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Overcoming Misconceptions

Testing the Conceptual Understanding of Mechanics with Mature Learners

Jinhua Mathias & Sam Nolan

To Cover

- **Introduction**
  - Conceptual Learning vs Algebraic Skill
- **The Force Concept Inventory Test**
  - Sample Questions
  - Previous Uses & Outcomes
- **This project**
  - The Students
  - The Deployment
  - The Results
- **Discussion – Is the Test Robust?**
- **Conclusions & Future Work**

Introduction

- Solving problems in physics requires two key skills:
  - Mathematical ability
  - Conceptual understanding
- Mathematical ability is easier to test and many students can get by without addressing conceptual understanding.
- Mechanics is perhaps the most conceptually misunderstood part of physics and yet more traditional undergraduate class time is devoted to it than anything else.

Ausubel's Dictum: "*Ascertain what the student knows and teach accordingly*"



"*Ascertain what the student* ***misunderstands*** *and teach accordingly*"

Mathematical Ability

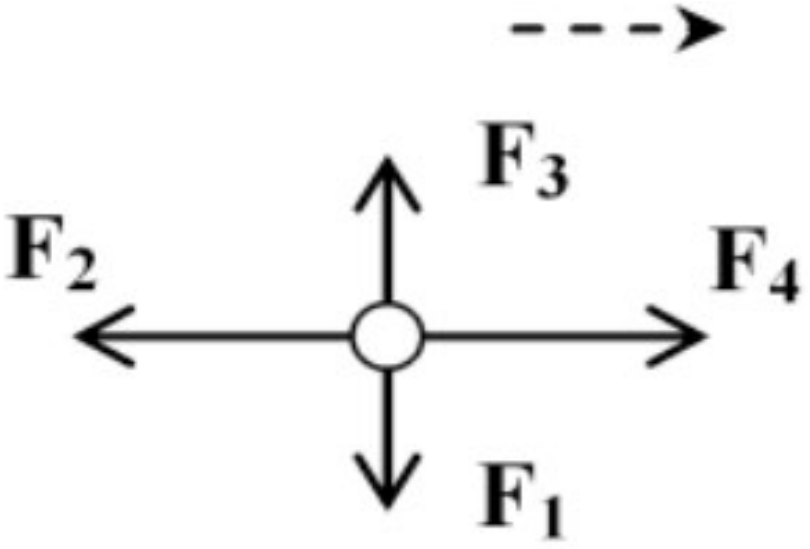
- **Example Question**

3. A particle P moving under the action of a force $\boldsymbol{F}$, has a position vector $\boldsymbol{r}$ at time t, relative to a fixed origin, given by

$$\boldsymbol{r} = (6+2t^2)\mathbf{i} + 5t\boldsymbol{j}$$

a) Find the velocity of the particle at time t

Conceptual Understanding



Hockey puck sliding on frictionless surface at constant speed.

How are the forces related ?

Conceptual Understanding

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Two metal balls are the same size but one weighs twice as much as the other. The balls are dropped from the roof of a single story building at the same instant of time. The time it takes the balls to reach the ground below will be:

(A) about half as long for the heavier ball as for the lighter one.

(B) about half as long for the lighter ball as for the heavier one.

(C) about the same for both balls.

Correct Answer

C

Conceptual Understanding

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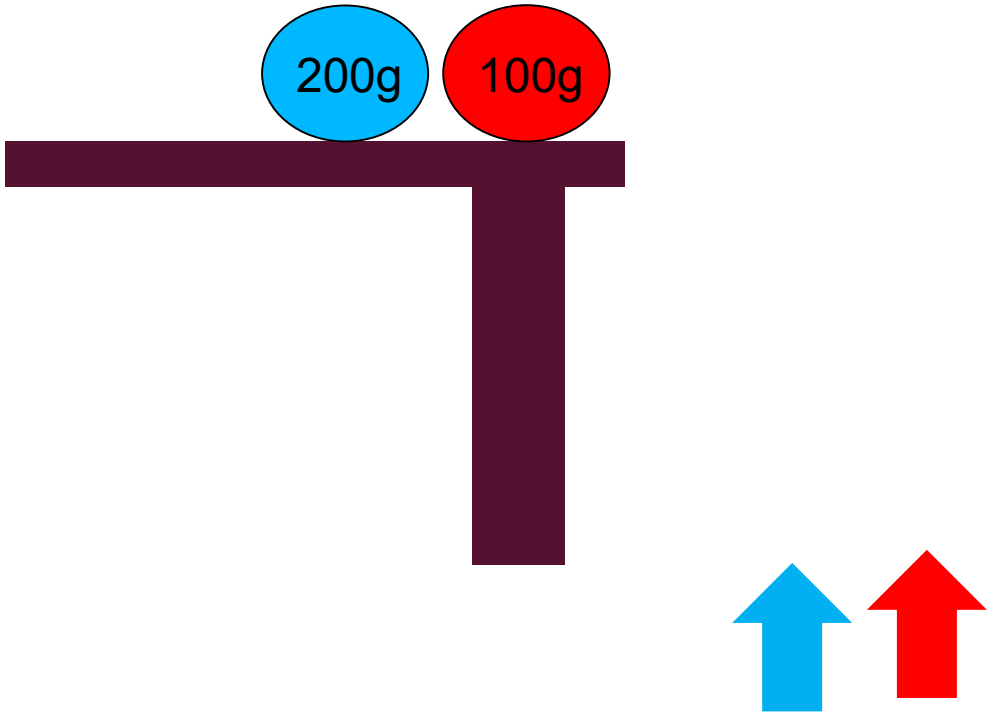
The two metal balls of the previous problem roll off a horizontal table with the same speed. In this situation:

(A) the heavier ball hits the floor considerably closer to the base of the table than the lighter ball.

(B) the lighter ball hits the floor considerably closer to the base of the table than the heavier ball.

(C) both balls hit the floor at approximately the same horizontal distance from the base of the table.

