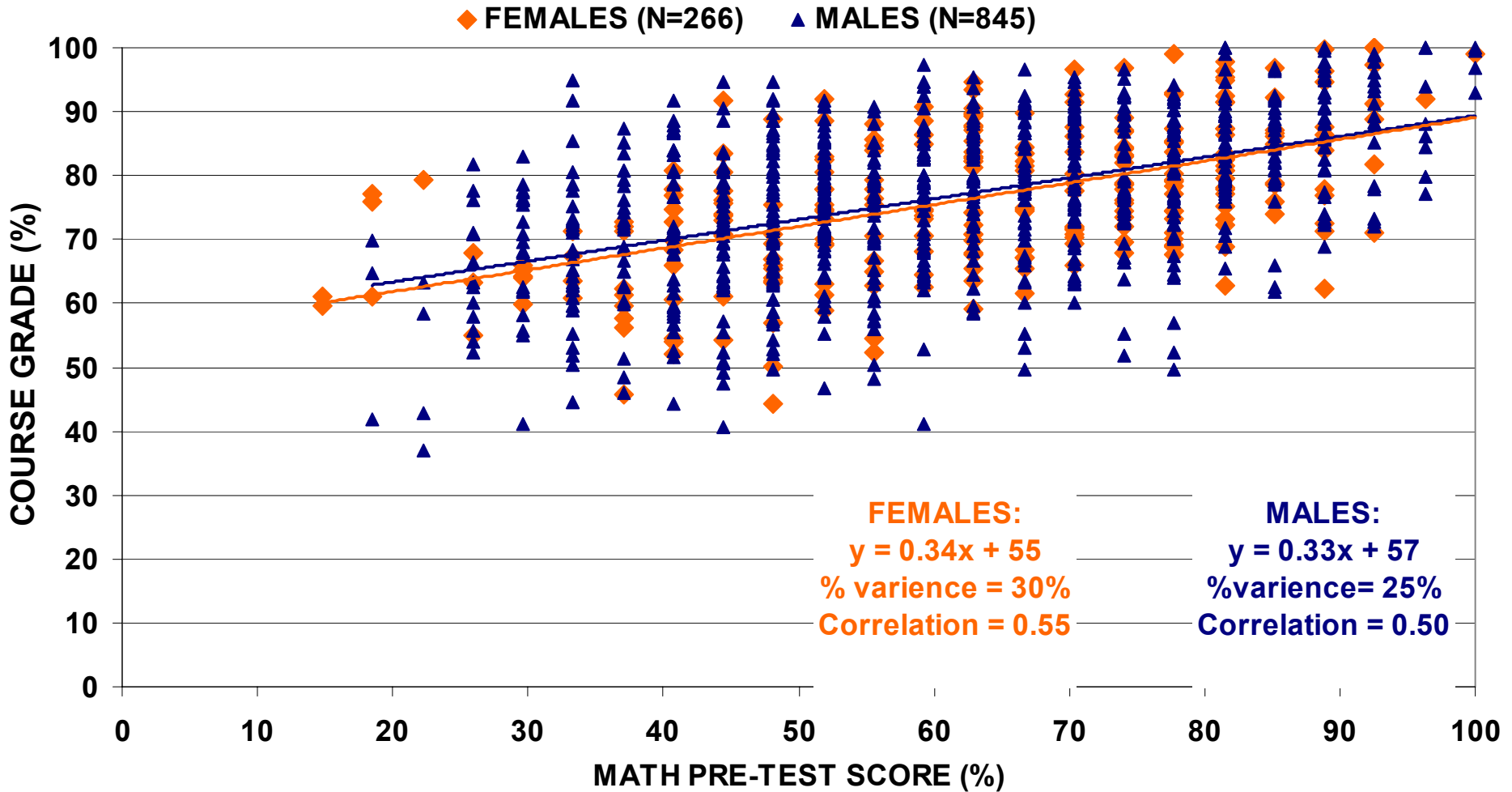


**There is a gender gap in math skills from high school
Females do slightly better.**

Can a Math Skills Test be used as a placement test?

COURSE GRADE VS. MATH PRE-TEST SCORE

CALCULUS-BASED PHYSICS FOR SCIENTISTS & ENGINEERS, FALL TERMS, 2005-2007



The Math Skills Test is not a good predictor of performance.

Predicting Success from PreTests

Math Skills (MST) accounts for 31% (F), 25% (M) of the grade

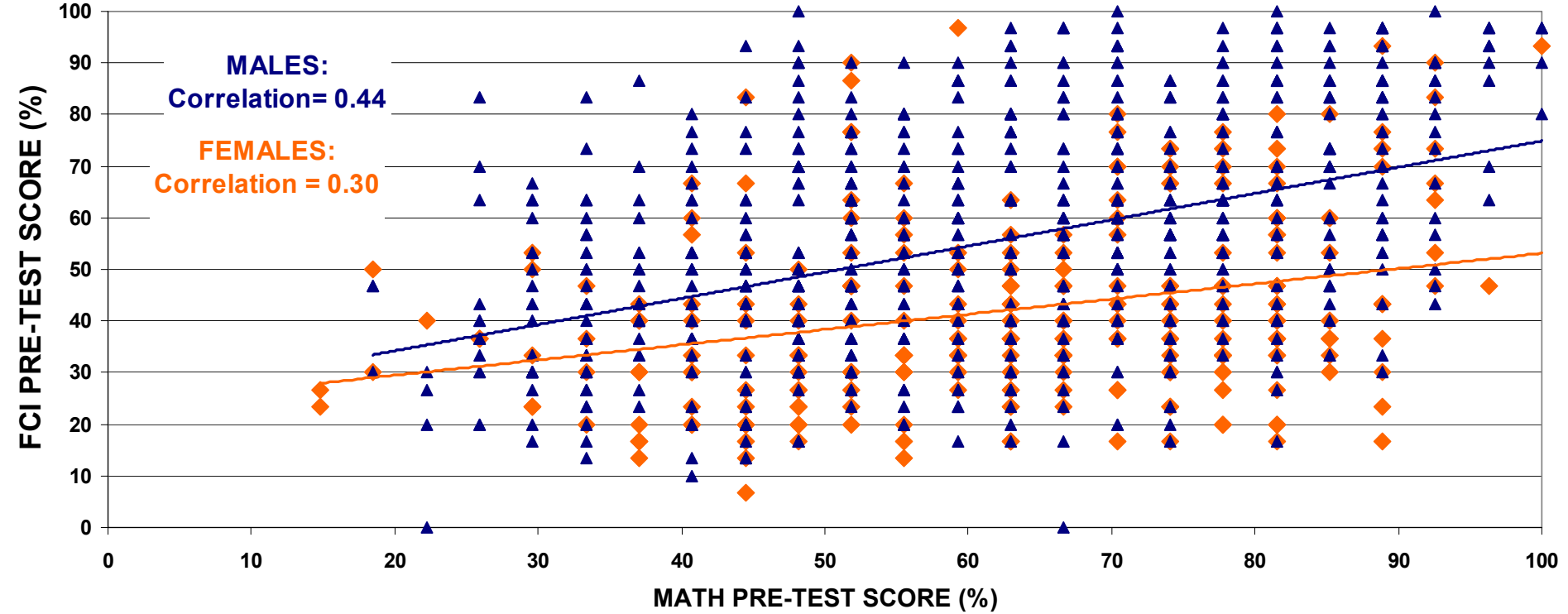
Concepts (FCI) accounts for 17% (F), 22% (M) of the grade

These seem to be very independent tests

Do they add to predict course grade? (Math + Concepts = Grade)

FCI PRE-TEST SCORE VS. MATH PRE-TEST SCORE
CALCULUS-BASED PHYSICS FOR SCIENTISTS & ENGINEERS, FALL TERMS, 2005-2007

◆ FEMALES (N=266) ▲ MALES (N=845)



The concept test is correlated with the math skills test.

A Puzzle

Math Skills (MST) accounts for 31% (F), 25% (M) of the grade

Concepts (FCI) accounts for 17% (F), 22% (M) of the grade

But the tests are correlated??

Females 30% Correlation

Males 43% Correlation

Does the sum predict course grade? (Math + Concepts = Grade)

Females (N= 257) :

MST predicts 31% of grade, add FCI predicts additional 7%

Males (N=806) :

MST predicts 25% of grade, add FCI predicts additional 8%

**Grade is predicted by some unknown parameter
correlated to both pre FCI and MST**

$$\mathbf{M + C \neq G}$$

The End

**Please visit our website
for more information:**



<http://groups.physics.umn.edu/physed/>

Identify Critical Failure Points



Fail Gracefully

Non-optimal implementation
gives some success



1. Inappropriate Tasks

Must engage all group members (not just one who knows how to do it)

2. Inappropriate Grading

Must not penalize those who help others (no grading on the curve)

