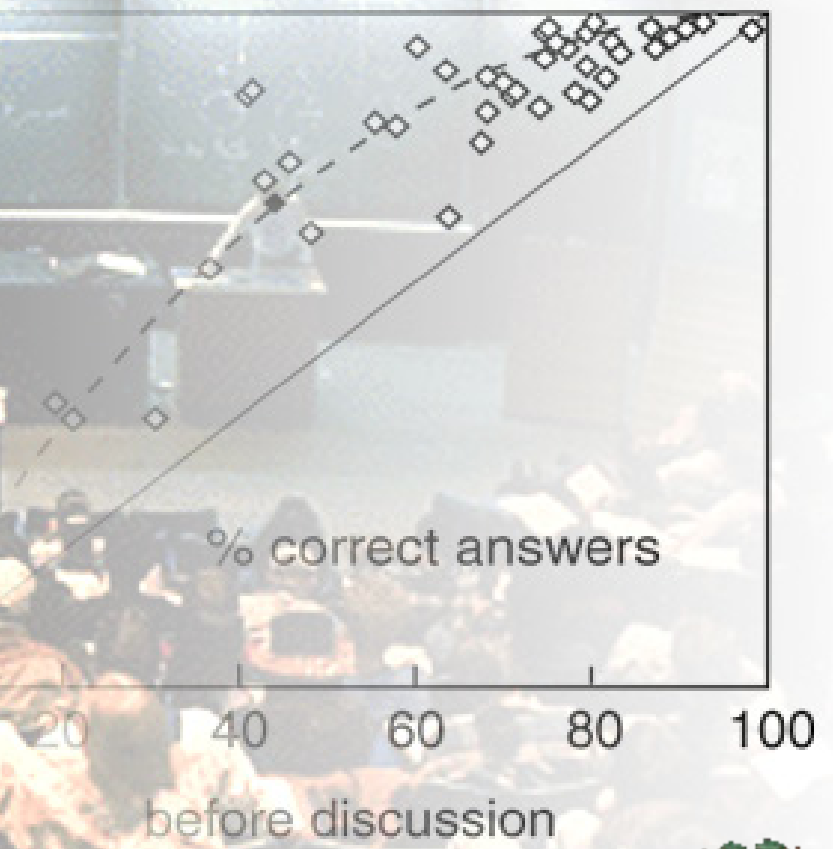


The Scientific Approach to Teaching: Research as a basis for course design



Program on Innovative Teaching and Learning
LASPAU Harvard University
Cambridge, MA, 1 May 2012



The Scientific Approach to Teaching: Research as a basis for course design



@eric_mazur

Program on Innovative Teaching and Learning
LASPAU Harvard University
Cambridge, MA, 1 May 2012



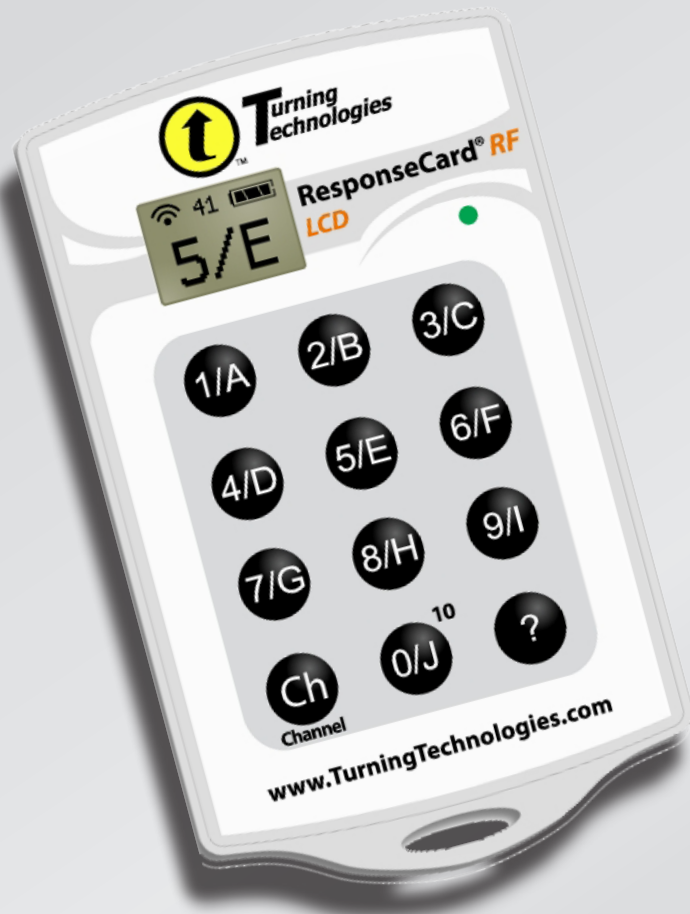
My message

let's not abandon the scientific method when teaching

The plural of anecdote is not data

Lee Shulman

Get your clickers ready!



- no ON/OFF button
- only last “click” counts
- display shows recorded answer

Get your clickers ready!



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unique ID on back of clicker

How do we learn?

Think of something you are good at — something that you know you do well.

How do we learn?

Think of something you are good at — something that you know you do well.

How did you become good at this?

How do we learn?

Became good at it by:

- 1. trial and error**
- 2. lectures**
- 3. practicing**
- 4. apprenticeship**
- 5. other**

How we teach...



Learning spaces



Learning spaces



Learning spaces



Education



Education

Some people talk in their sleep.

A large lecture hall with a professor at a podium and students in the audience. The room is filled with students sitting at desks, many of whom appear to be sleeping or resting. The professor is standing at a podium in the center of the stage, facing the audience. The room has a curved wall and a large screen at the front. The lighting is dim, and the overall atmosphere is one of a lecture in progress.

Education

A large lecture hall with a lecturer at the front and many students in the audience. The room is filled with rows of students sitting at desks, facing the front where a lecturer is standing. The room has a curved wall and a large screen at the front.

Some people talk in their sleep.

Lecturers talk while other people are sleeping.

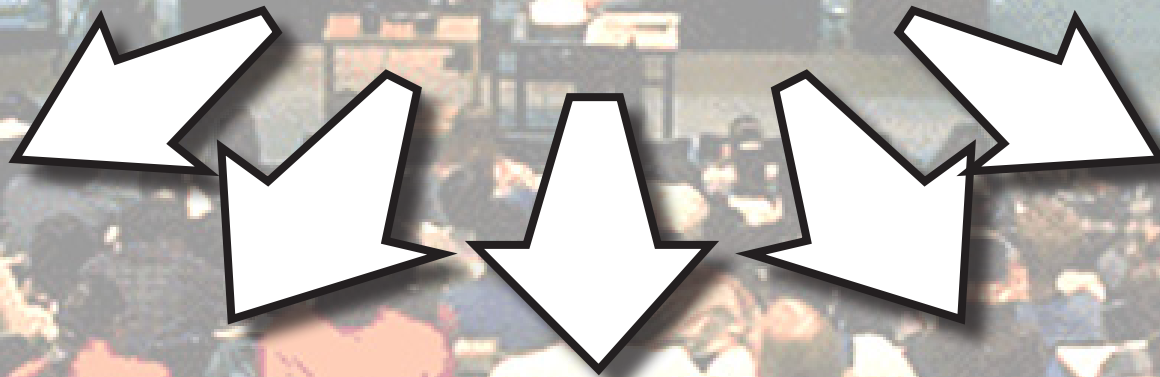
Albert Camus

Education



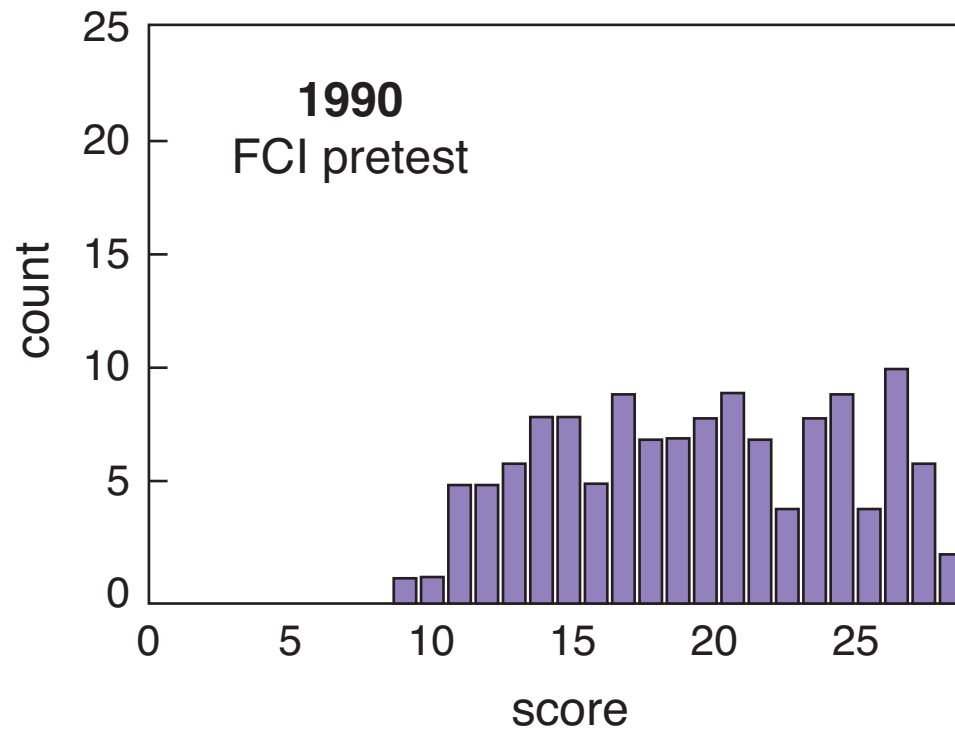
Education

lectures focus on information transfer...