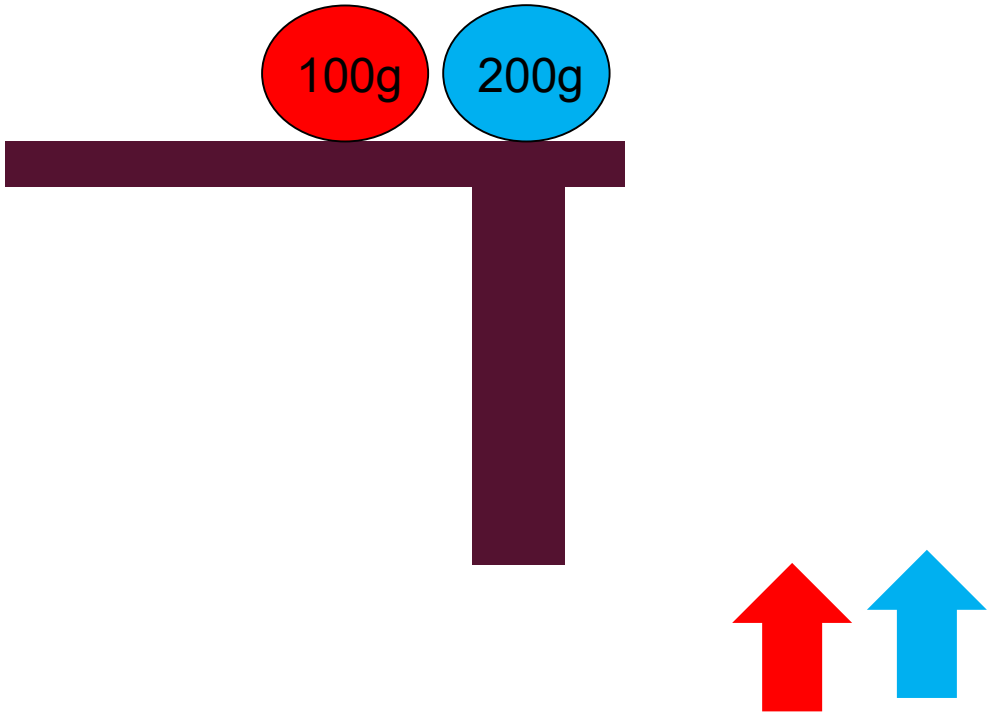
Conceptual Understanding



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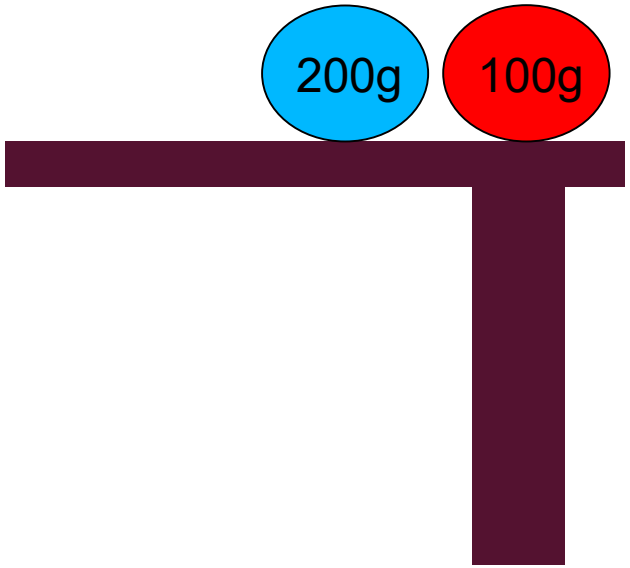
Conceptual Understanding

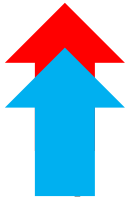


The two metal balls of the previous problem roll off a horizontal table with the same speed. In this situation:

(B) the lighter ball hits the floor considerably closer to the base of the table than the heavier ball.

Conceptual Understanding





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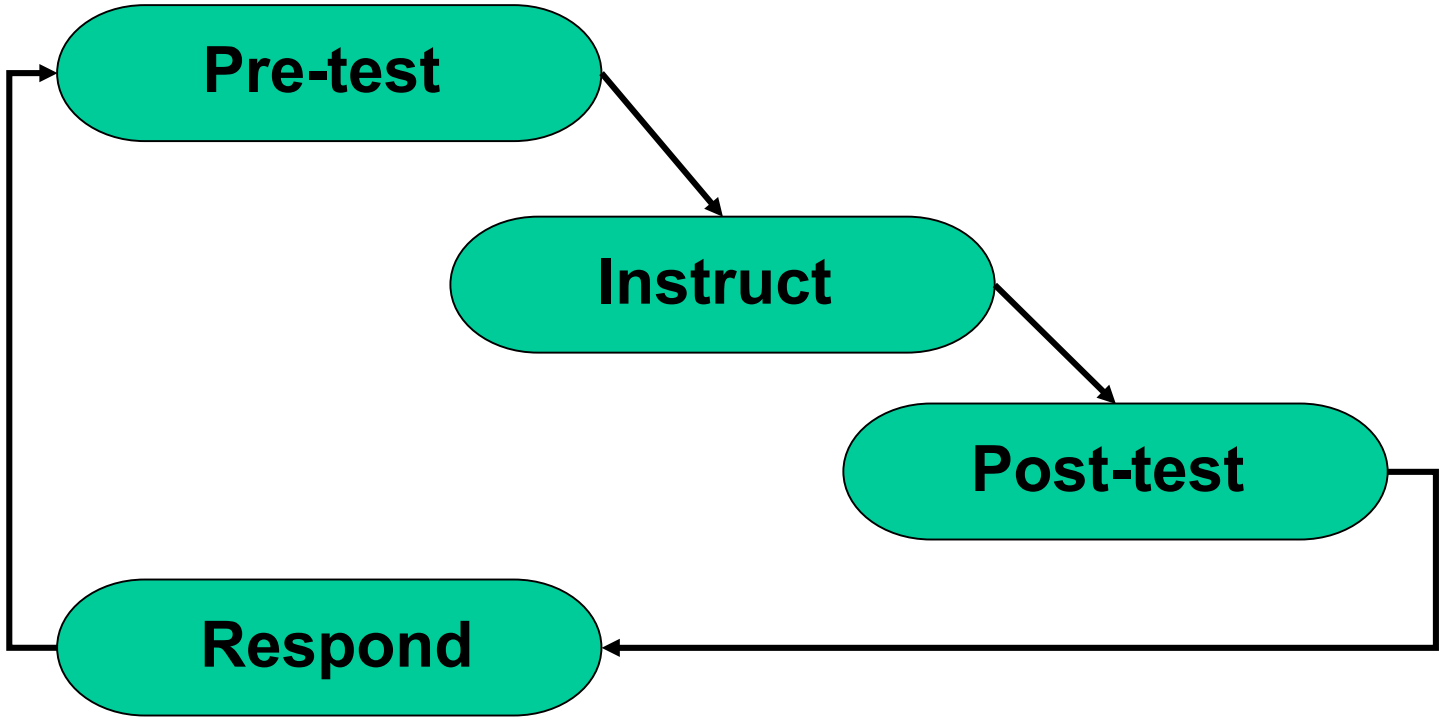
Why is physics so difficult