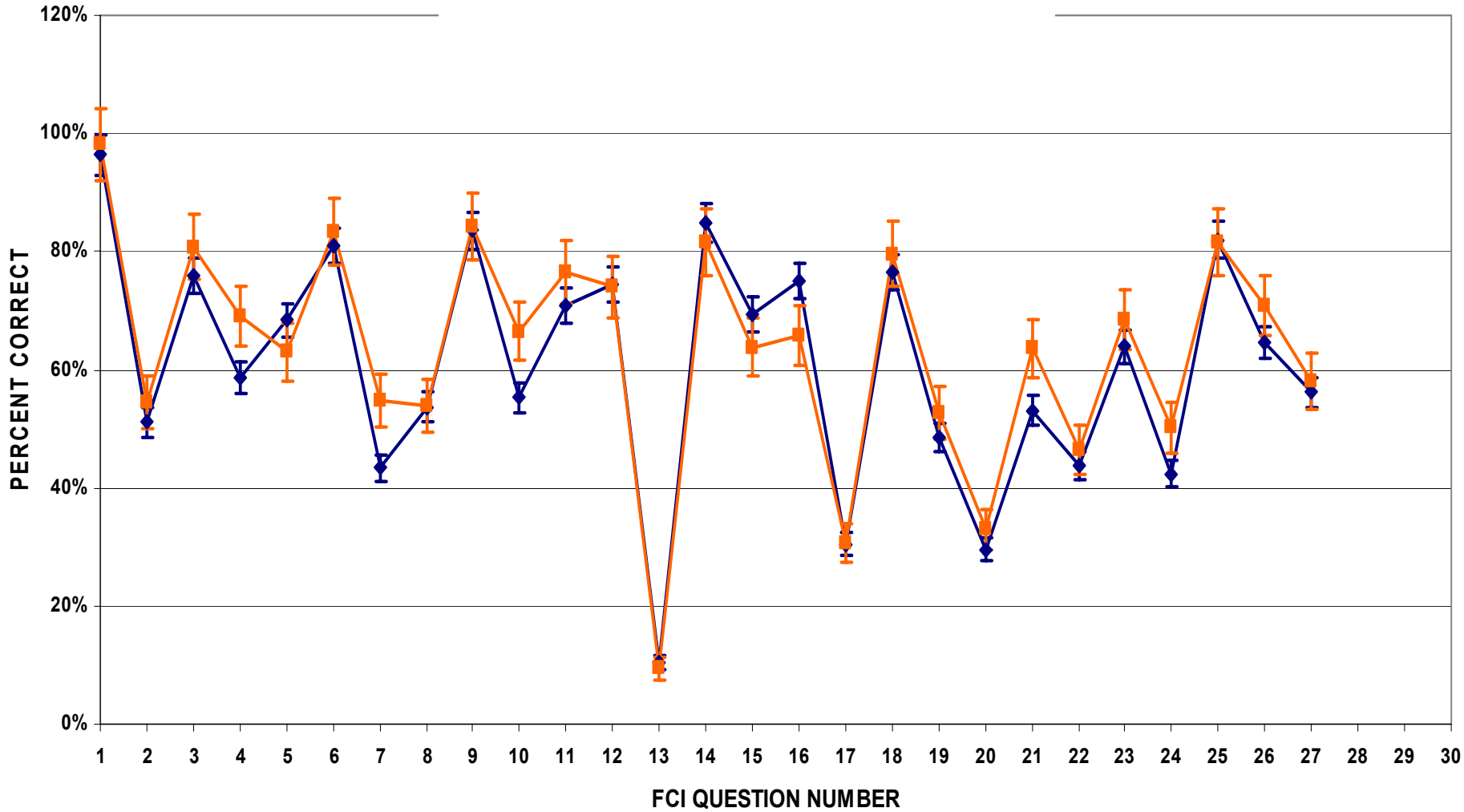
Must reward for individual learning

3. Poor structure and management of Groups

MATH PRE-TEST BY QUESTION & GENDER

CALCULUS-BASED PHYSICS FOR SCIENTISTS & ENGINEERS, FALL TERMS 2005-2007

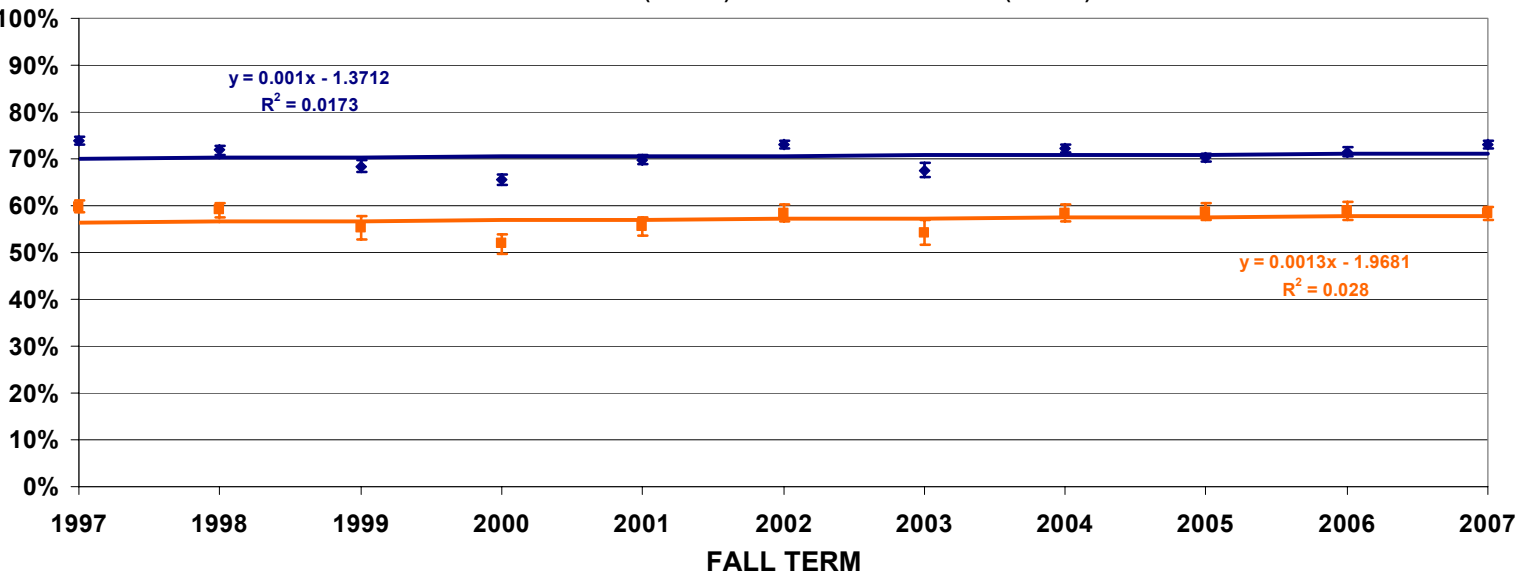
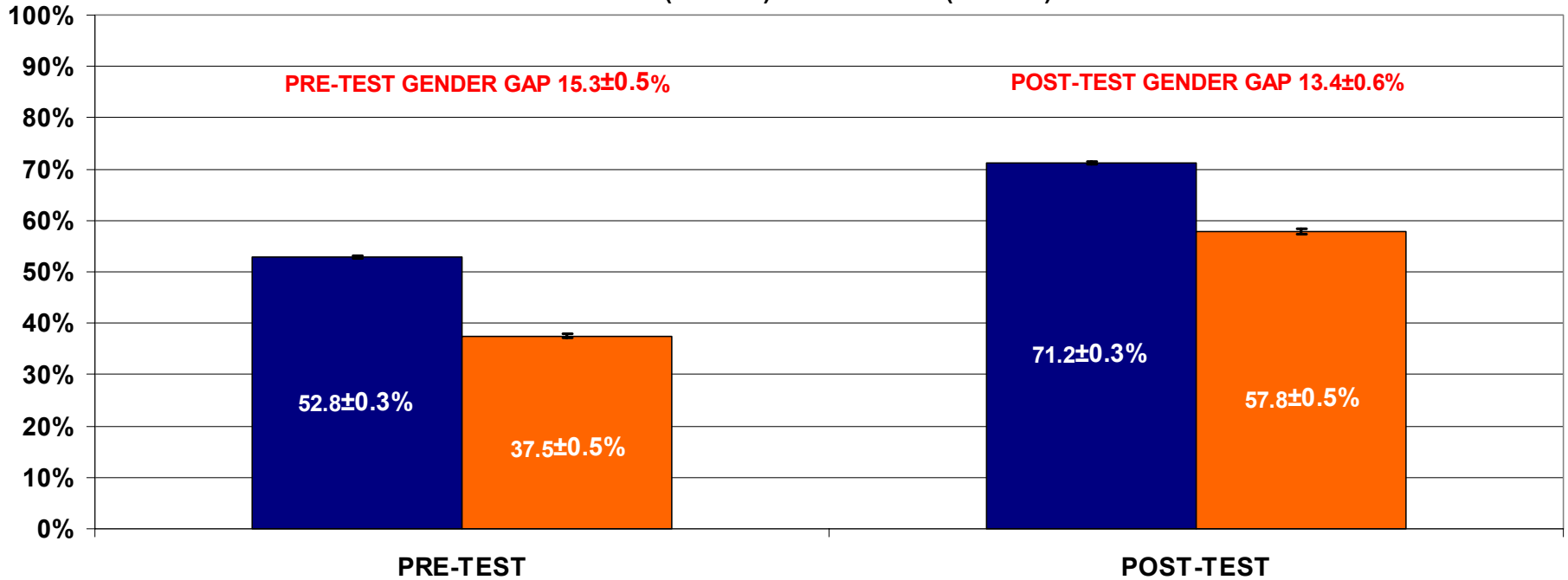
◆ MALES (N=845) ■ FEMALES (N=266)



AVERAGE FCI PRE-TEST & POST-TEST SCORES BY GENDER

CALCULUS-BASED PHYSICS FOR SCIENTISTS & ENGINEERS, FALL TERMS 1997-2007

■ MALES (N=4375) ■ FEMALES (N=1261)