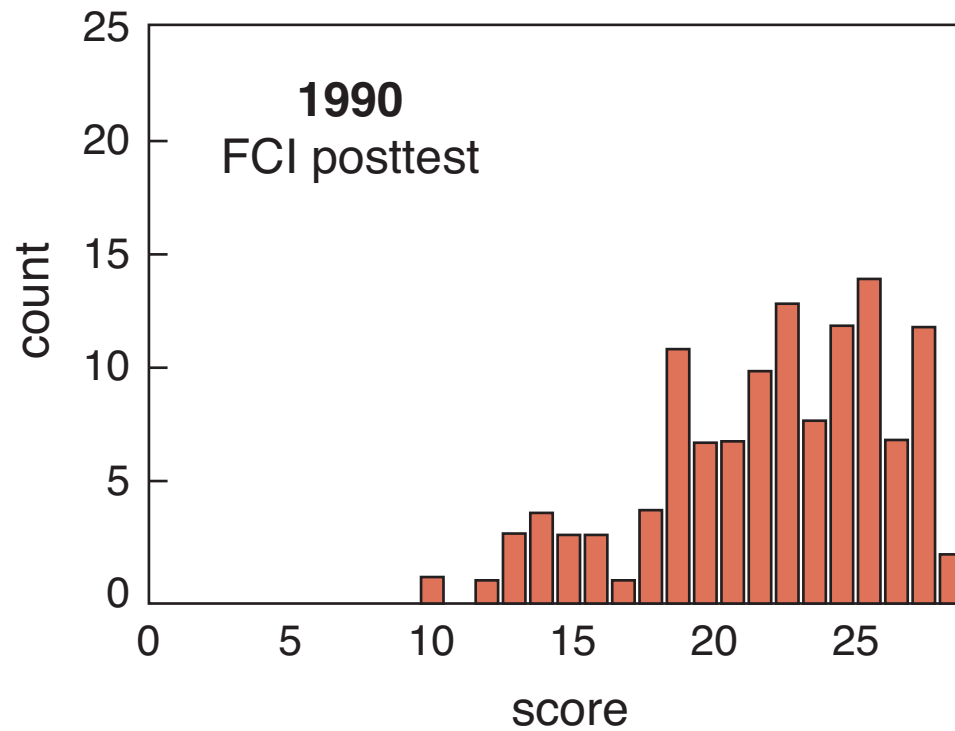
Education

education is not just information transfer



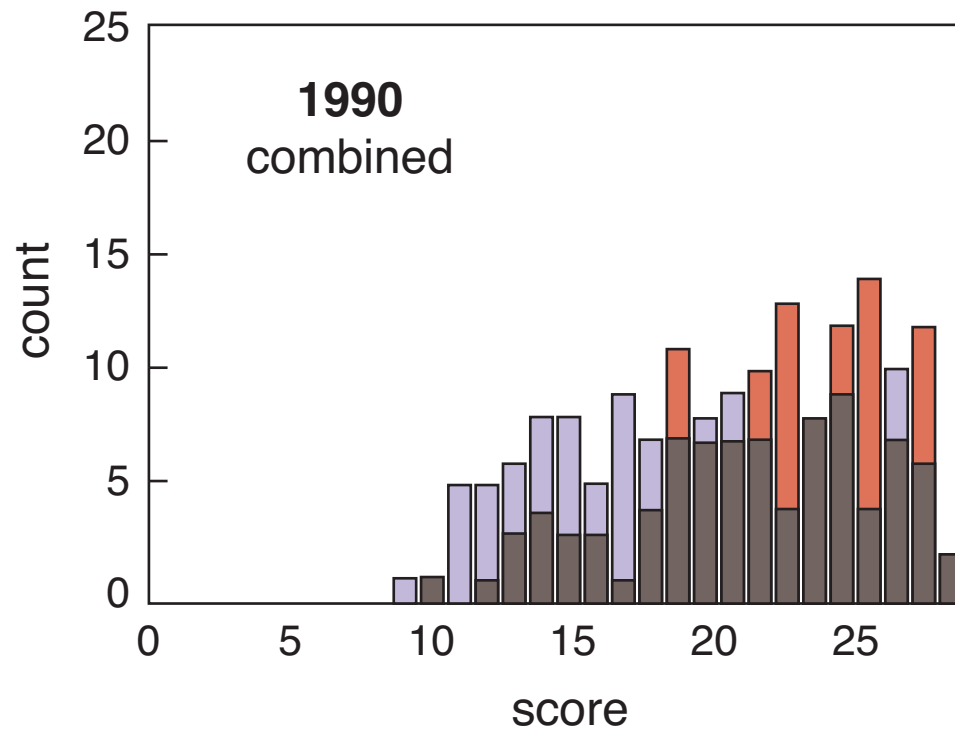
Education

education is not just information transfer

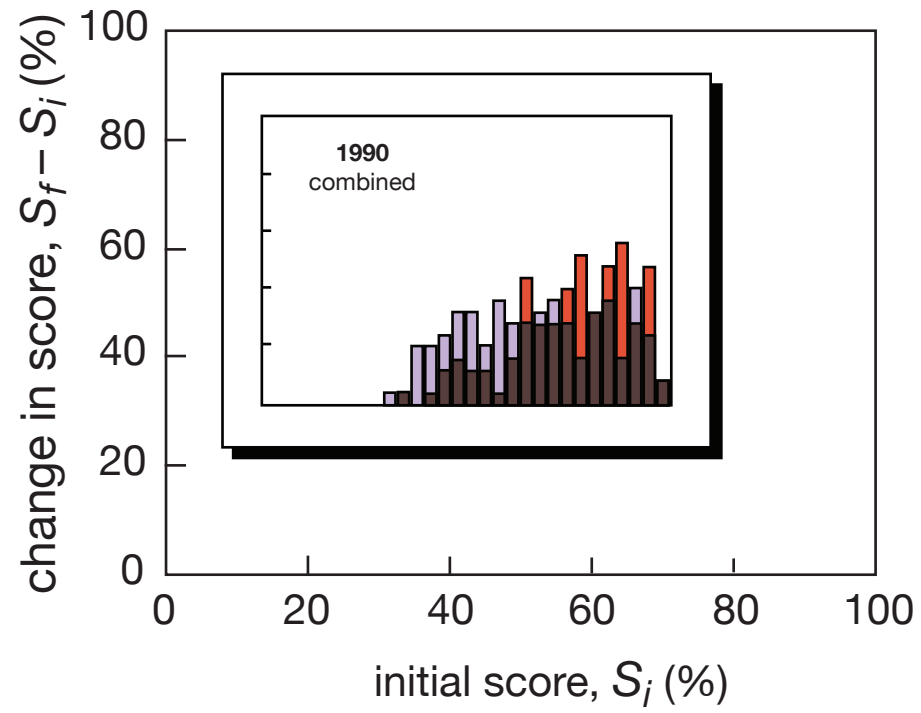


Education

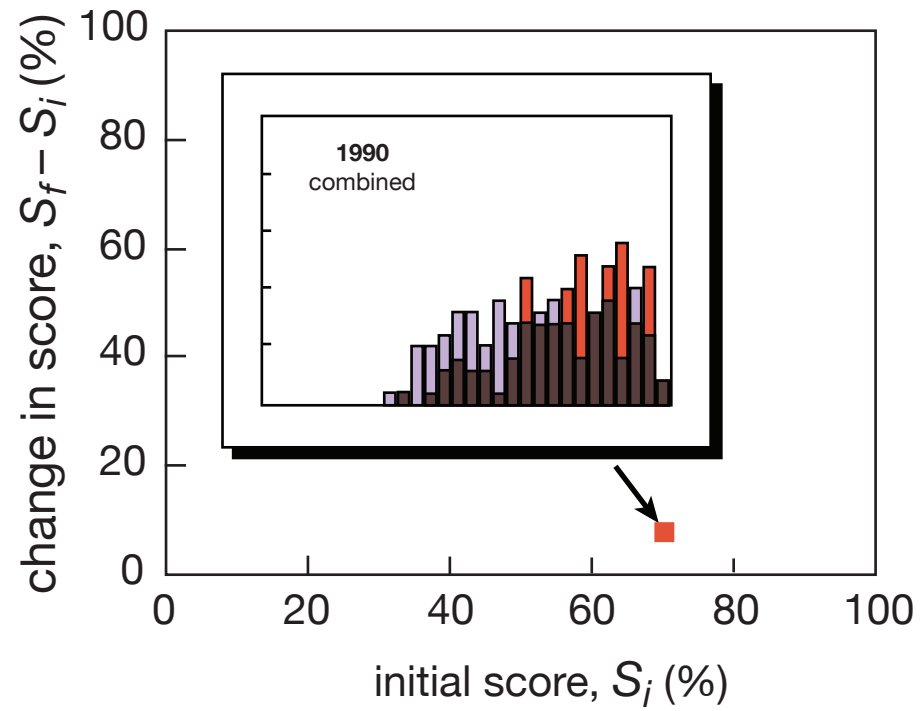
education is not just information transfer