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- **Stock answer – <u>Few have the talent for it!</u>**
- Science education research has a different answer, from thorough investigation of: **personal beliefs about how the world works uninformed by science**
- Learning physics involves transforming this belief – its a pretty rough road.
- First we need to know what the most common misconceptions are.

Need a diagnostic test

- Standardised, robust tests
- Objectively marked (nearly always MCQ)
- Target key learning outcomes
- Use pre- and post-instruction


Pre-test
Instruct
Post-test
Respond

Validity and reliability

- **Tests should be *valid***
  - They actually test what you want them to
- **Tests should be *reliable***
  - They give reproducible results

Taken from Bates & Galloway 2010

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The Force Concept Inventory

Force Concept Inventory

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- **The Force Concept Inventory (Hestenes et al. 1995) is the most frequently used diagnostic test for assessing conceptual understanding in physics:**
  - Tested on > 50,000 students globally
  - Reliability checked
  - Use in UK has started (Edinburgh, Hull, Manchester)
- **It's been used to transform the way physics is taught in the US and to open up a debate on conceptual understanding in FE and HE.**
- **Its aim is to assess student understanding of the concept of Newtonian Force.**

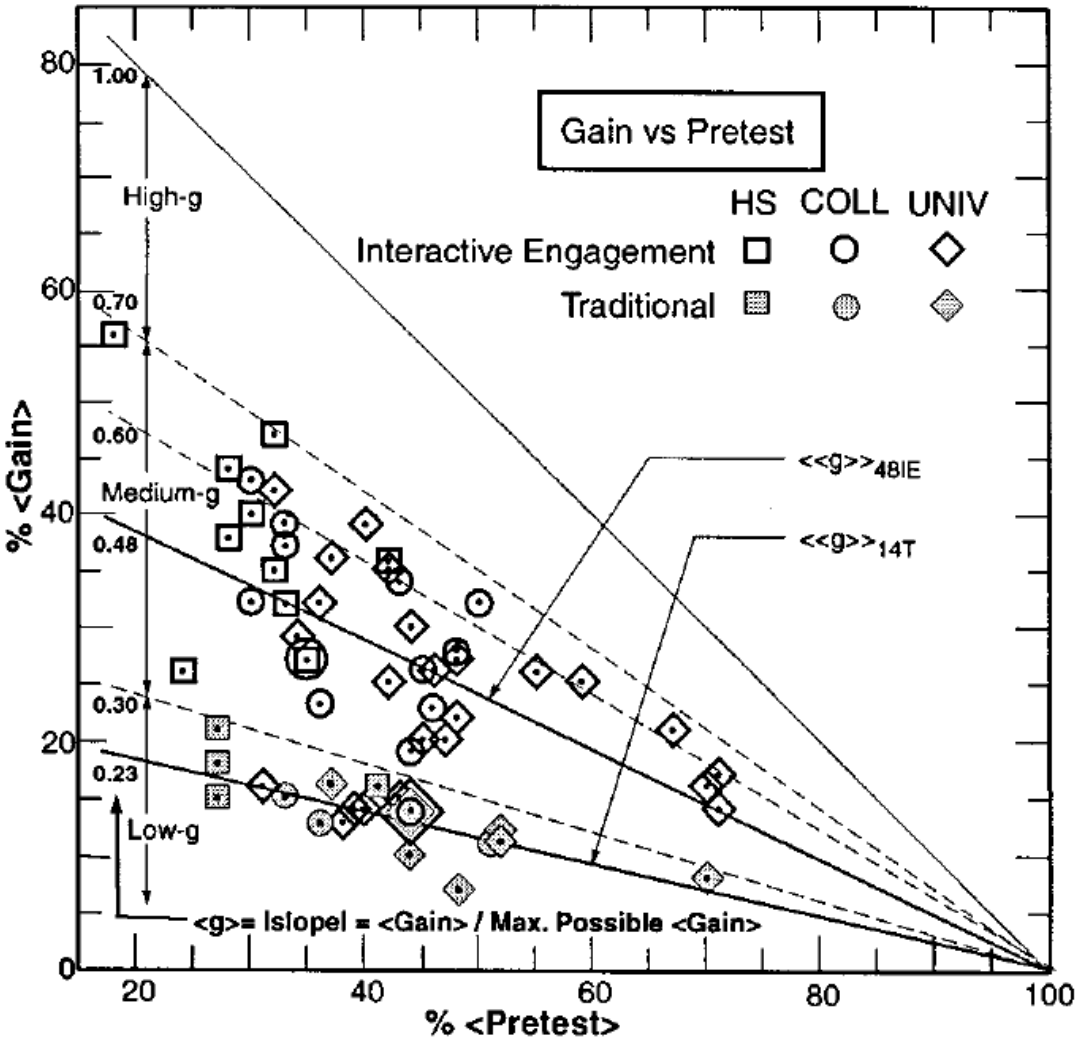
Measuring change in conceptual understanding