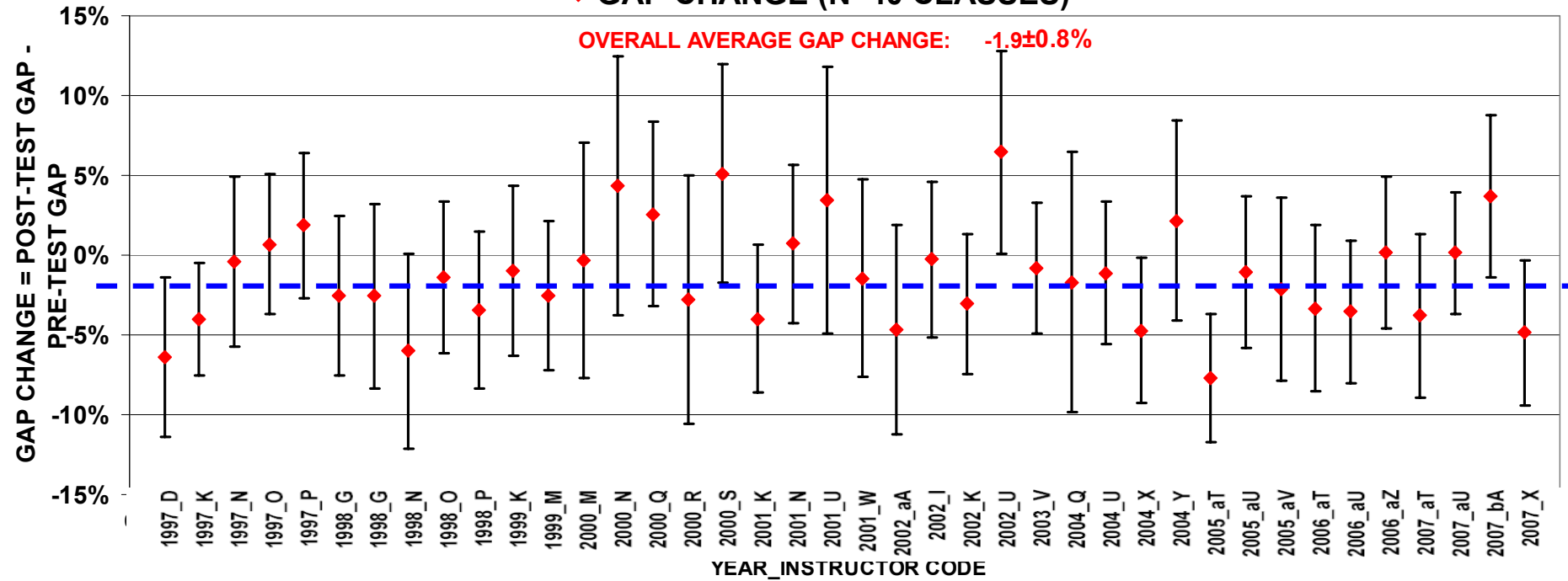


AVERAGE CHANGE IN THE GENDER GAP BY CLASS

CALCULUS-BASED PHYSICS FOR SCIENTISTS & ENGINEERS, FALL TERMS 1997-2007

◆ GAP CHANGE (N=40 CLASSES)

OVERALL AVERAGE GAP CHANGE: $-1.9 \pm 0.8\%$

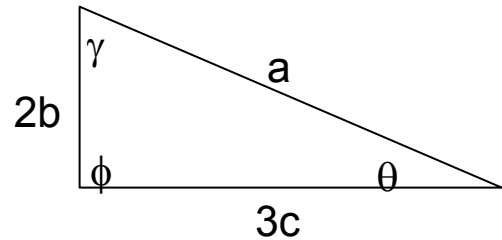


Math Diagnostic Test

Powers of ten $\frac{4 \times 10^{-3}}{10^{-4}} = ?$ (a) 4×10^{-7} [10-20%] (b) $4 \times 10^{-\frac{3}{4}}$ (c) 4 [20-28%]
(d) **40** [51-63%] (e) 4×10^7

Triangles

For this right triangle, $\cos \theta = ?$

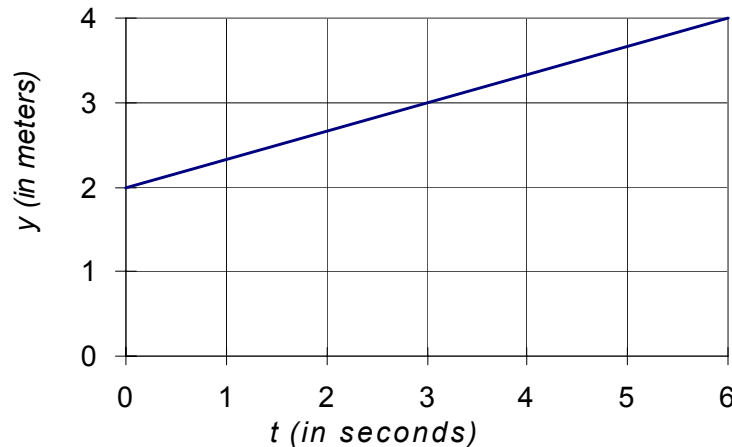


- (a) $2b/3c$ (b) $a/3c$ (c) $2b/a$ [7-16%]
(d) **$3c/a$** [69-89%] (e) $a/2b$

Graphs

The slope of the curve pictured is equal to:

- (a) 0 m/s (b) **$1/3$ m/s** [85-96%] (c) 2 m/s (d) 3 m/s [4-12%] (e) 6 m/s



Simultaneous Equations If you know $at = b$ and $cx + dt = f$ and the values of a, b, c, d and f , but you don't know the value of t , solve for the value of x .

(a) $\frac{f + dt}{c}$ (b) $\frac{b + f}{c(a + d)}$ (c) $\frac{f}{c} - \frac{db}{ac}$ [65-88%]

(d) $\frac{f}{c} - \frac{db}{a}$ (e) $\frac{b}{a}$

If you know $\frac{b}{2}y^2 - cd^2 = 0$, $ax + y = d$ and the values of a, b, c and d but you don't know the value of y , solve for the value of x .

(a) $\frac{y - d}{a}$ (b) $\frac{d}{a} \left(1 \pm \sqrt{\frac{2c}{b}} \right)$ [22-40%] (c) $\frac{d}{a} \pm \frac{1}{a} \sqrt{\frac{2cd}{b}}$ [31-45%]

(d) $\frac{b}{2}(d - ax)^2 - cd^2$ [9-28%] (e) $\frac{d}{a} - \frac{2cd^2}{ab}$

Derivatives

If $z = ax^3 + bx + c$, then $\frac{dz}{dx} = ?$

(a) $ax^2 + b$

(b) $a + b + c$

(c) $3ax^2 + 2b$

(d) $3ax^2 + b + c$

(e) $3ax^2 + b$ [73-93%]

If $z = ae^{bt}$, where a and b are not functions of t , then $\frac{dz}{dt} = ?$

(a) bz [4-15%]

(b) ae^b [7-27%]

(c) az

(d) abe^t [39-58%]

(e) abe^b [6-21%]

Anti-Derivatives

If $\frac{dx}{dt} = 5at^3 + b$, where **a** and **b** are constants, then **x** = ?

(a) $15at^2$ [7-19%] (b) $\frac{5}{4}at^4 + bt + c$ [60-88%] (c) $\frac{5}{4}at^4 + b$

(d) $5at^2$ (e) $\frac{5}{4}at^4$

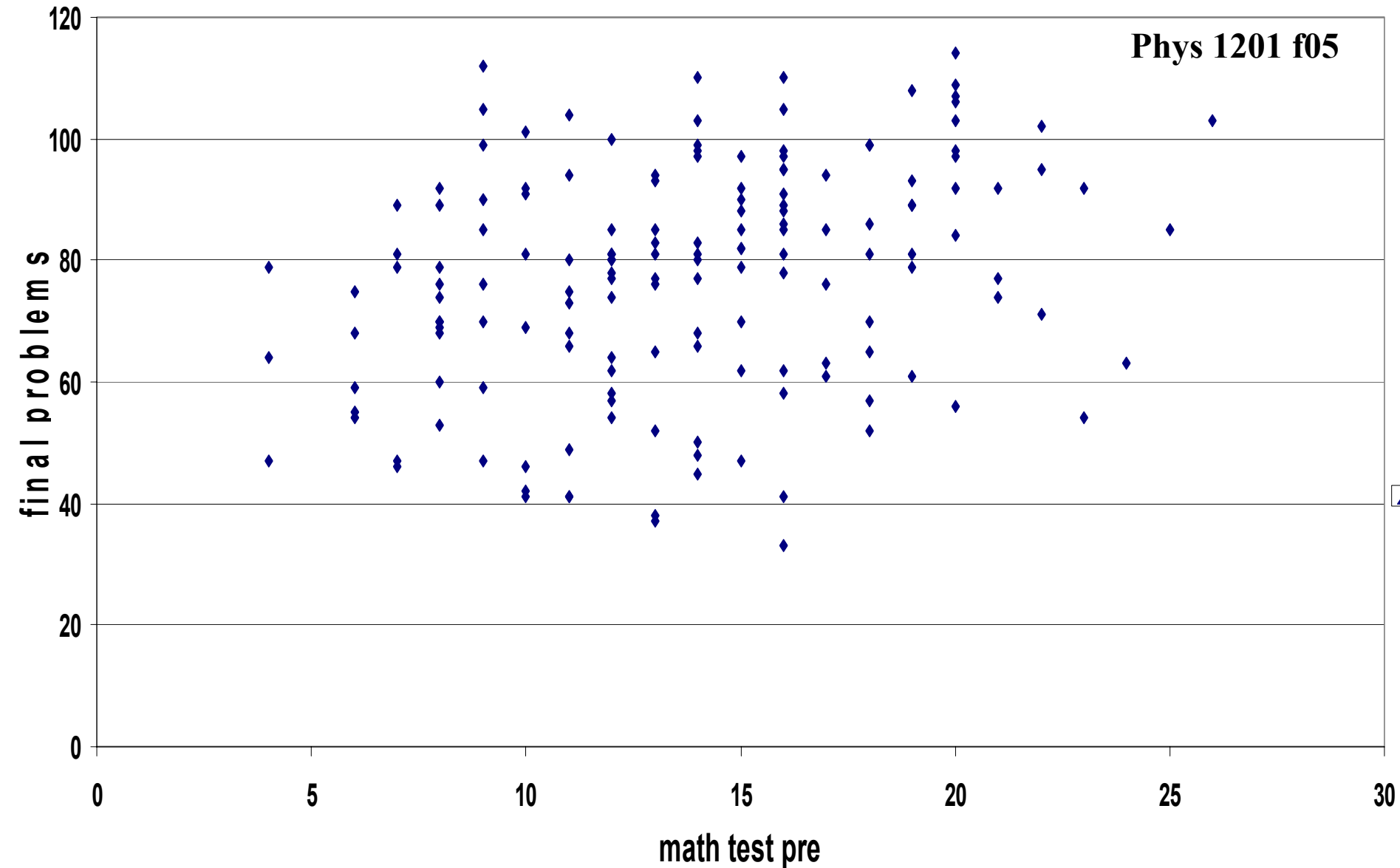
If $\frac{dz}{dt} = -ab^2 \sin(b^2 t)$, where **a** and **b** are constants, then **z** = ?