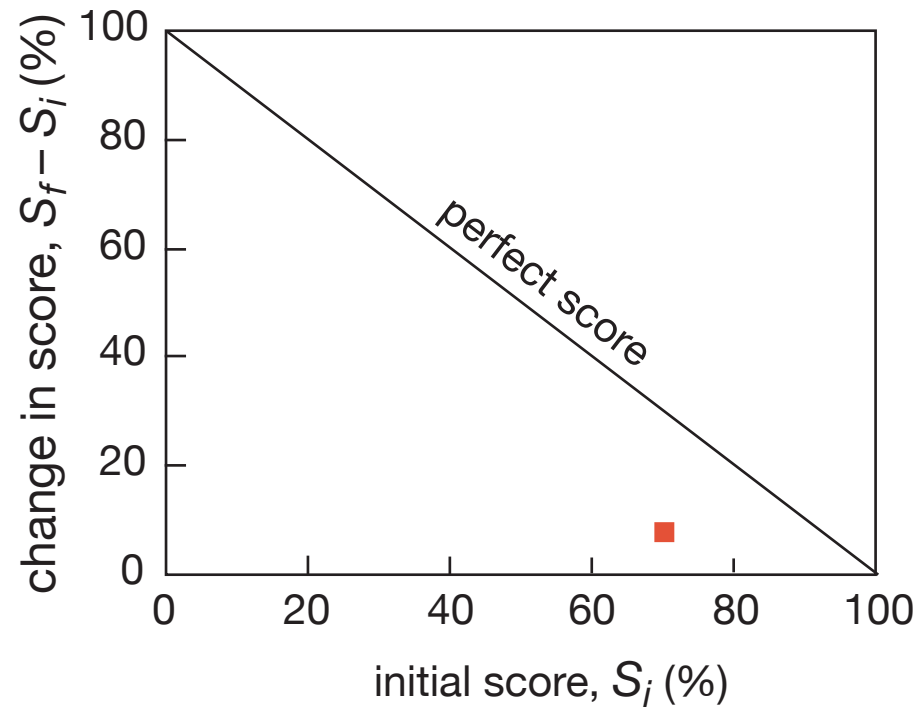
Education



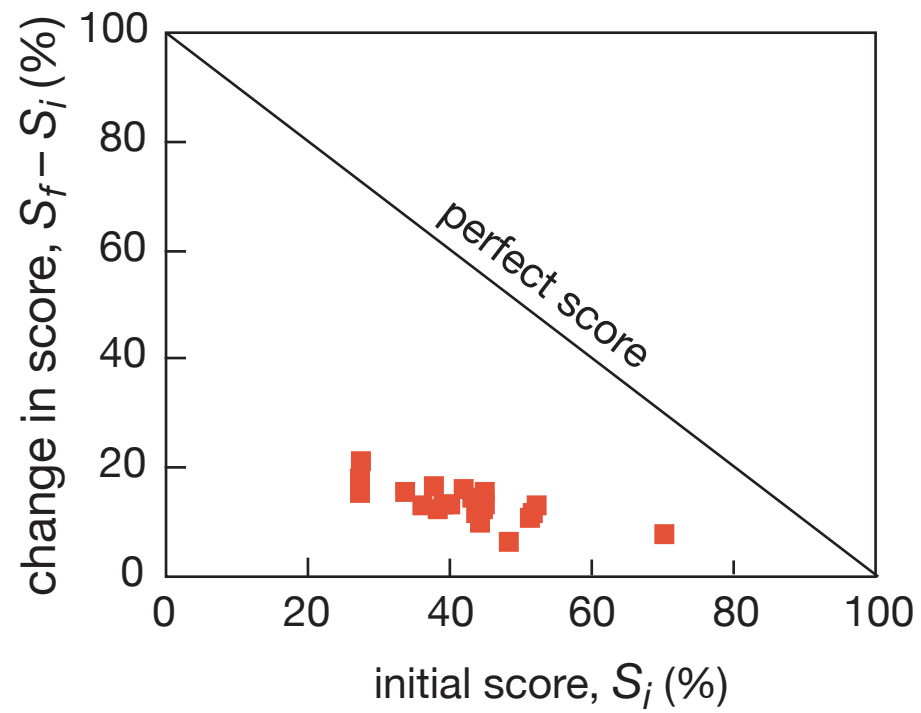
Education



Education

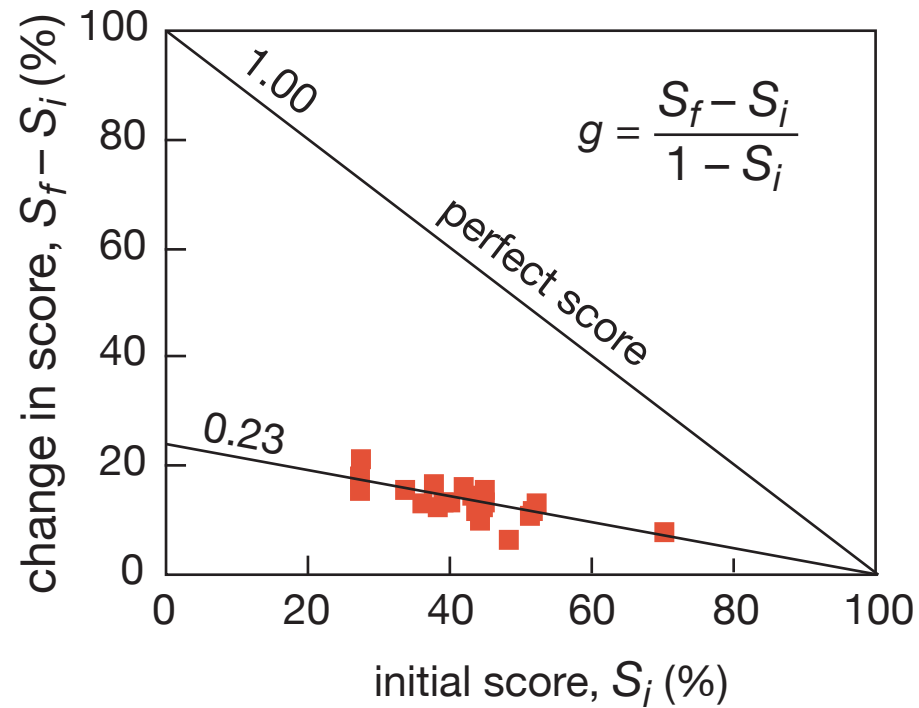


Education



Education

only one quarter of maximum gain realized



A large lecture hall with students seated at desks, facing a stage with a lecturer and a large screen displaying text. The text on the screen is partially legible and appears to be a list or a set of instructions. The room is dimly lit, with the stage area being the primary source of light. The students are mostly seen from behind, looking towards the front of the room. The lecturer is standing at a podium on the stage, facing the audience. The overall atmosphere is that of a formal academic setting.

So what should we do?

Peer Instruction

Give students more responsibility for gathering information...

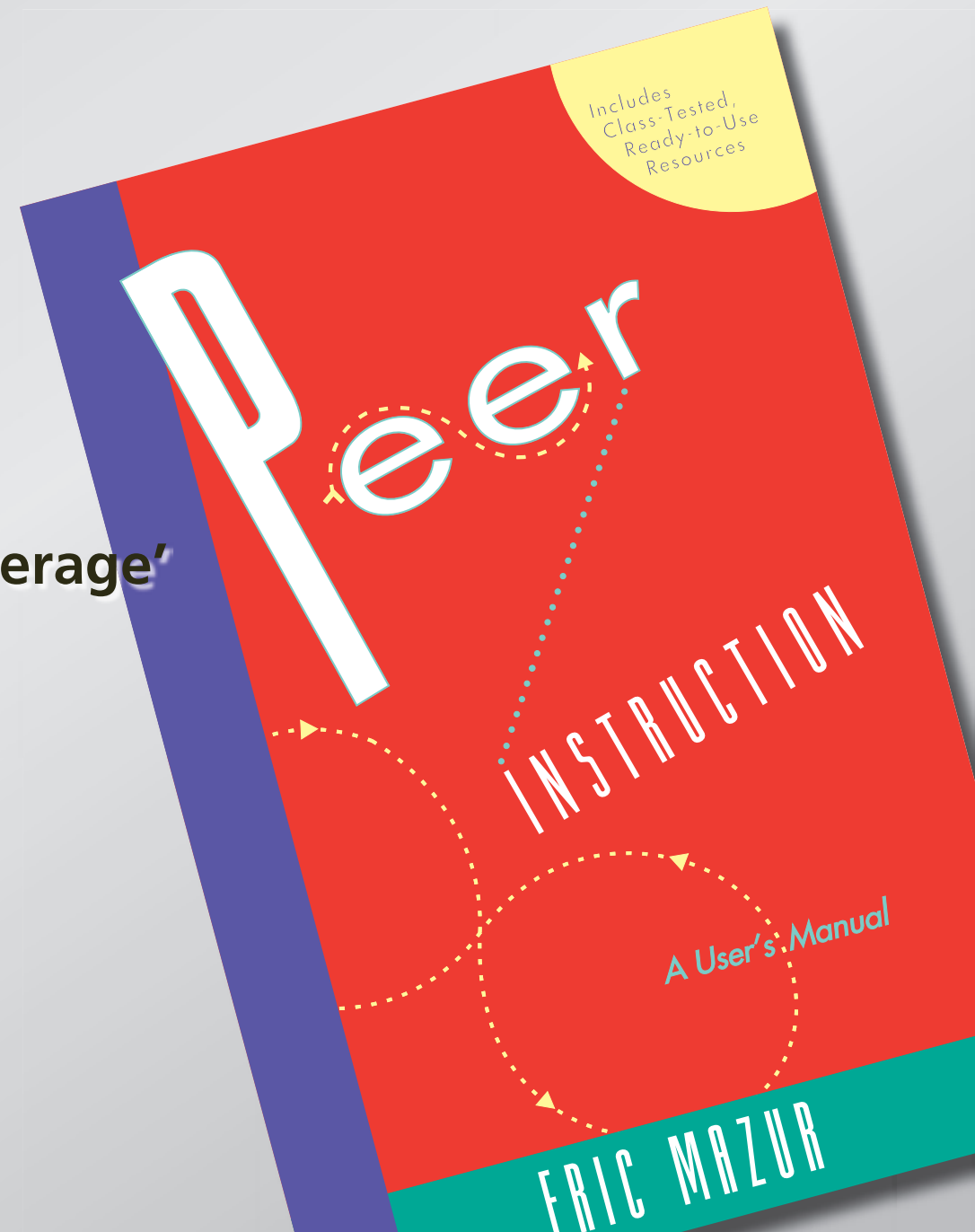
Peer Instruction

**Give students more responsibility for gathering information...
so we can better help them assimilate it.**

Peer Instruction

Main features:

- pre-class reading
- in-class: depth, not 'coverage'
- ConcepTests



Peer Instruction

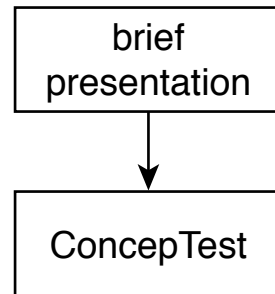
ConcepTest:

- 1. Question**
- 2. Thinking**
- 3. Individual answer**
- 4. Peer discussion**
- 5. Revised/Group answer**
- 6. Explanation**

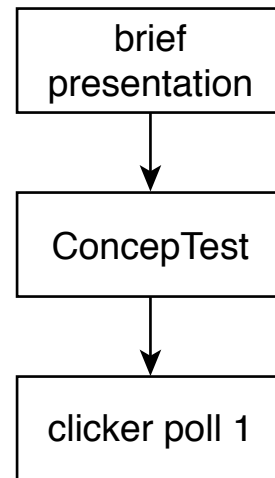
Peer Instruction

brief
presentation

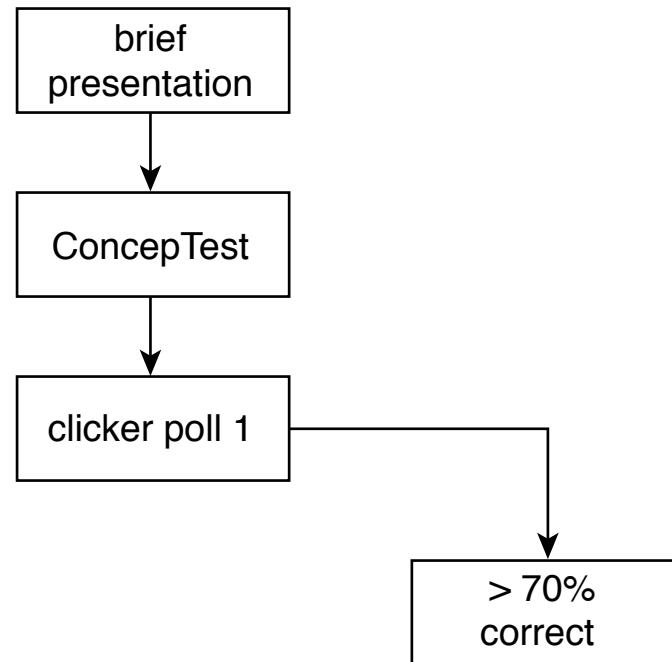
Peer Instruction



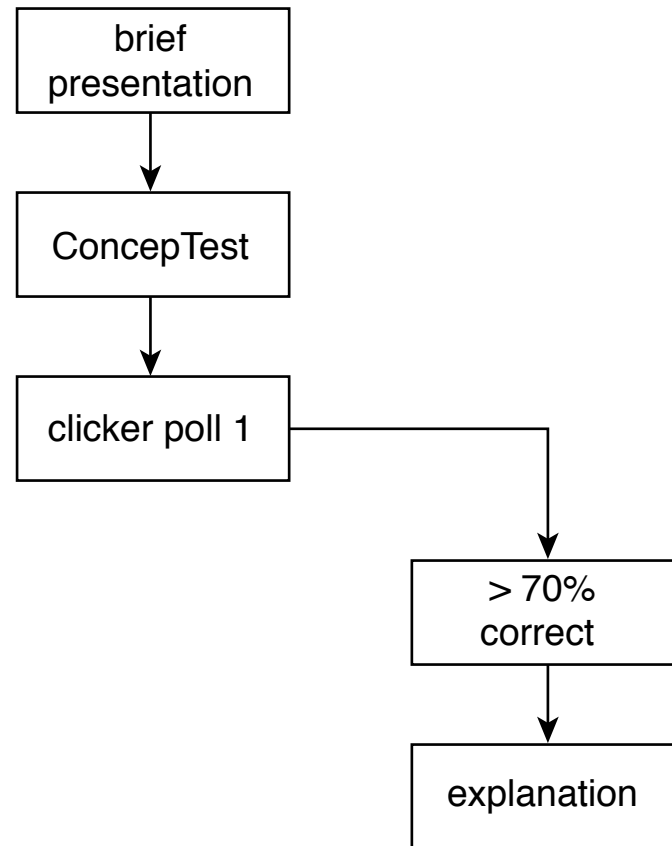
Peer Instruction



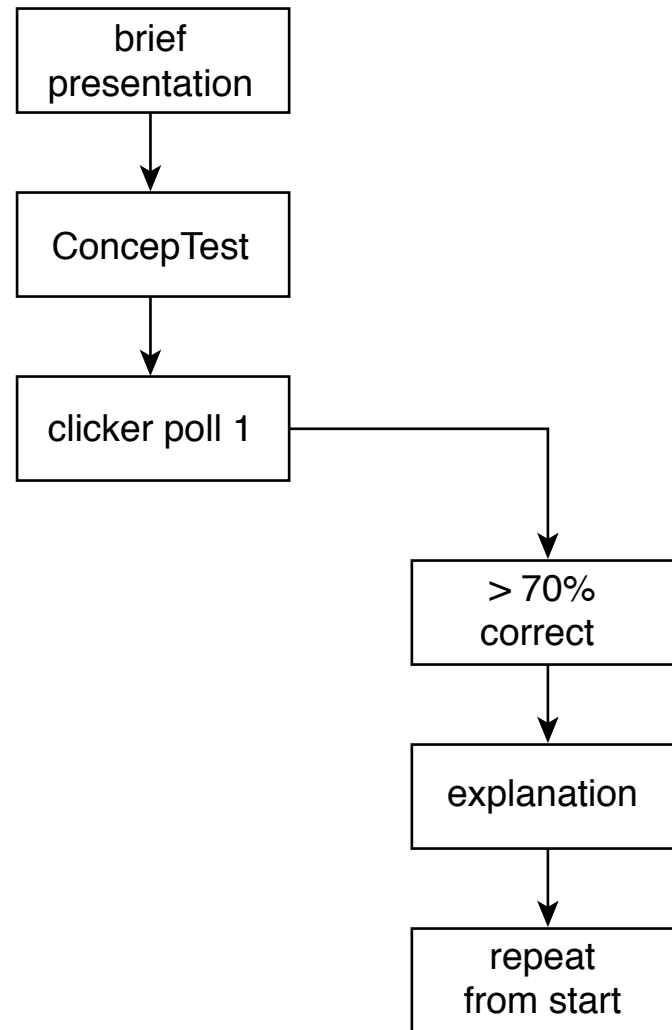
Peer Instruction



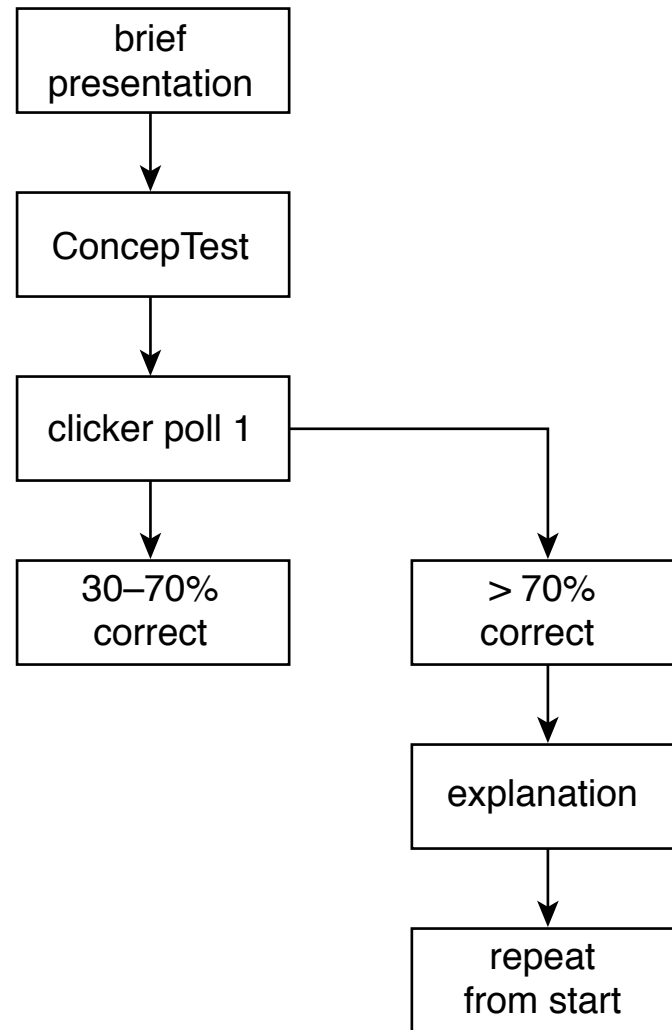
Peer Instruction



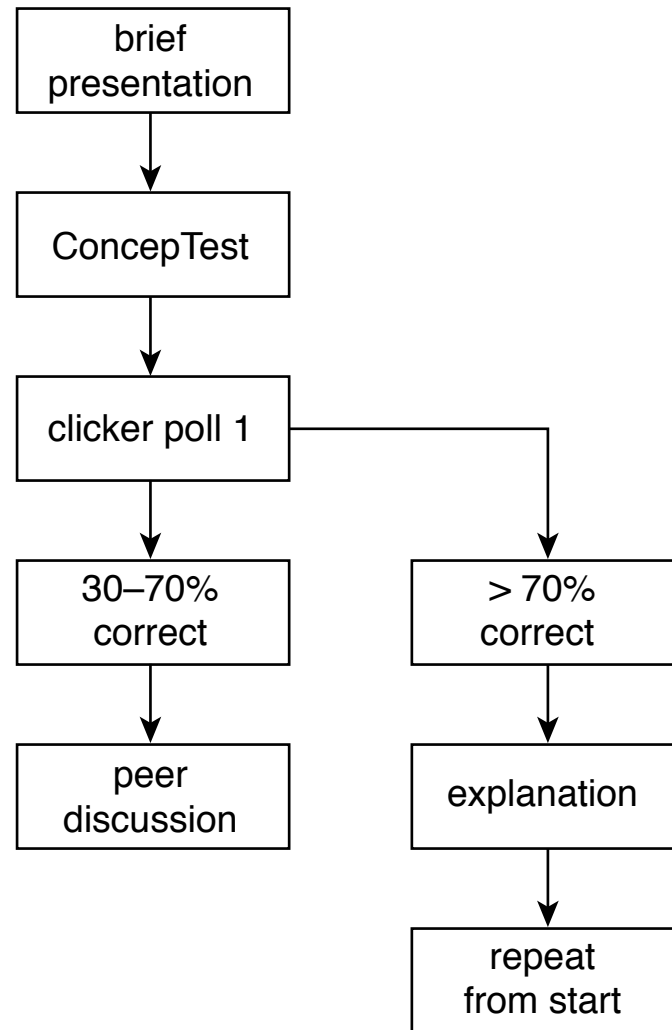
Peer Instruction



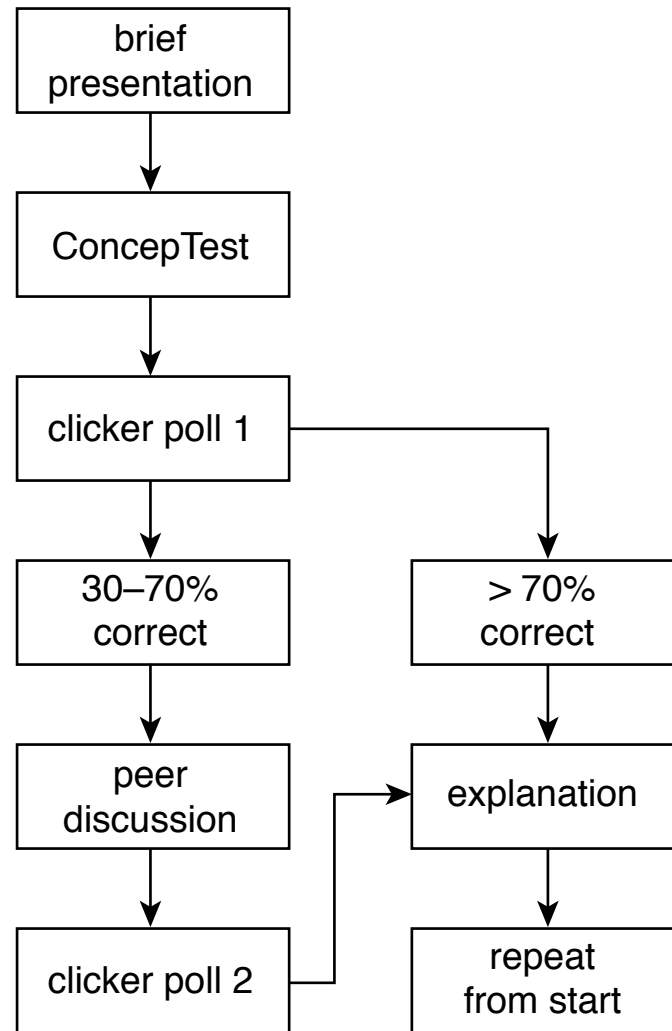
Peer Instruction



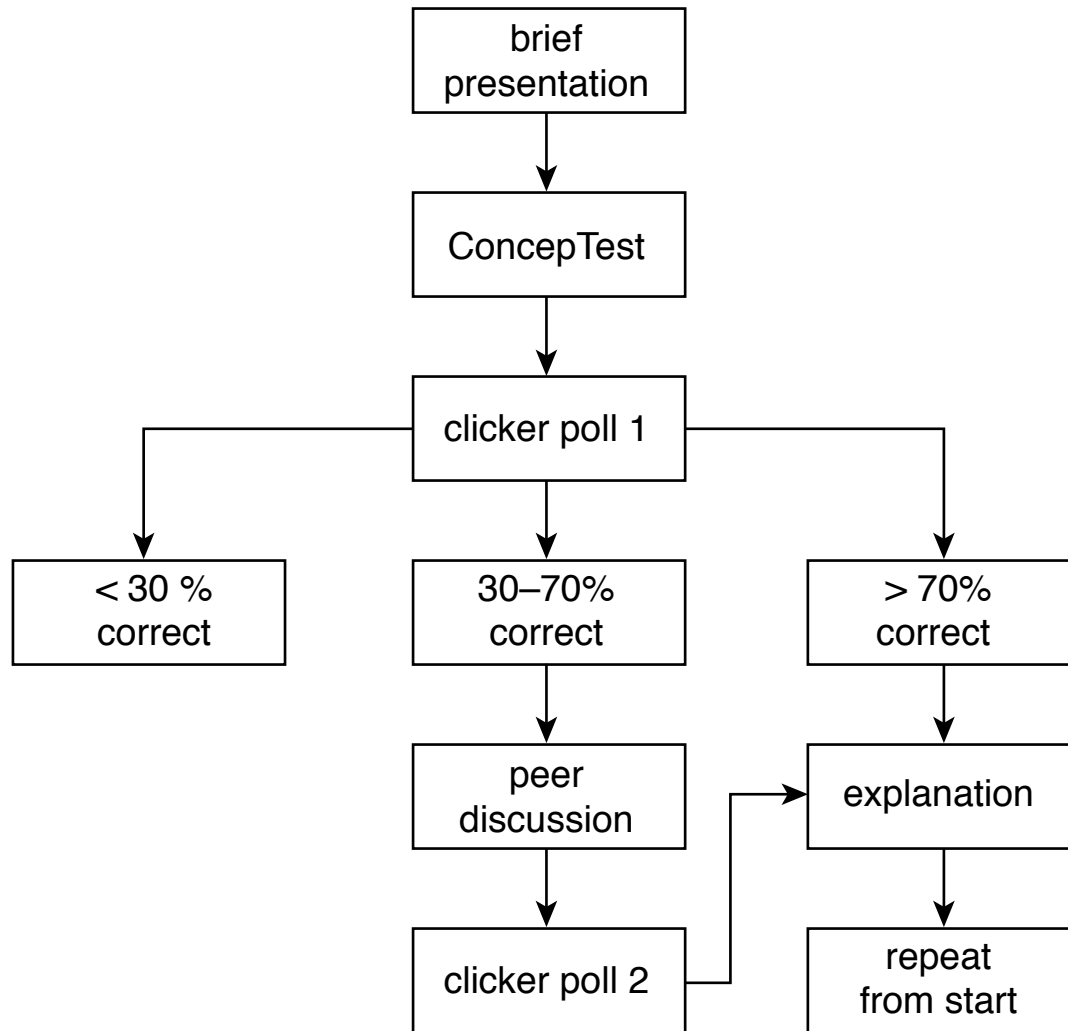