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Normalised gain

$$\langle g \rangle = \frac{\text{post} - \text{pre}}{100\% - \text{pre}}$$

Impact



Taken from Hake (1998) (6000 students)

Using the FCI with Foundation Students

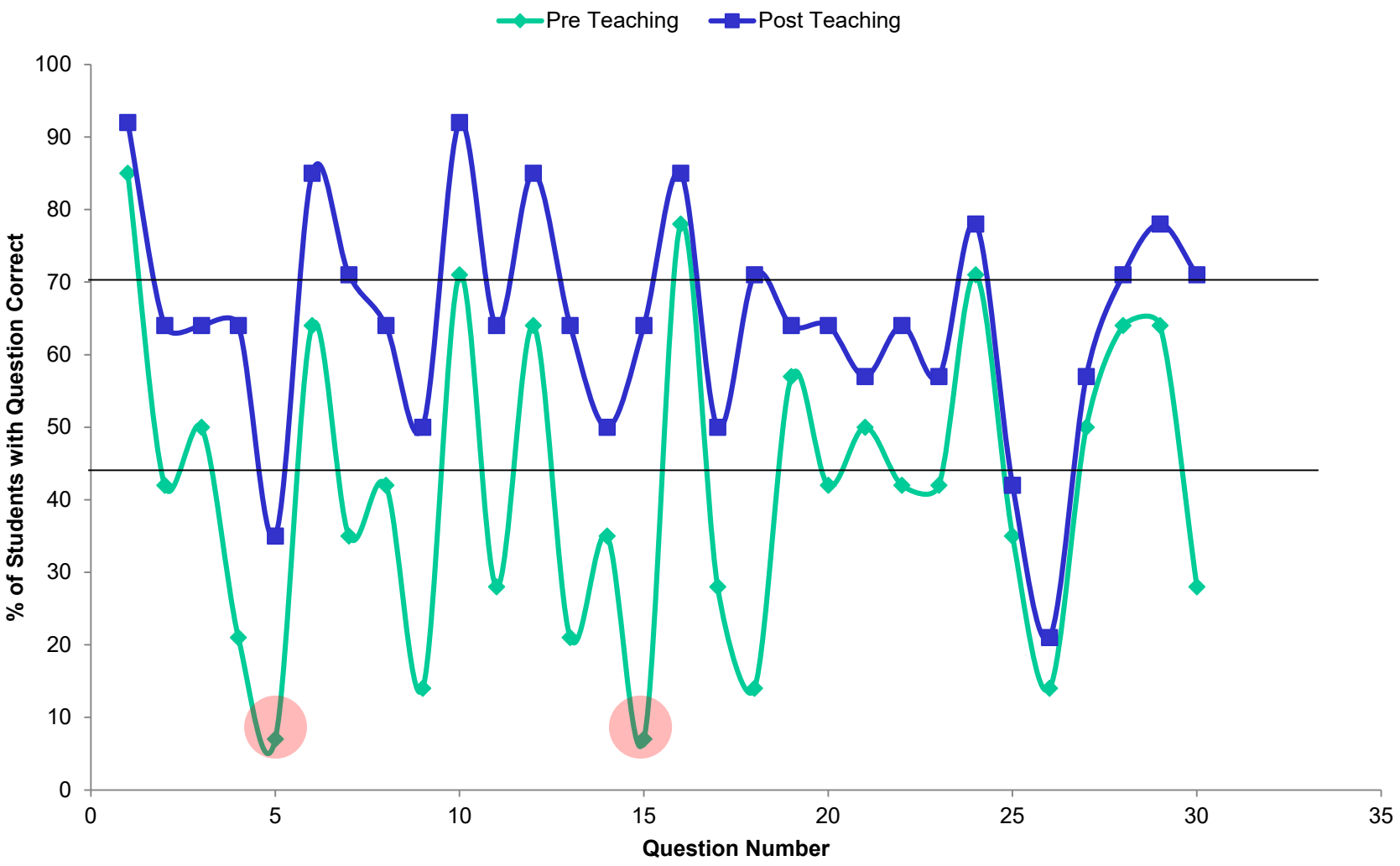
Method

The study

- The course
- The student cohort
- The teaching
- The data

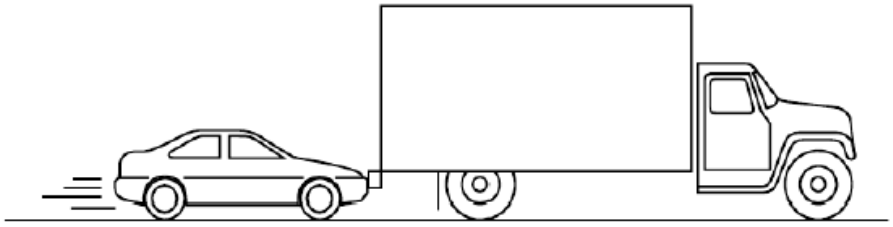
Pre- and Post-Test Results

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Example: Most Misunderstood Pre-Questions

A large truck breaks down out on the road and receives a push back into town by a small compact car as shown in the figure below.



15. While the car, still pushing the truck, is speeding up to get up to cruising speed,

(A) the amount of force with which the car pushes on the truck is equal to that with which the truck pushes back on the car.