(a) $2abc\cos(t) + k$ (b) $-2ab\sin(b^2 t) + k$ (c) $-2ab\sin(bt) + k$

(d) $a\cos(b^2 t) + k$ [33-63%] (e) $-2abc\cos(bt) + k$ [17-30%]

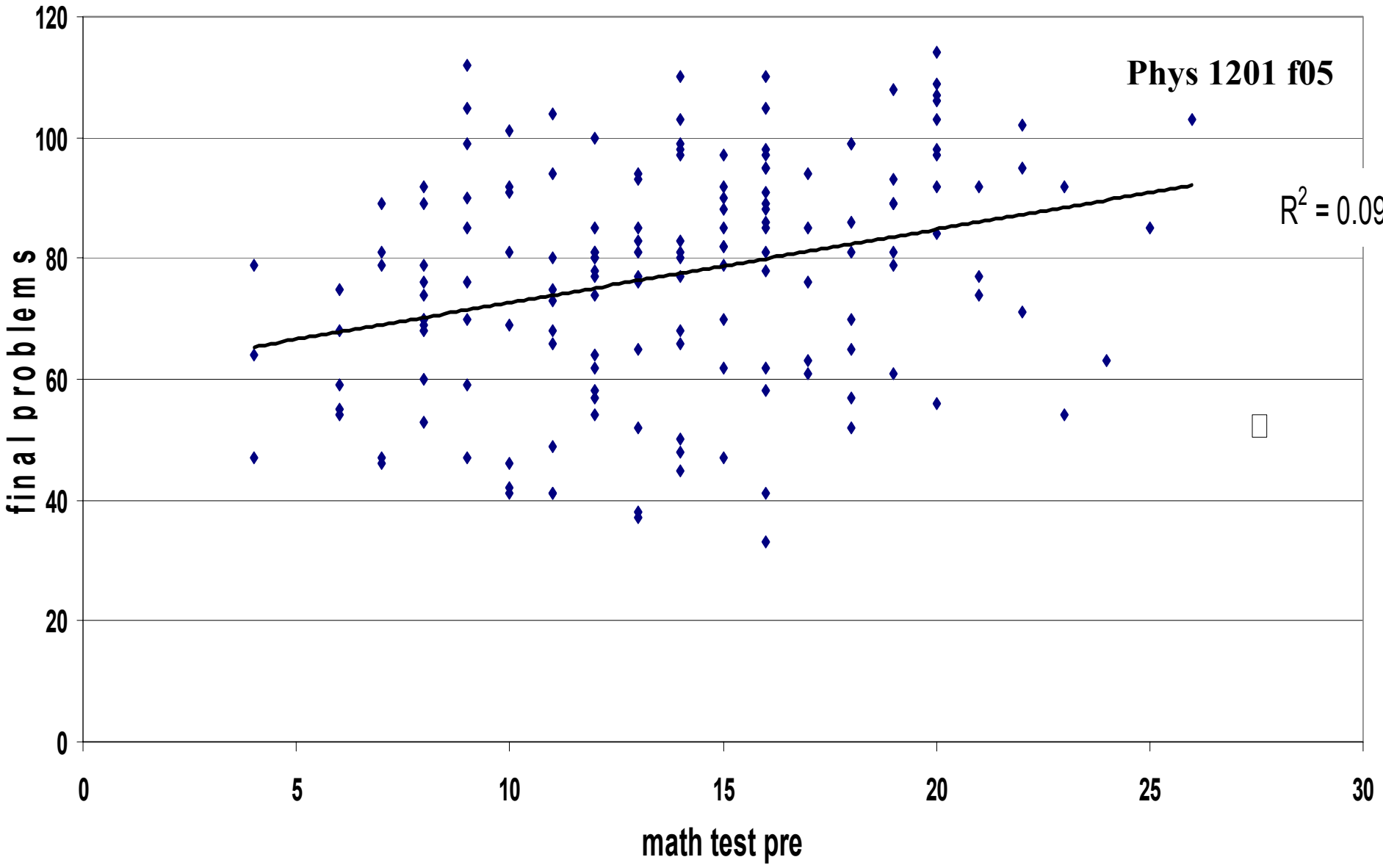
Problem Solving performance is NOT strongly dependent on initial math skills