Peer Instruction



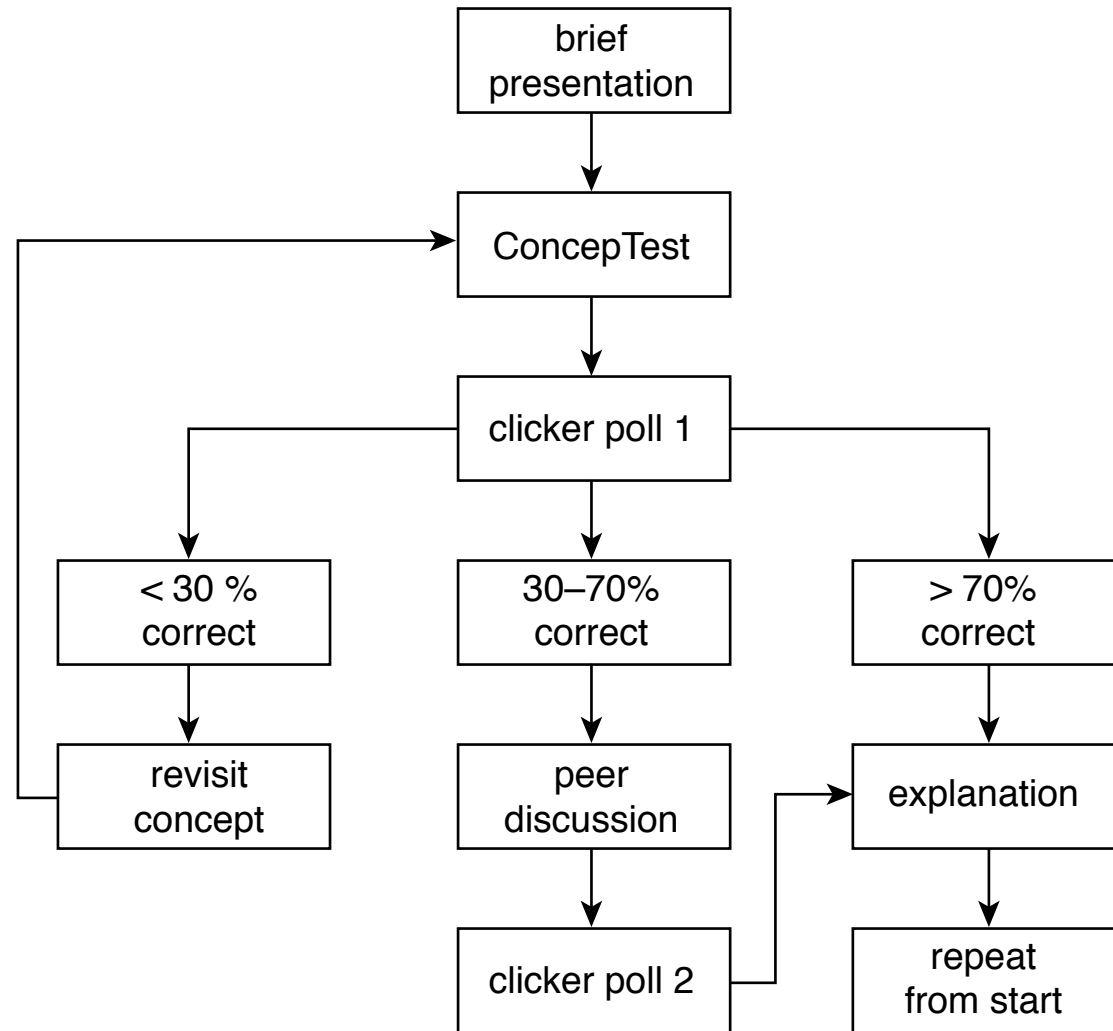
Peer Instruction



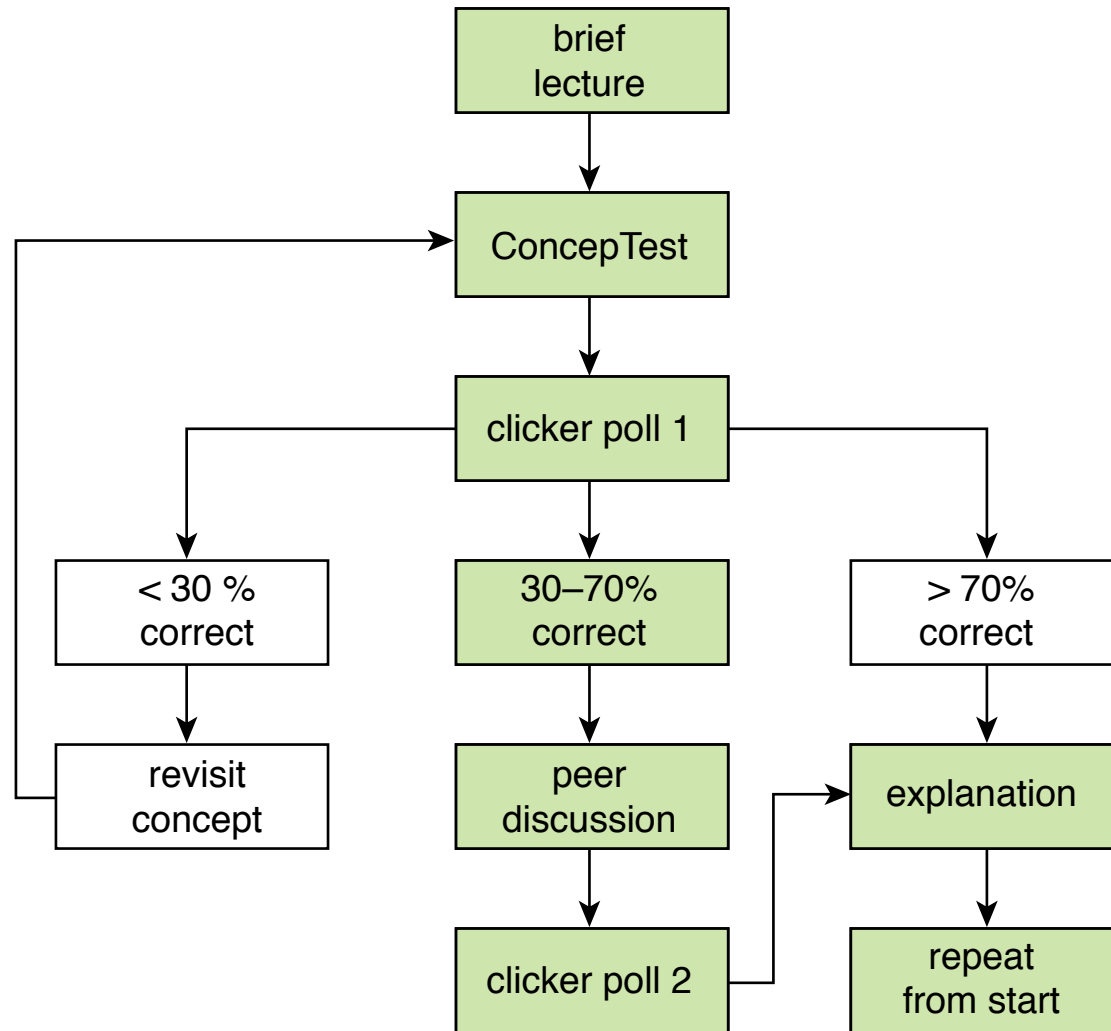
Peer Instruction



Peer Instruction

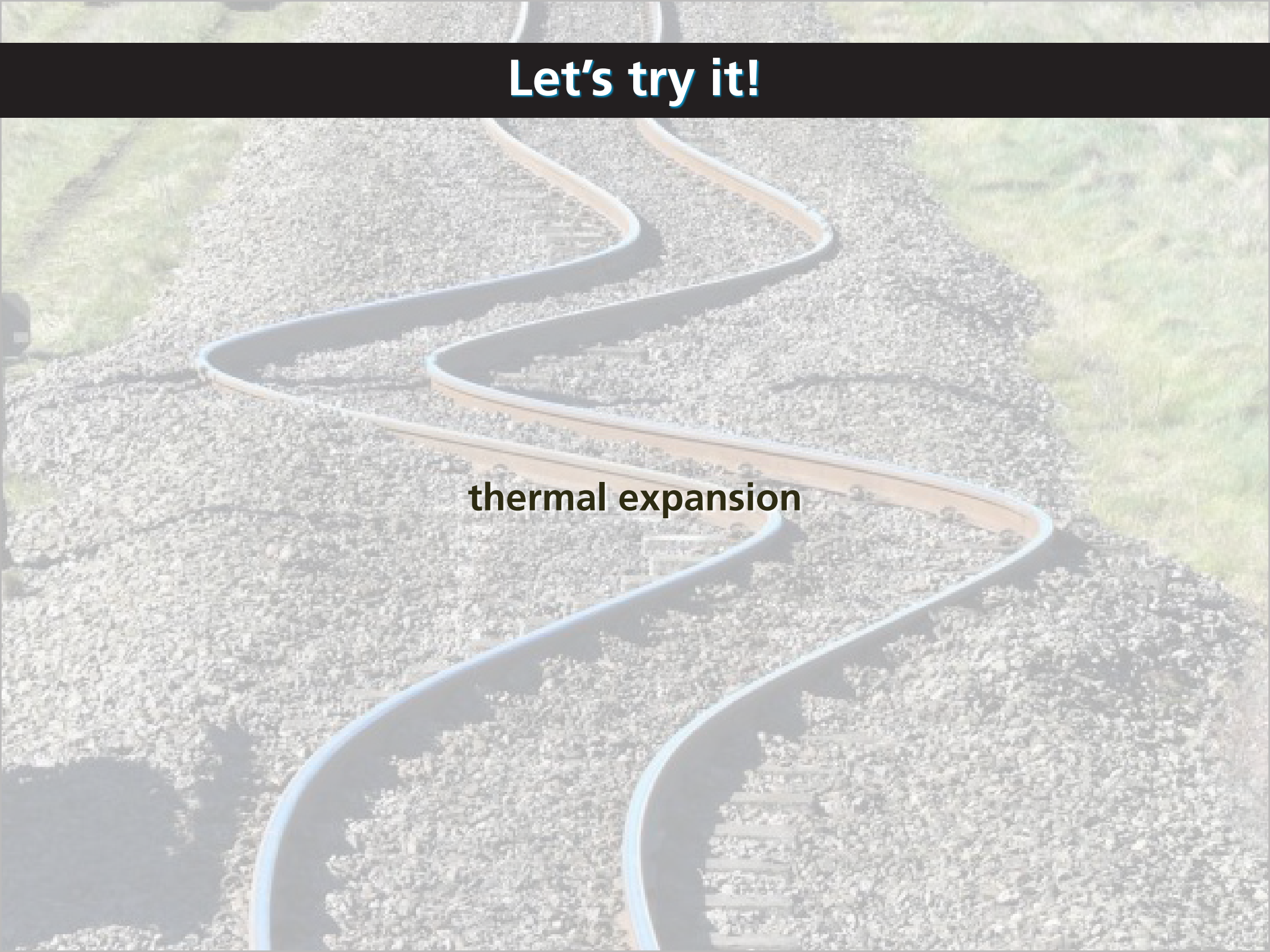


Peer Instruction



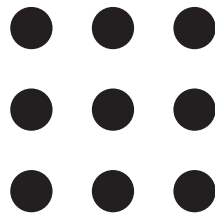
Let's try it!

thermal expansion



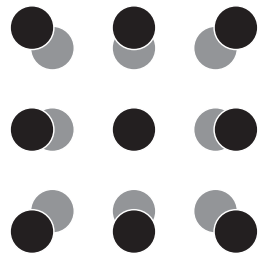
Let's try it!

When metals heat up, they expand because all atoms get farther away from each other.



Let's try it!


When metals heat up, they expand because all atoms get farther away from each other.



Let's try it!

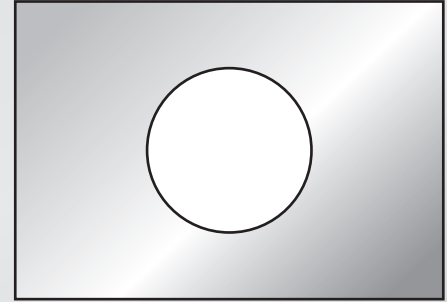
When metals heat up, they expand because all atoms get farther away from each other.

all of them



Let's try it!

Consider a rectangular metal plate with a circular hole in it.

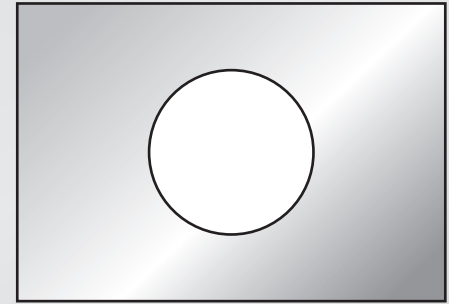


Let's try it!

Consider a rectangular metal plate with a circular hole in it.

When the plate is uniformly heated, the diameter of the hole

1. increases.
2. stays the same.
3. decreases.



Let's try it!

Consider a rectangular metal plate with a circular hole in it.

When the plate is uniformly heated, the diameter of the hole

1. increases.
2. stays the same.
3. decreases.



you got all fired up!