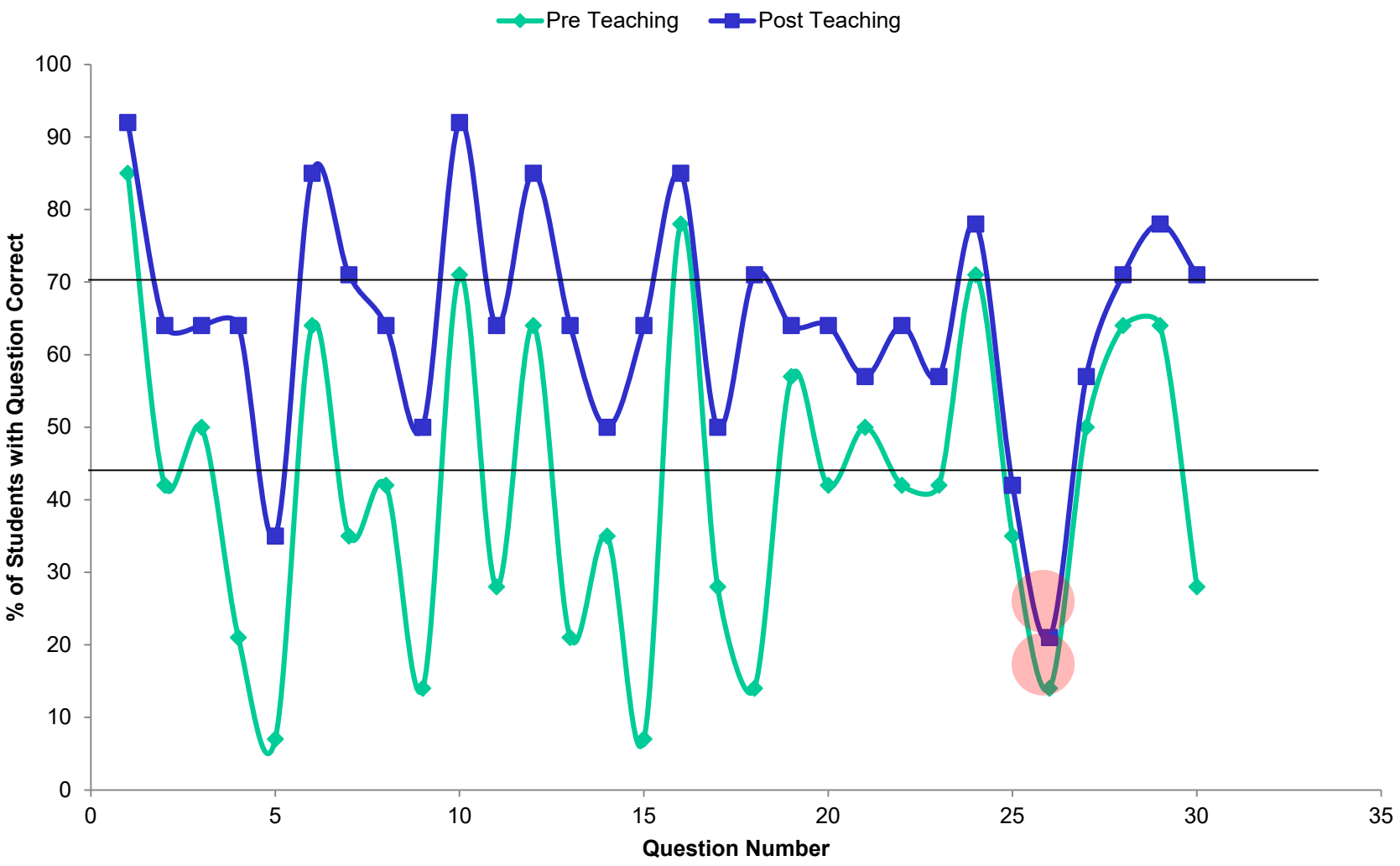
(B) the amount of force with which the car pushes on the truck is smaller than that with which the truck pushes back on the car.

(C) the amount of force with which the car pushes on the truck is greater than that with which the truck pushes back on the car.

(D) the car's engine is running so the car pushes against the truck, but the truck's engine is not running so the truck cannot push back against the car. The truck is pushed forward simply because it is in the way of the car.

(E) neither the car nor the truck exerts any force on the other. The truck is pushed forward simply because it is in the way of the car.

Pre and Post Test Results



Question with smallest gain

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25. A woman exerts a constant horizontal force on a large box. As a result, the box moves across a horizontal floor at a constant speed v_0.

The constant horizontal force applied by the woman

(A) has the same magnitude as the weight of the box.

(B) is greater than the weight of the box.

(C) has the same magnitude as the total force that resists the motion of the box.

(D) is greater than the total force that resists the motion of the box.

(E) is greater than either the weight of the box or the total force that resists its motion.

26. If the woman in the previous question doubles the constant horizontal force that she exerts on the box to push it on the same horizontal floor, the box then moves

(A) with a constant speed that is double the speed v_0 in the previous question.

(B) with a constant speed that is greater than the speed v_0 in the previous question, but not necessarily twice as great.

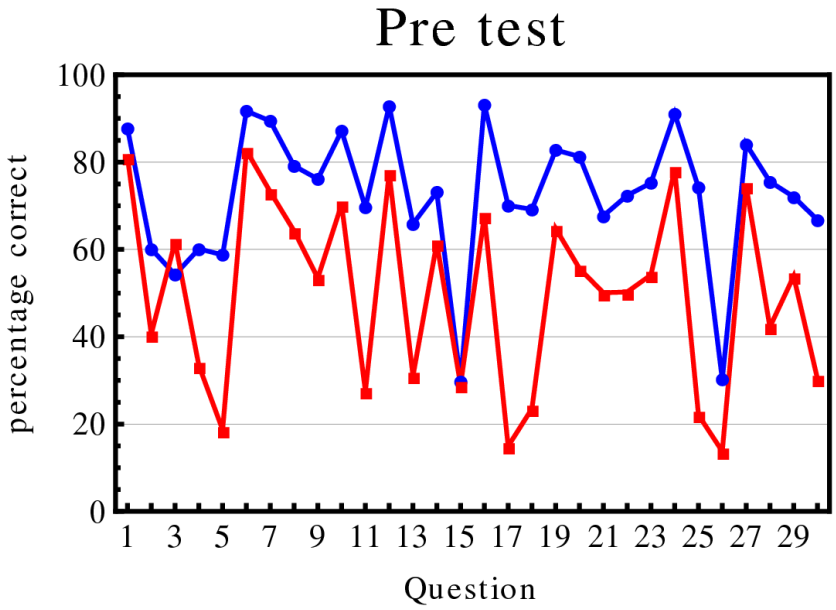
(C) for a while with a speed that is constant and greater than the speed v_0 in the previous question, then with a speed that increases thereafter.