There must be a threshold but problem solving is more complicated than math



Phys 1201 f05

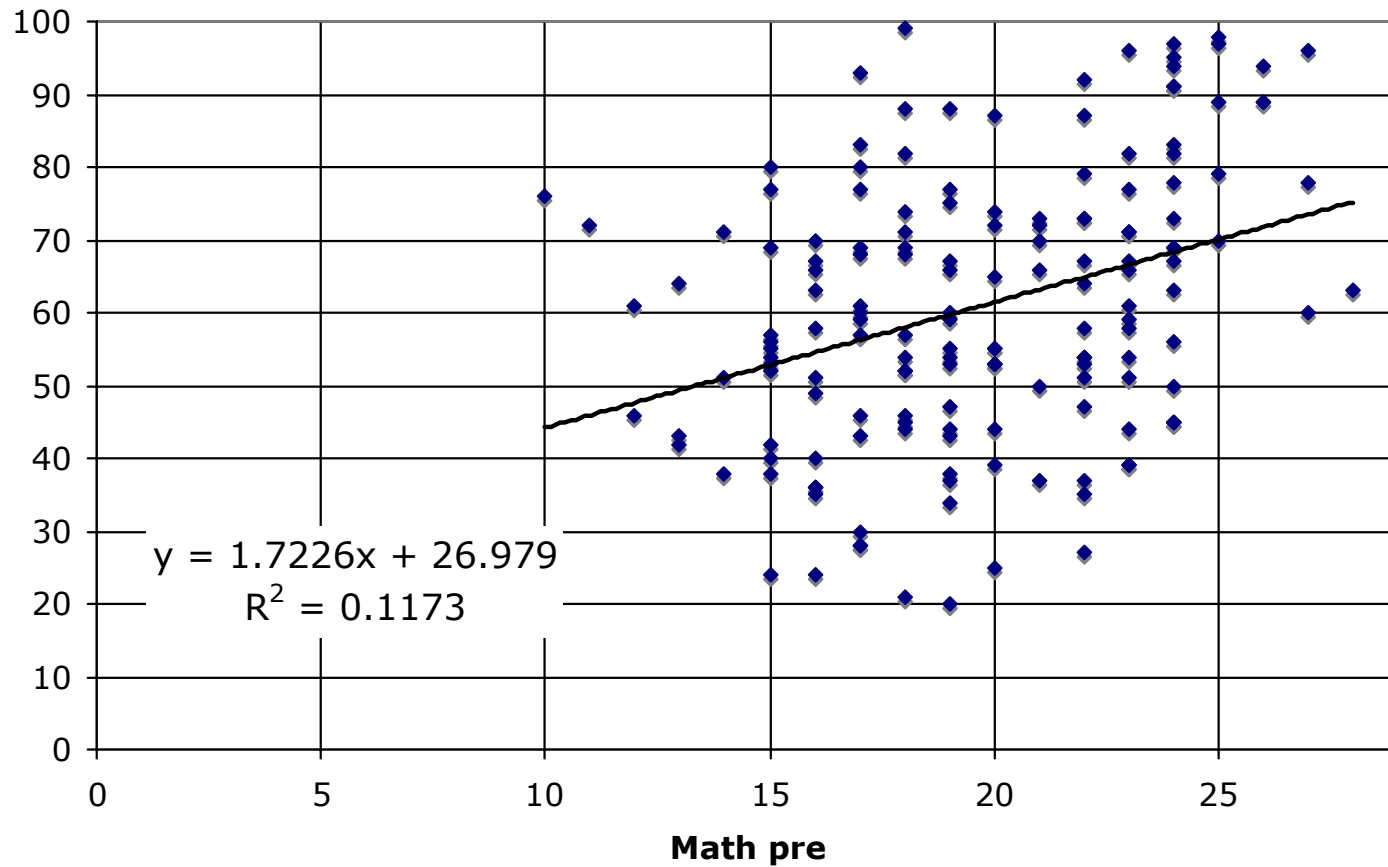
$R^2 = 0.09$



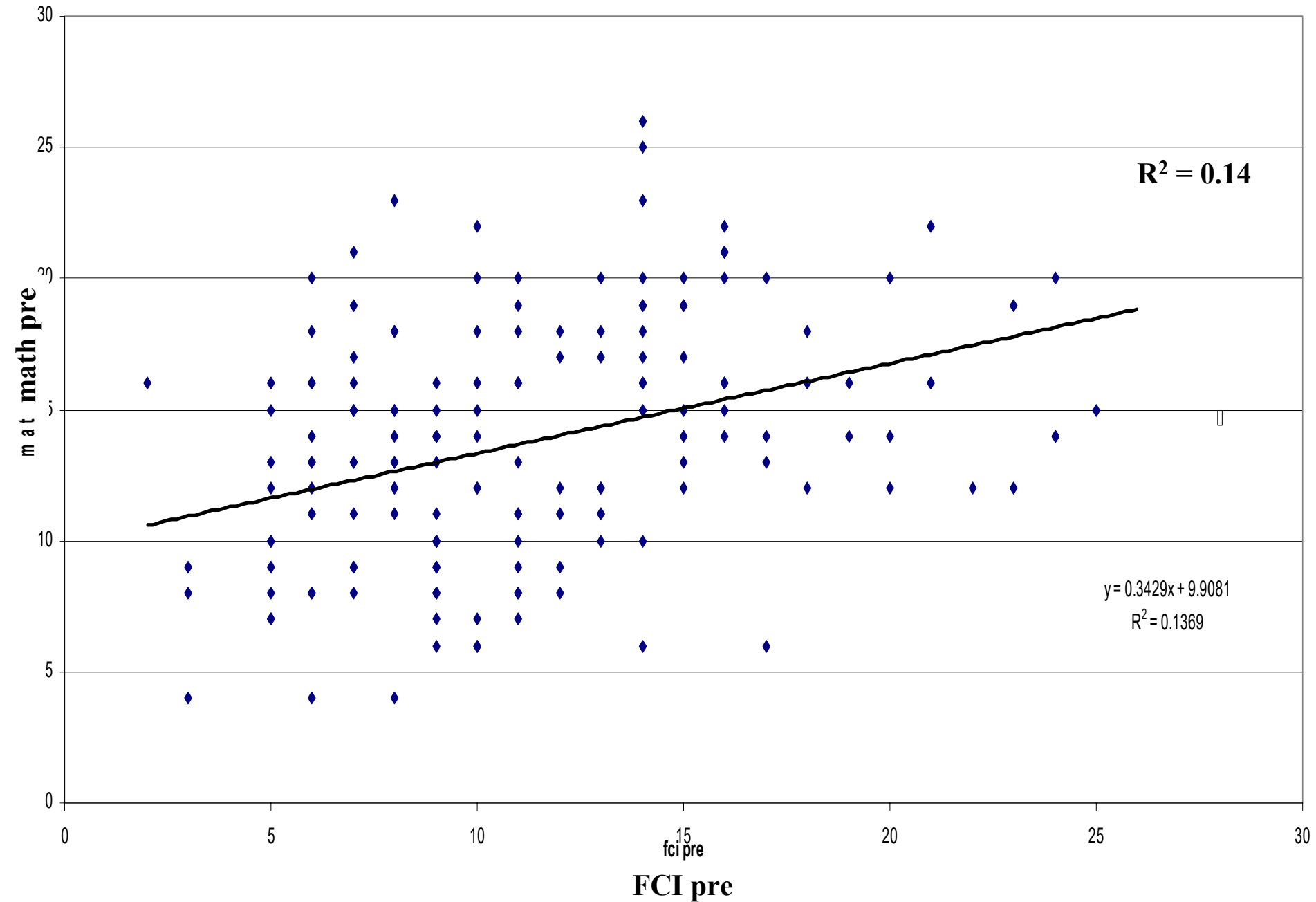
Problem-Solving vs. Math pre - Engineers