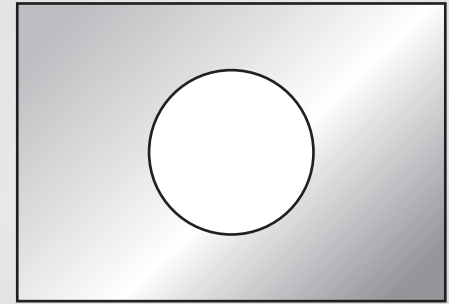


Let's try it!

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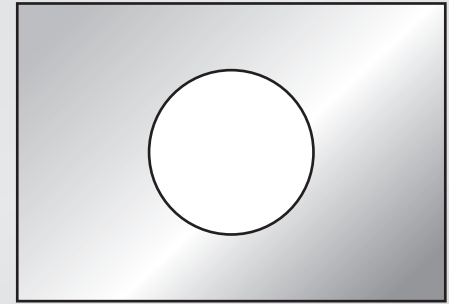


Let's try it!

Consider a rectangular metal plate with a circular hole in it.

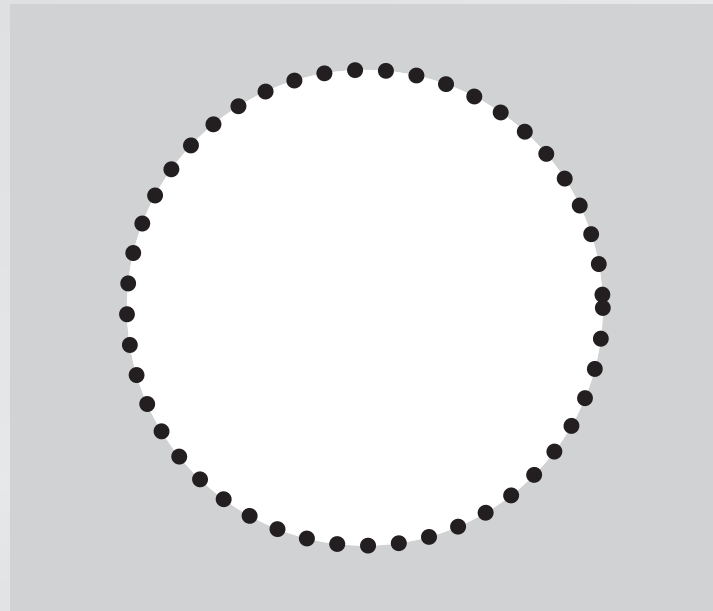
When the plate is uniformly heated, the diameter of the hole

1. increases. ✓
2. stays the same.
3. decreases.



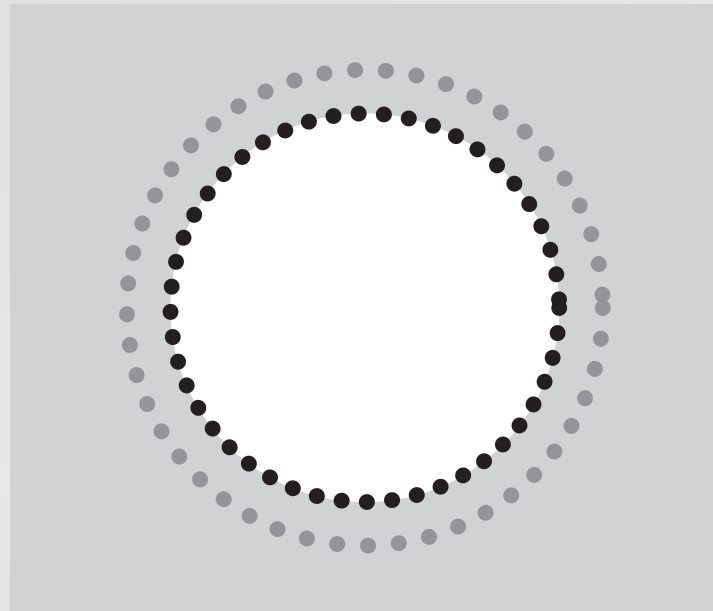
Let's try it!

consider the atoms at the rim of the hole



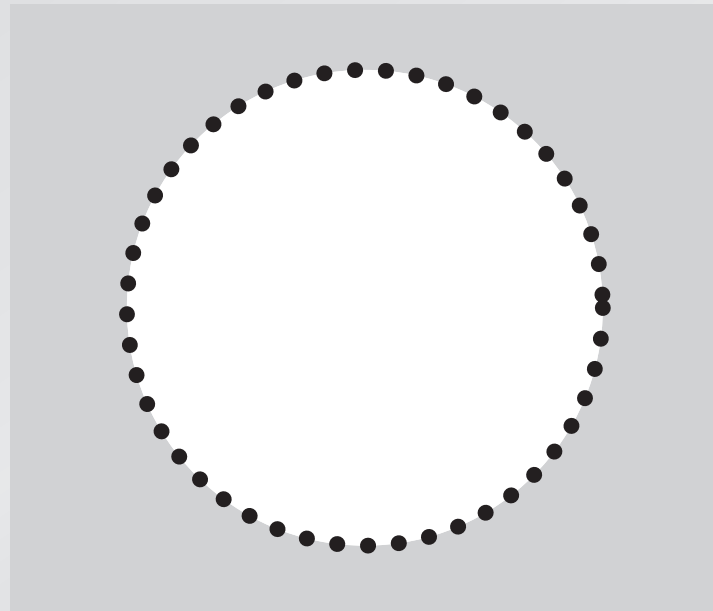
Let's try it!

consider the atoms at the rim of the hole



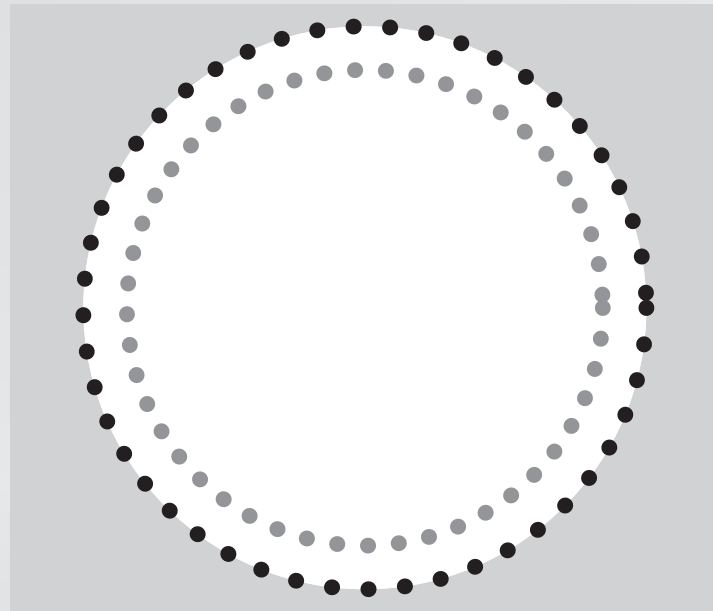
Let's try it!

consider the atoms at the rim of the hole



Let's try it!

consider the atoms at the rim of the hole



Let's try it!

consider the atoms at the rim of the hole

you won't forget this

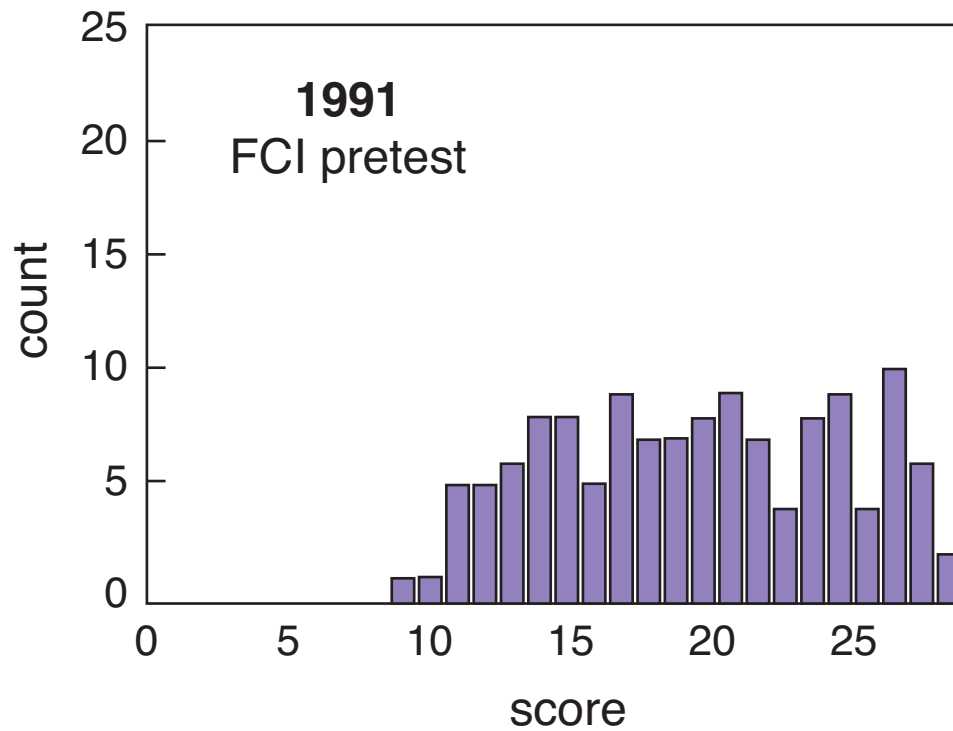


Results

is it any good?