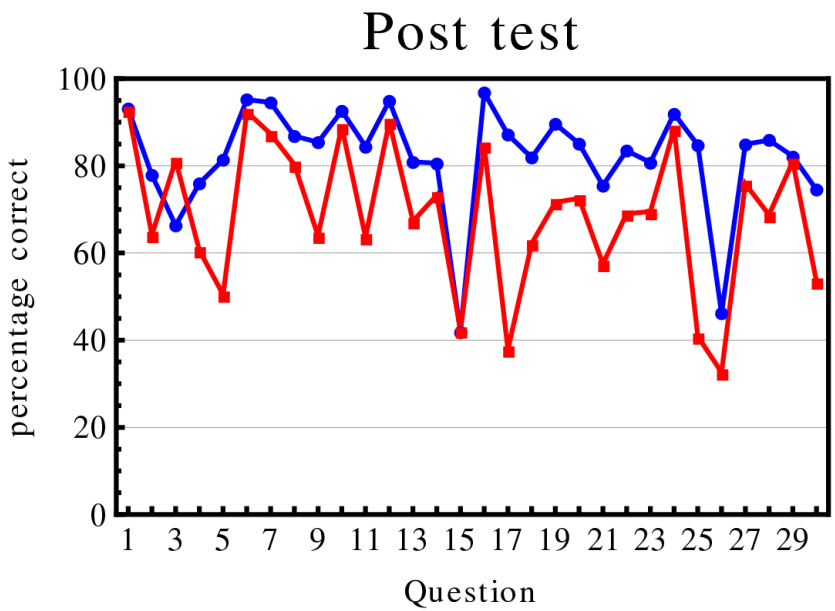
(D) for a while with an increasing speed, then with a constant speed thereafter.

(E) with a continuously increasing speed.

Taken from Birch, 2011

These Results Seen at Other HEIs





Blue: Manchester (post=mid)

Red: University of Minnesota – 10yrs of data (1997-2007)

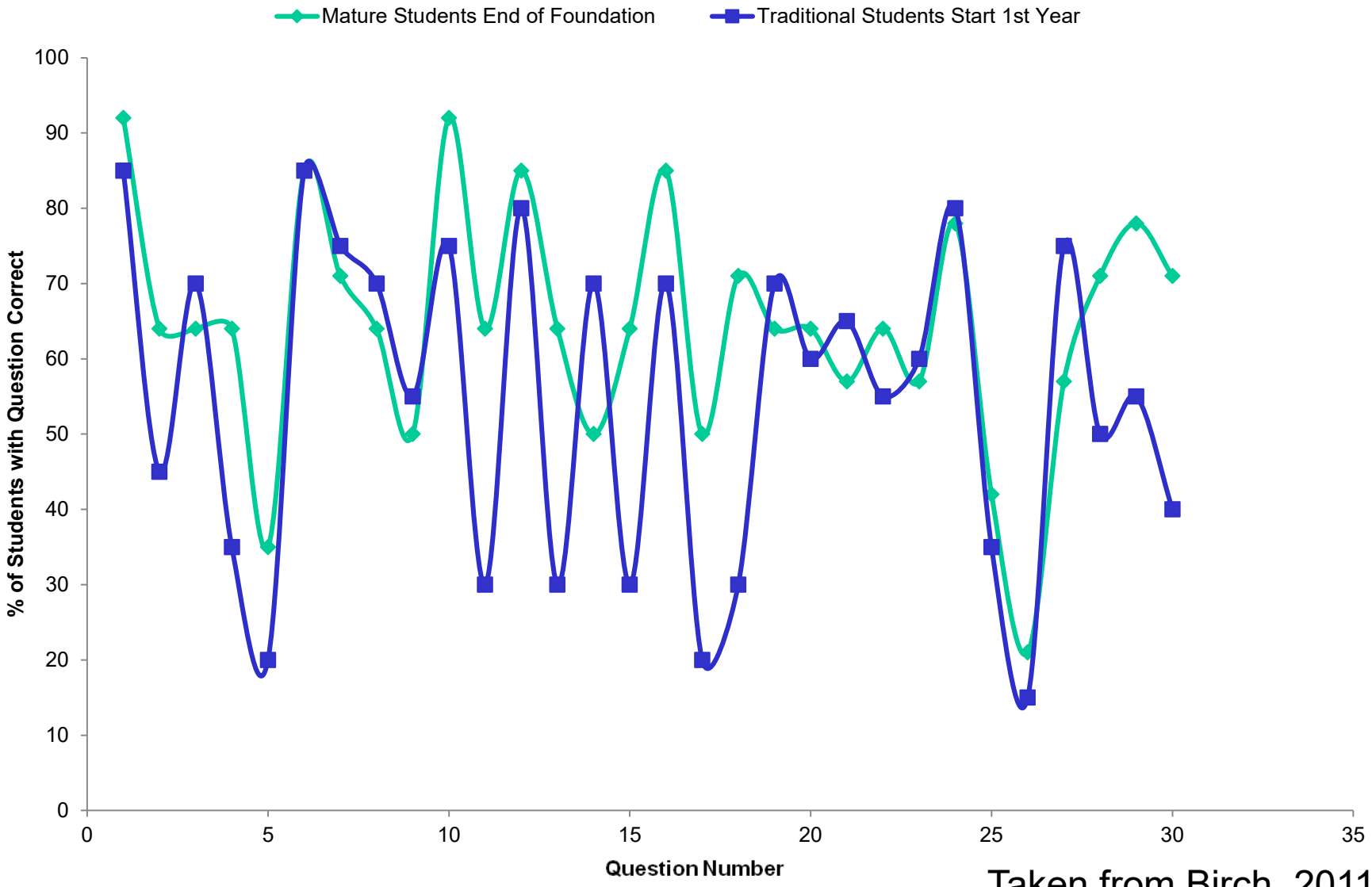
5600 1st year science & engineering students

Docktor & Heller, American Institute of Physics Conference Proceedings Vol:1064(1): 15-18, 2008

Taken from Birch, 2011

Are we preparing our students conceptual mechanics understanding for 1st Year Physics?