Phys 1301 f05

Eng, PS grade vs. Math pre



FCI pre vs. Math pre



Phys 1201 f05

$R^2=0.03$

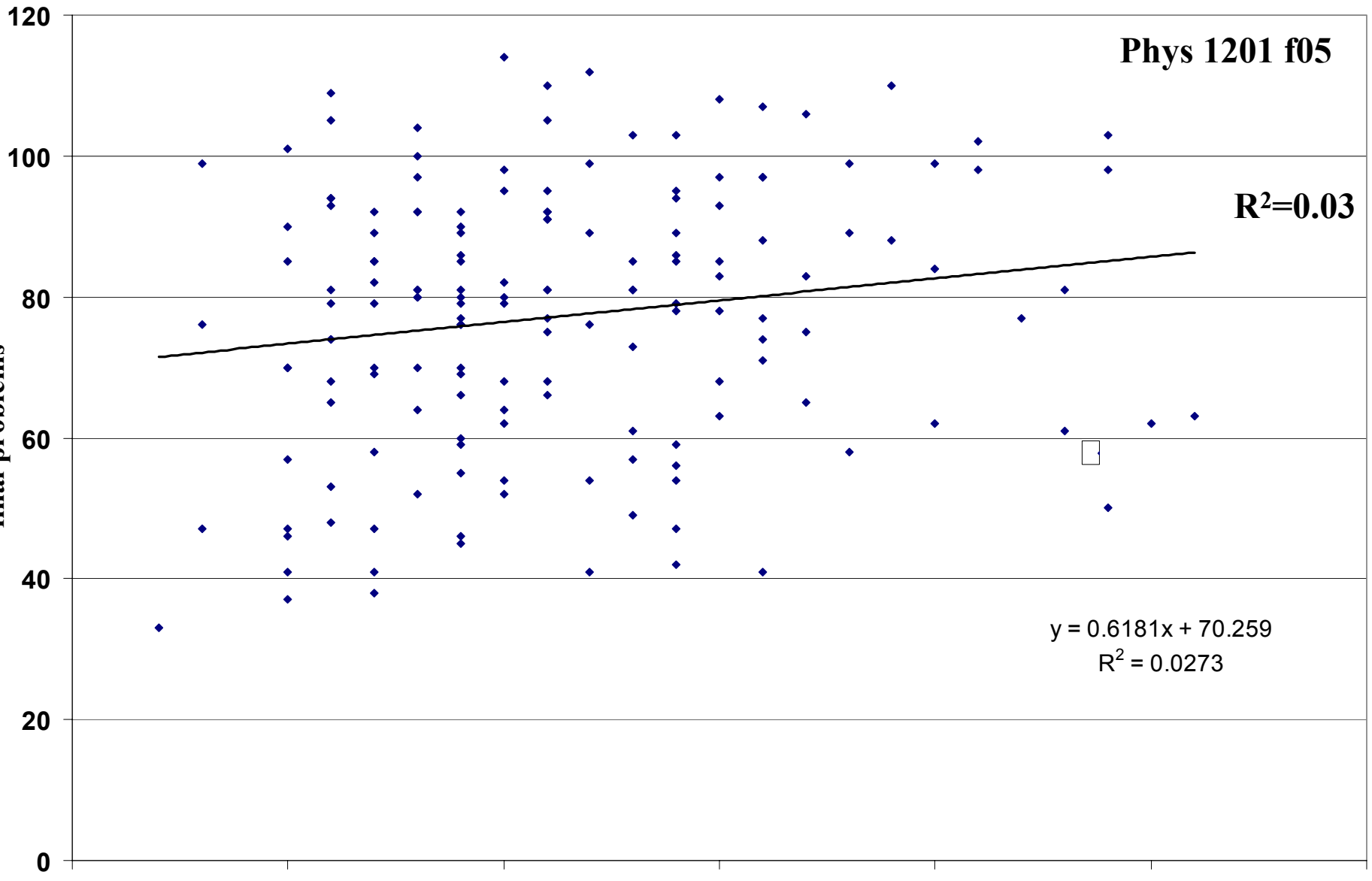
$y = 0.6181x + 70.259$
 $R^2 = 0.0273$

final problems

fci pre

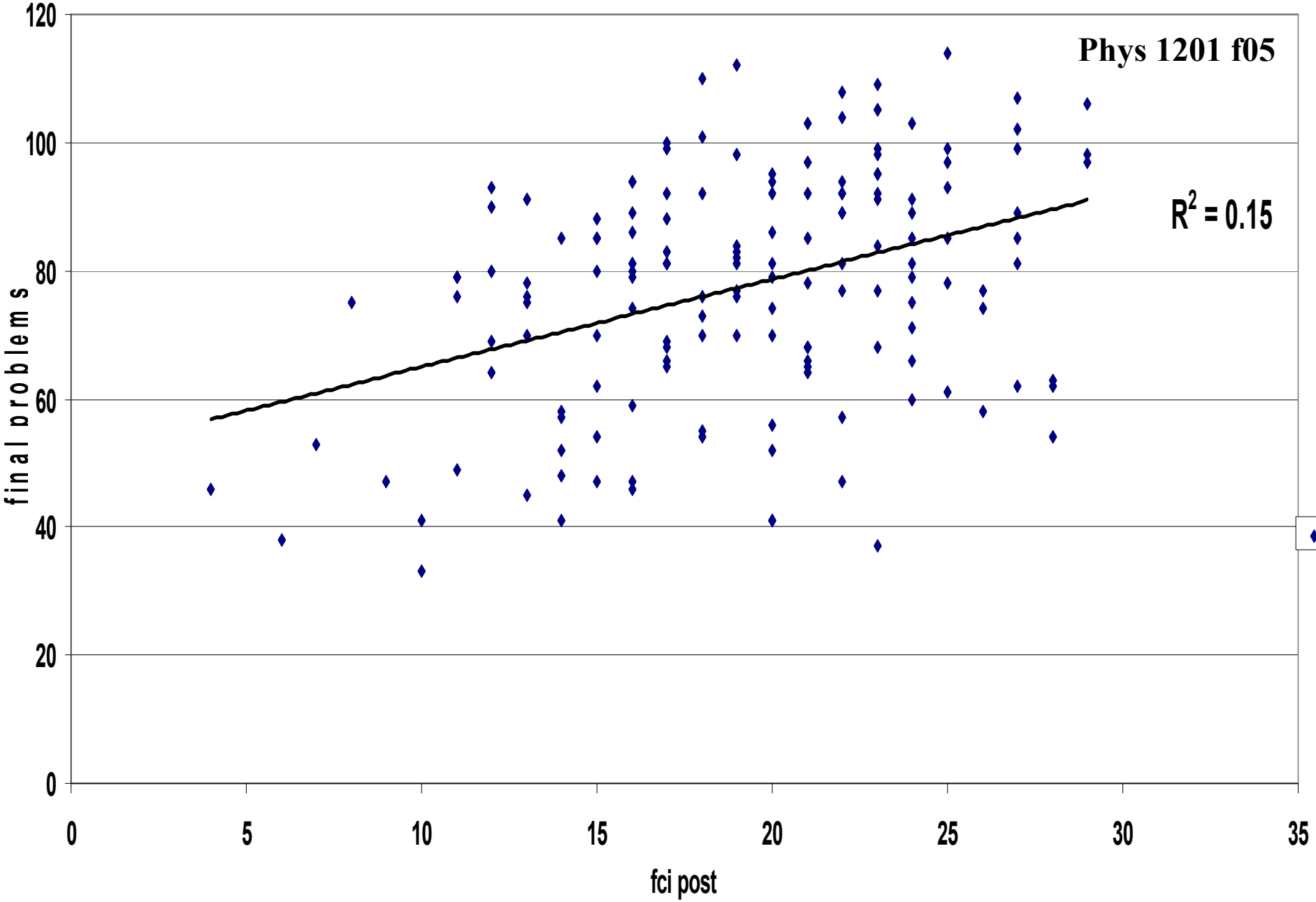
120
100
80
60
40
20
0

0 5 10 15 20 25 30



Phys 1201 f05

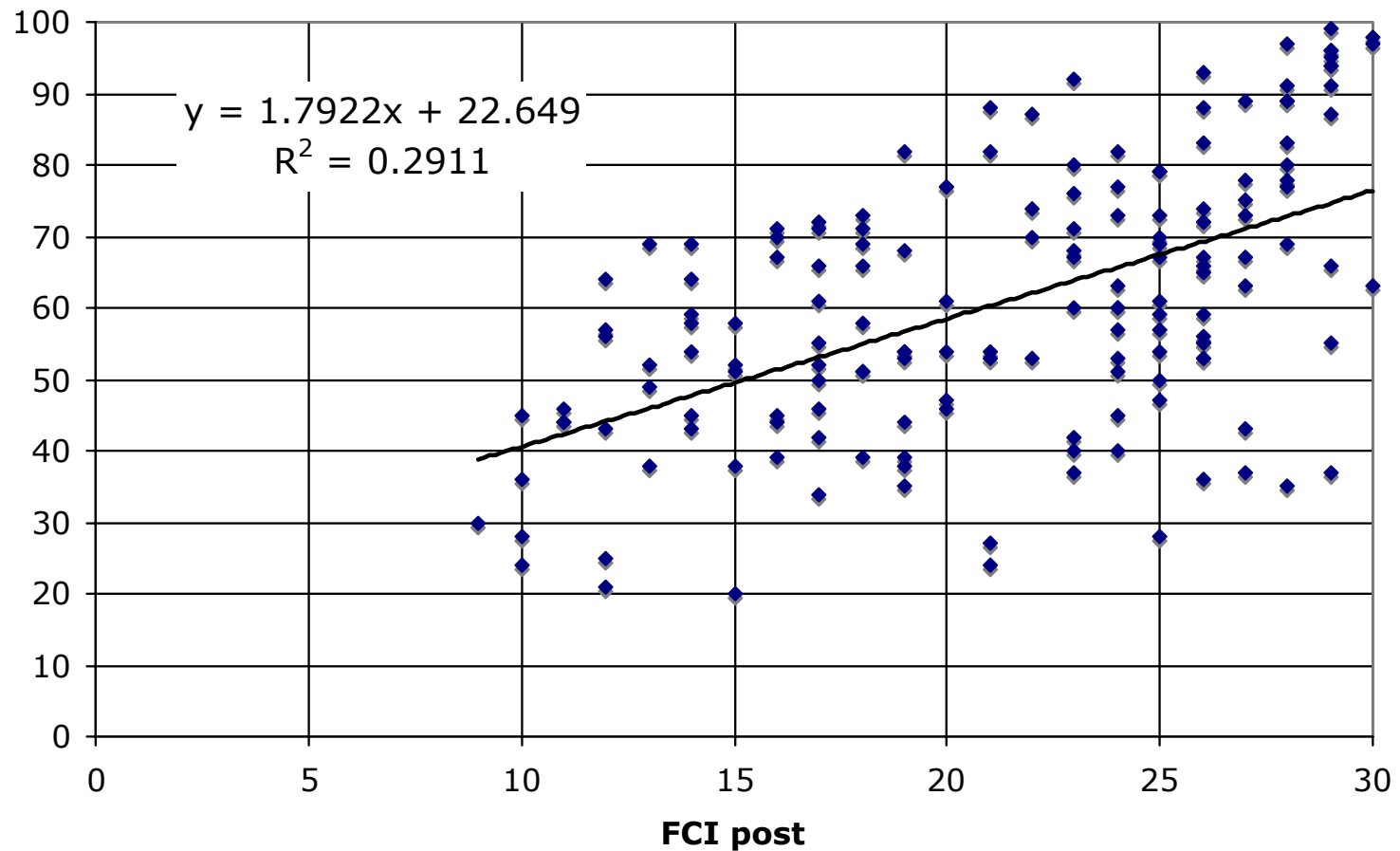
$R^2 = 0.15$



PS vs FCI post -- Engineers

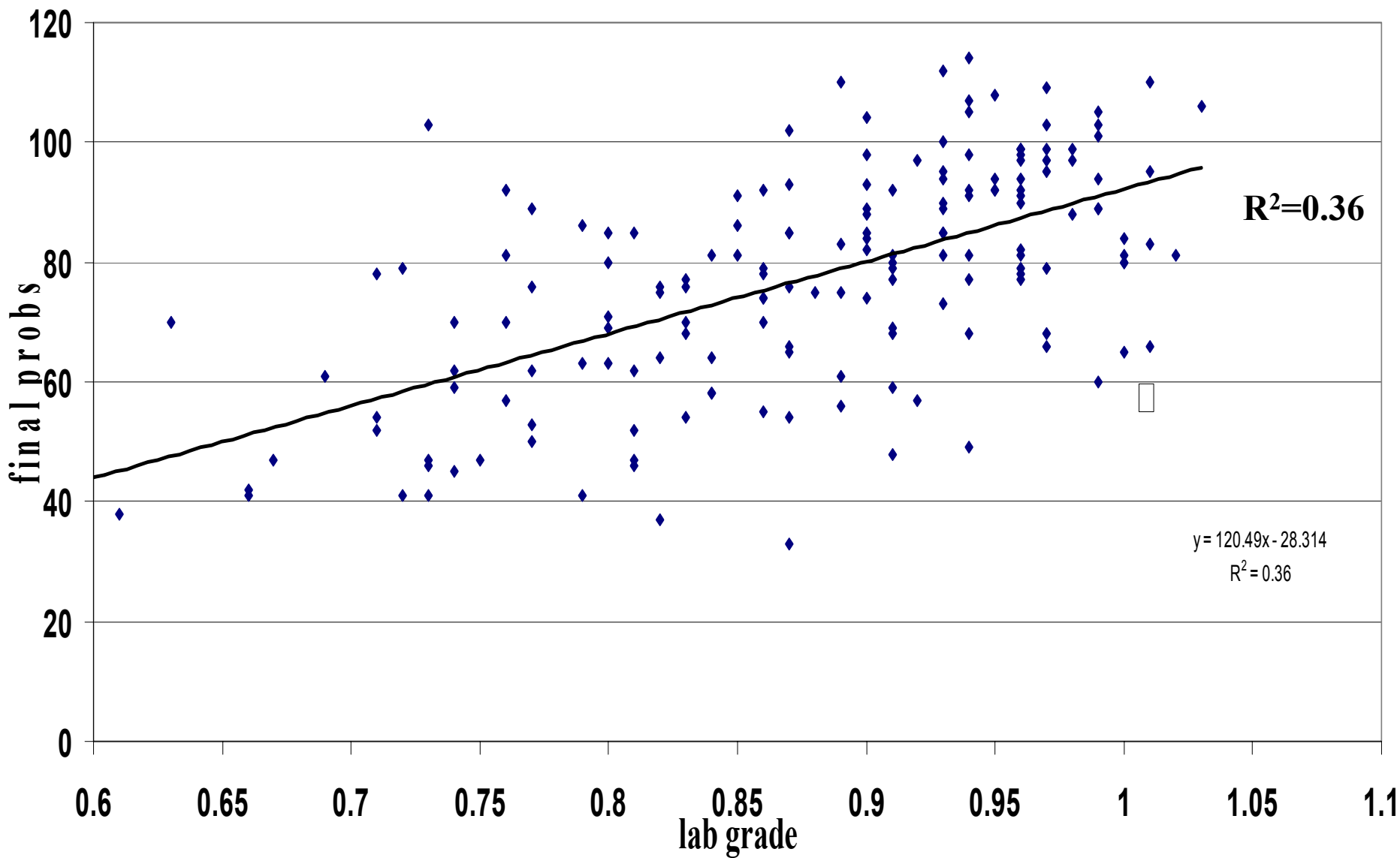
Eng, PS grade vs. FCI post

Phys 1301 f05



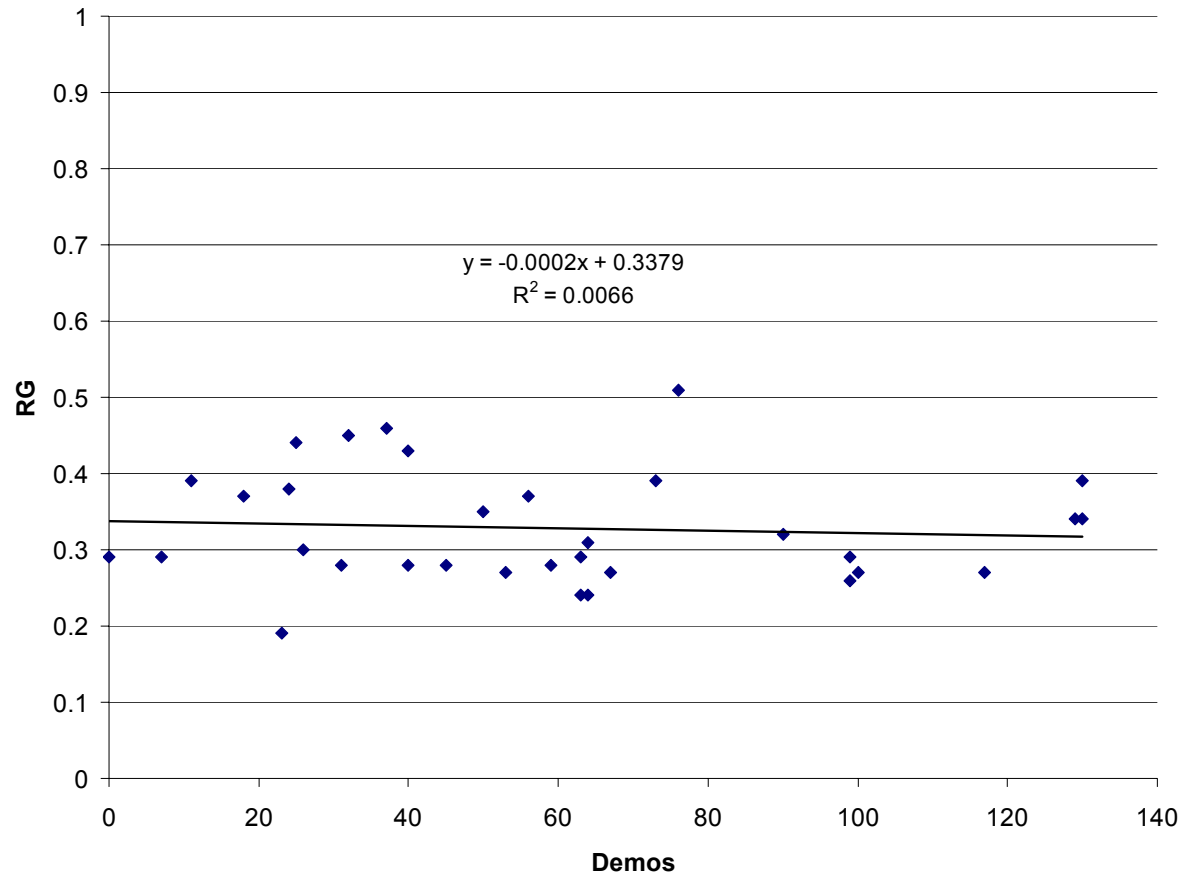
Final Exam Problems vs Lab Grade

Phys 1201 f05



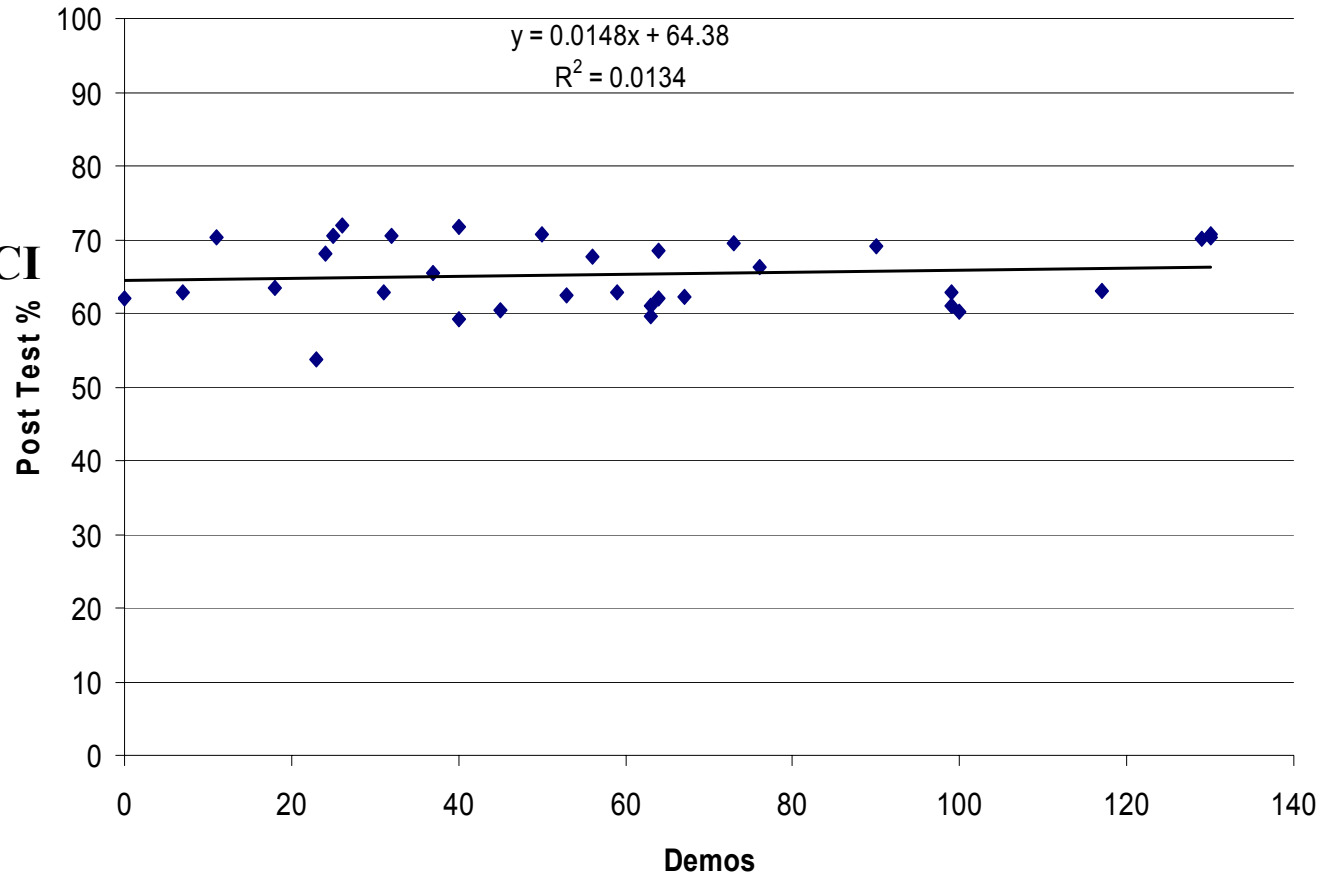
Relative Gain vs. Demos

- Plot shows no noticeable connection between RG and # of demos used.