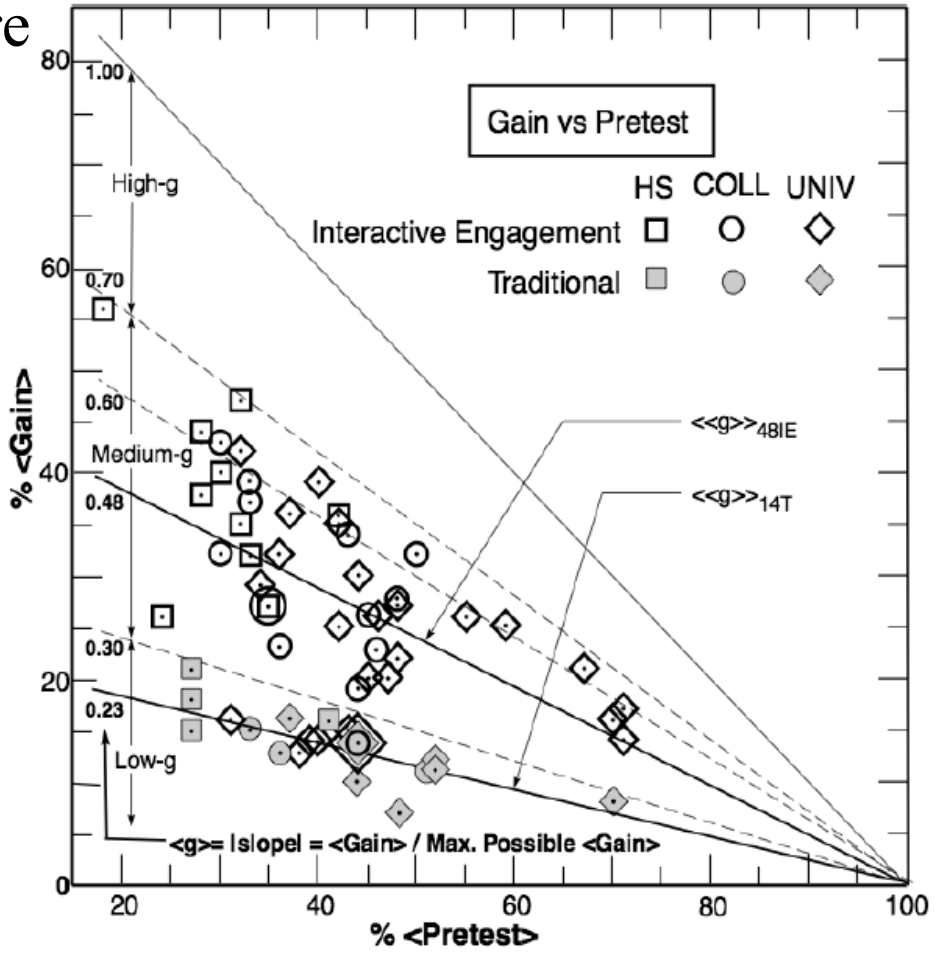
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Taken from Birch, 2011

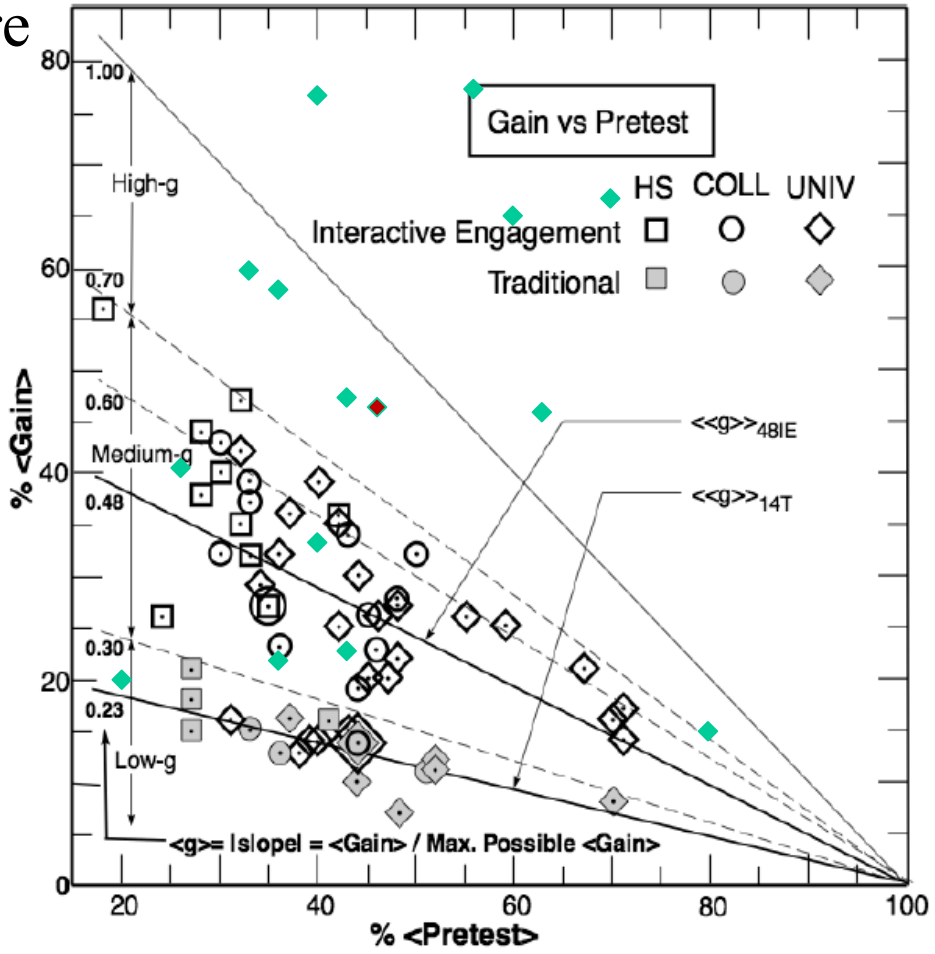
How does this relate to game-changing American result ?