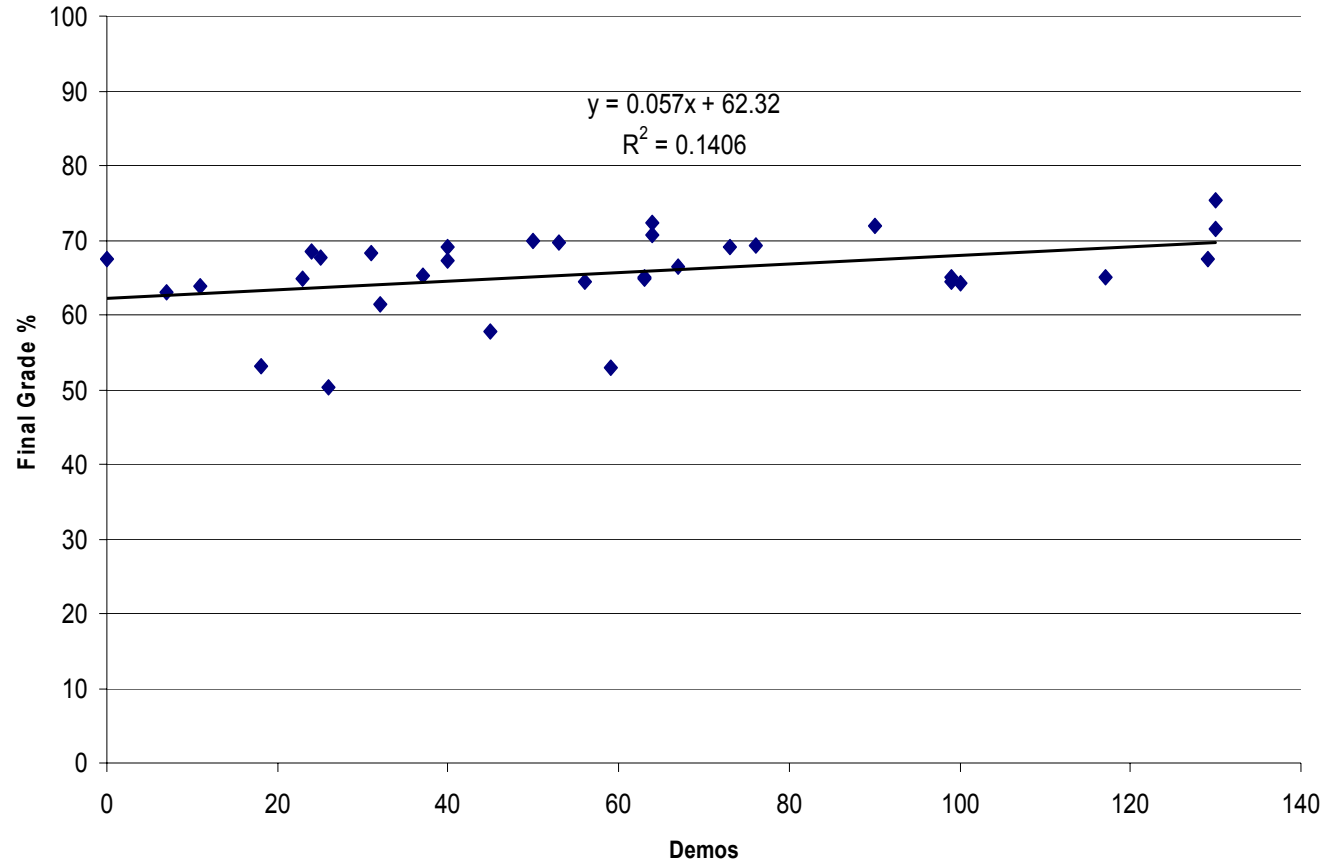
Post Test % vs. Demos

- **No detectable connection between FCI score and # of demos used.**



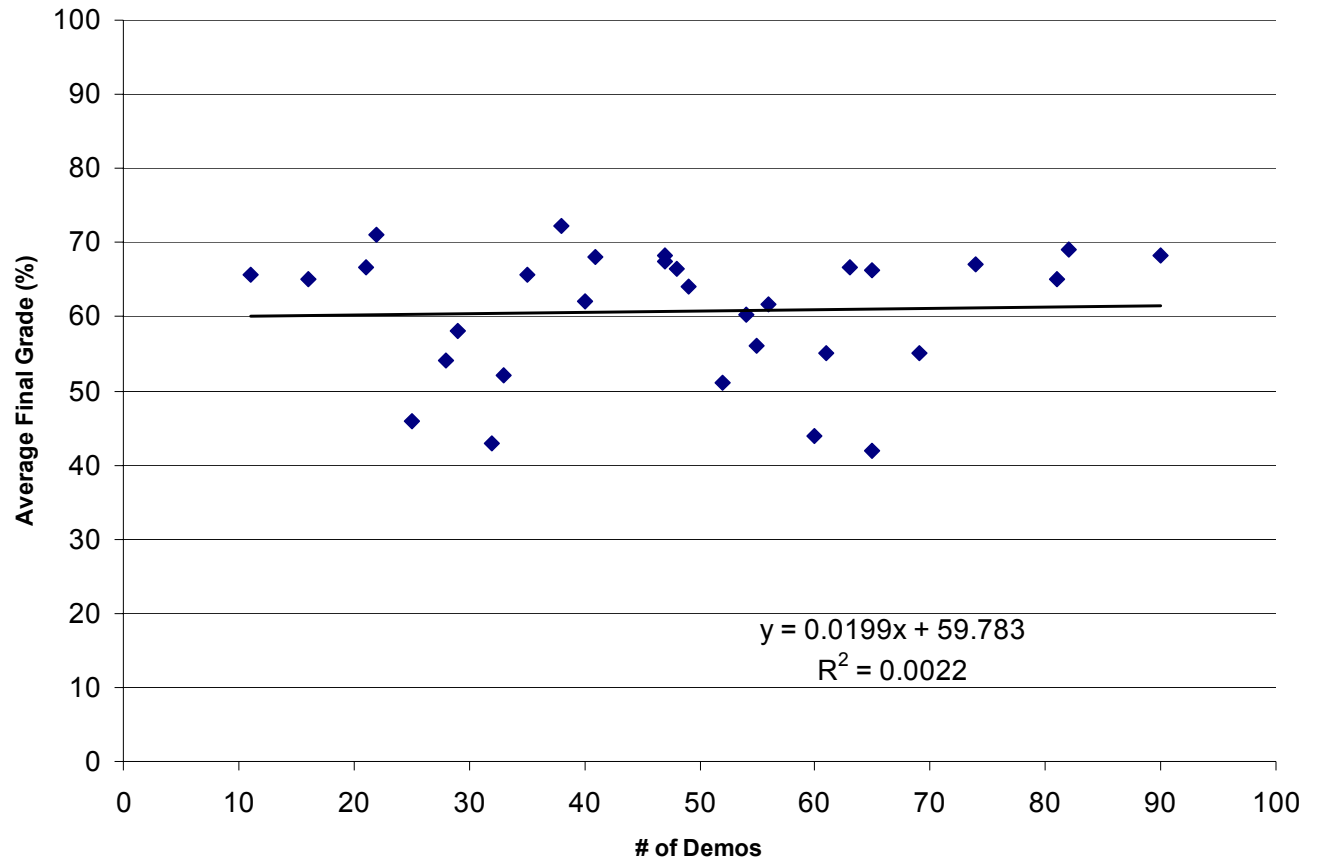
Intro Mechanics Grades vs. Demos

- **No large correlation between the class final exam performance and number of demos.**

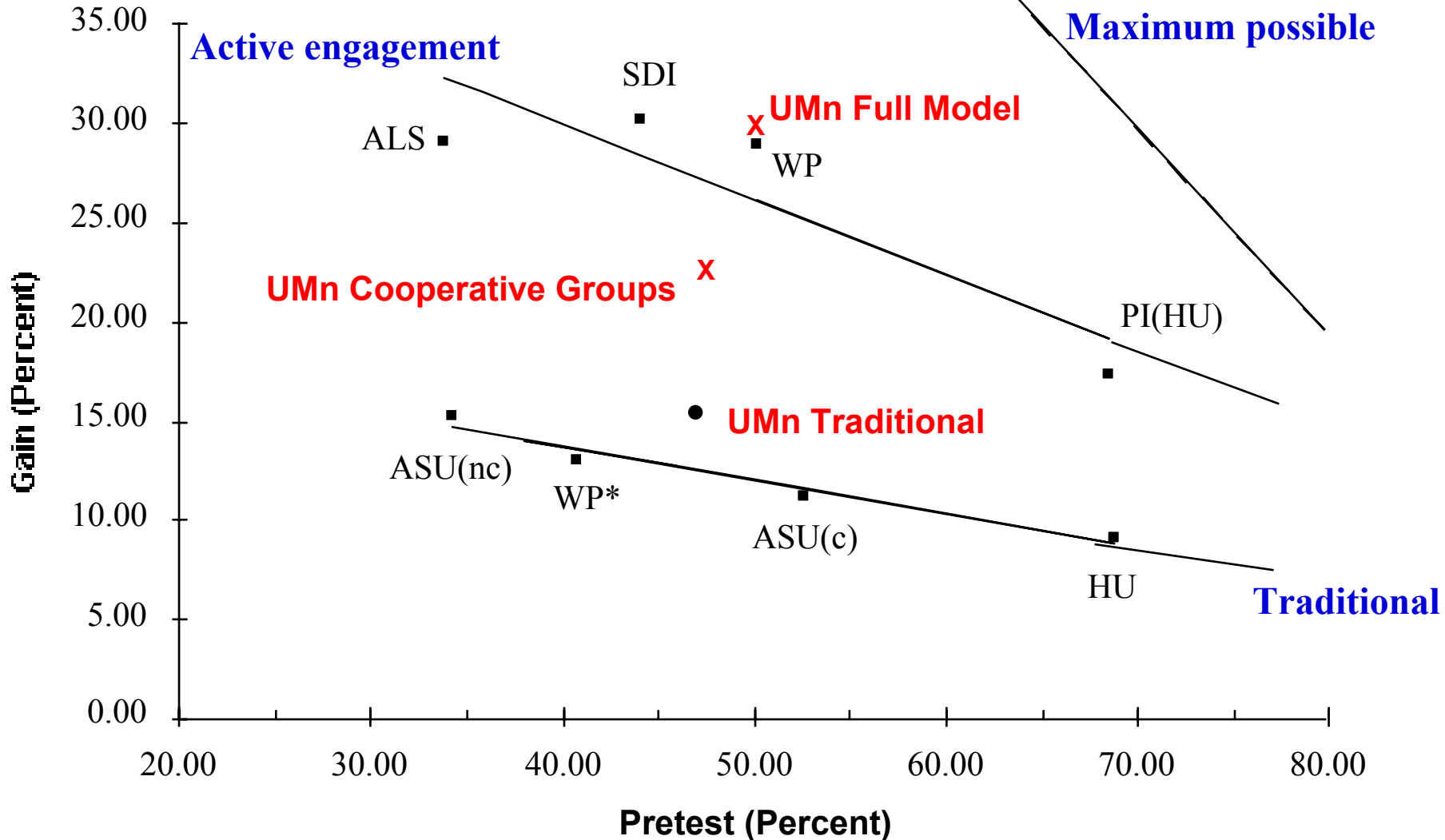


Intro E&M Grades vs. Demos

- **No large correlation between the class final exam performance and number of demos.**



Gain on FCI (Hake plot)



FCI PRE-TEST BY QUESTION & GENDER

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