$$\langle g \rangle = \frac{\text{post} - \text{pre}}{100\% - \text{pre}}$$



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Common Criticisms of the Force Concept Inventory

Giving the students the test twice affects their post-test score

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- **25% (~200 students not given pre-test)**
- **No statistically significant difference in post-test scores**

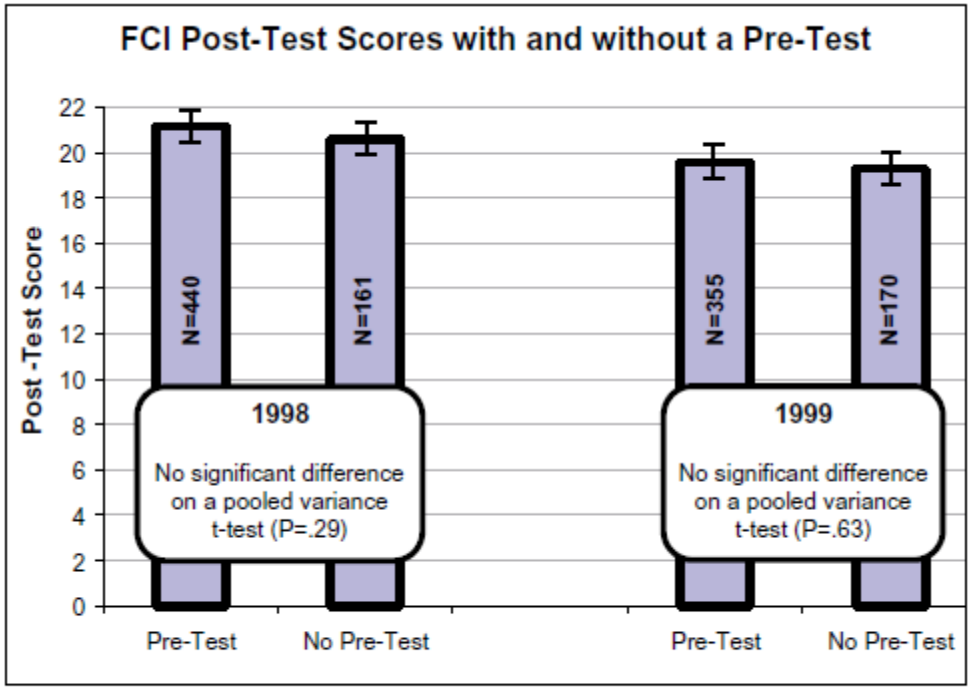


Fig. 3. A comparison of FCI post-test scores for groups of students who did and did not take the pre-test.

Taken from Henderson, C. (2002). Common Concerns About the Force Concept Inventory, The Physics Teacher, *40, 542-547*

The test is formative: will students engage meaningfully?

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There are several ways you can see students not taking the test seriously

- Refusing to take the test
- Answering all A's, B's etc
- Drawing pictures on the answer sheet
- Leaving 6 or more blanks
- Answering with patterns e.g. ABCDE, AABBCC etc

Taken from Henderson, C. (2002).

The test is formative: will students engage meaningfully?

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	Pre-Ungraded	Post-Ungraded	Post-Graded	Maximum % of students not taking test seriously as a result of grading option
	N = 1856	*N* = 524	*N* = 1332	
	1997, 1998, 1999	1999	1997, 1998	
Refuses to take test	0.5%	0.5%	0.0%	0.5%
Draws a picture	0.2%	0.2%	0.0%	0.2%
Answers all A's, B's, etc.	0.0%	0.0%	0.0%	0.0%
Leaves a lot of blanks (six or more)	1.5%	1.5%	0.1%	1.4%
Other Patterns				
ABCDE, EDCBA	0.8%	1.0%	0.5%	0.5%
Six A's, B's, etc.	0.2%	0.2%	0.0%	0.2%
Total	**3.2%**	**3.4%**	**0.6%**	**2.8%**

Taken from Henderson, C. (2002).

Is this FCI really testing what it aims to test?

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- **Huffman and Heller (1995) asked: "what does the FCI actually measure?"**
  - Used correlation analysis, and found that question scores only correlated roughly.
  - They interpreted this as indicating that the questions had no underlying connectivity and were not assessing a common principle.
  - This was refuted by the FCI authors (Hestenes et al.1995) and more recently by Lasry et al (2011) who performed an alternative correlation study and found that the question responses were adequately correlated.

Conclusions & Future Work

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- **We have a mathematically rigorous module, but we wanted to check that it addressed conceptual understanding.**
- **Used the proven Force Concept Inventory Test to check student conceptual understanding pre- and post-test.**
- **The conceptual understanding of these students increased significantly in the post-teaching test.**
- **Future work:**
  - Better statistics
  - Using versions of FCI in other languages to assess the role language plays in developing student conceptual understanding.
  - Does gender play a role in understanding mechanics questions?

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Is the FCI a robust test ?

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- High Kuder–Richardson reliability coefficient values, which estimate the average correlation of scores obtained on all possible halves of the test, suggest strong internal consistency.
- However, 31% of the responses changed from test to retest, suggesting weak reliability for individual questions.
- A chi-square analysis shows that change in responses was neither consistent nor completely random.
- The puzzling conclusion is that although individual FCI responses are not reliable, the FCI total score is highly reliable

Taken from Lasry et al. (2011)