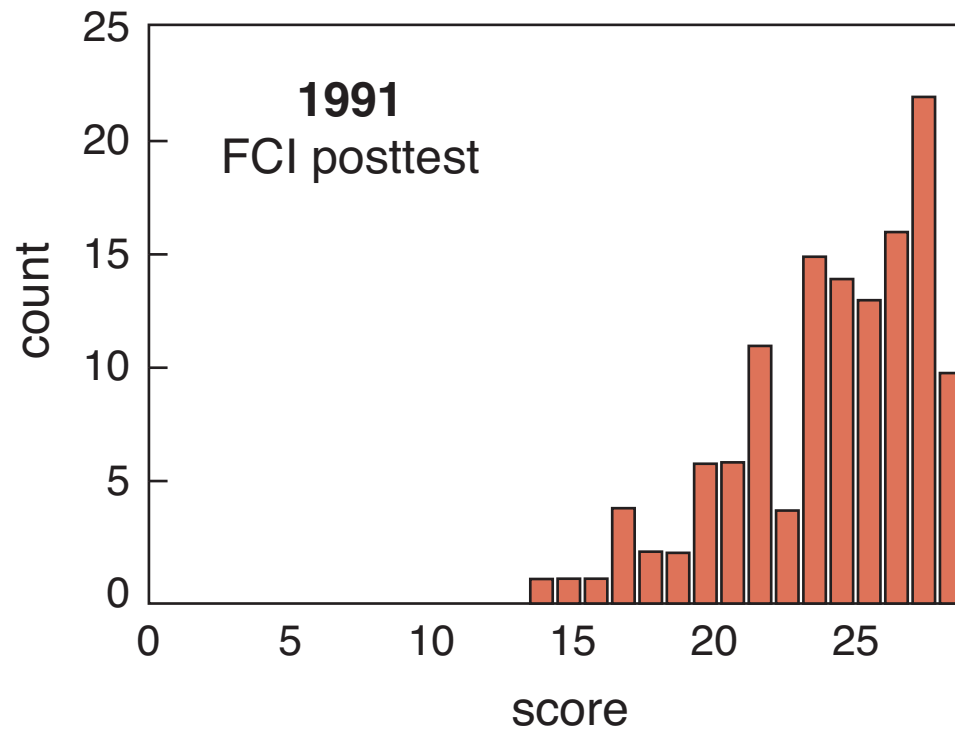
Results

first year of implementing PI



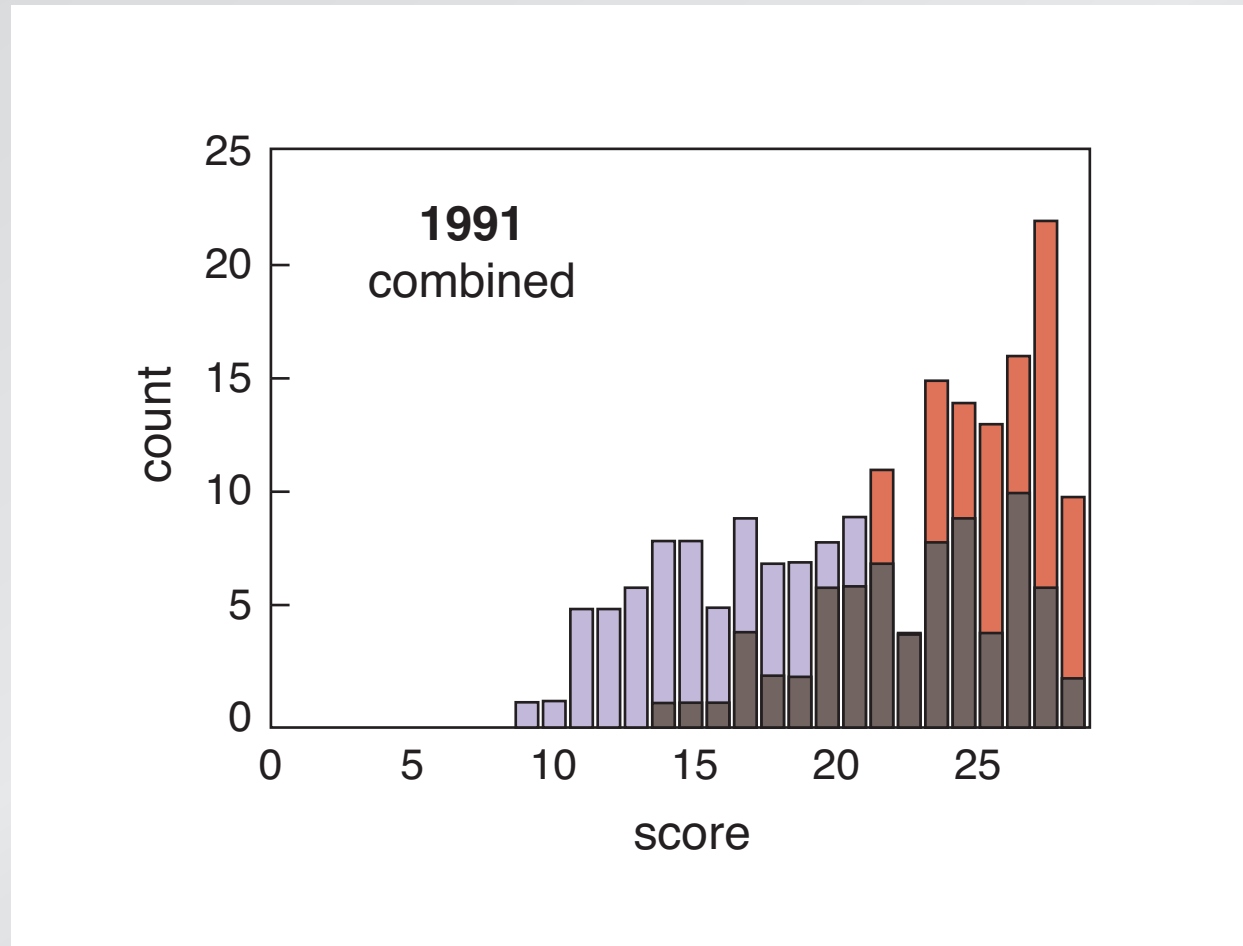
Results

first year of implementing PI

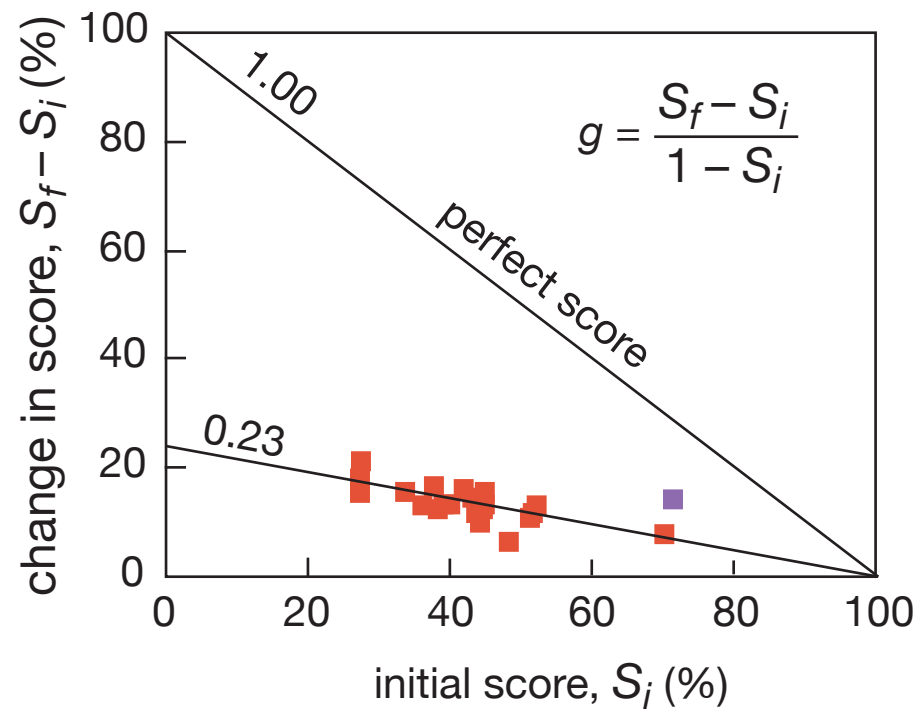


Results

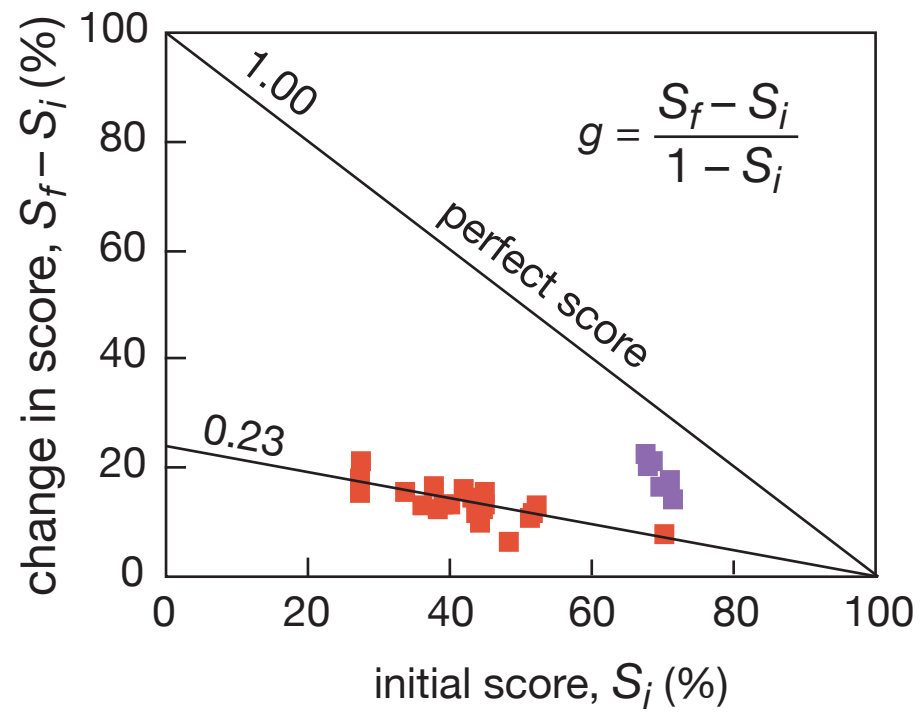
first year of implementing PI



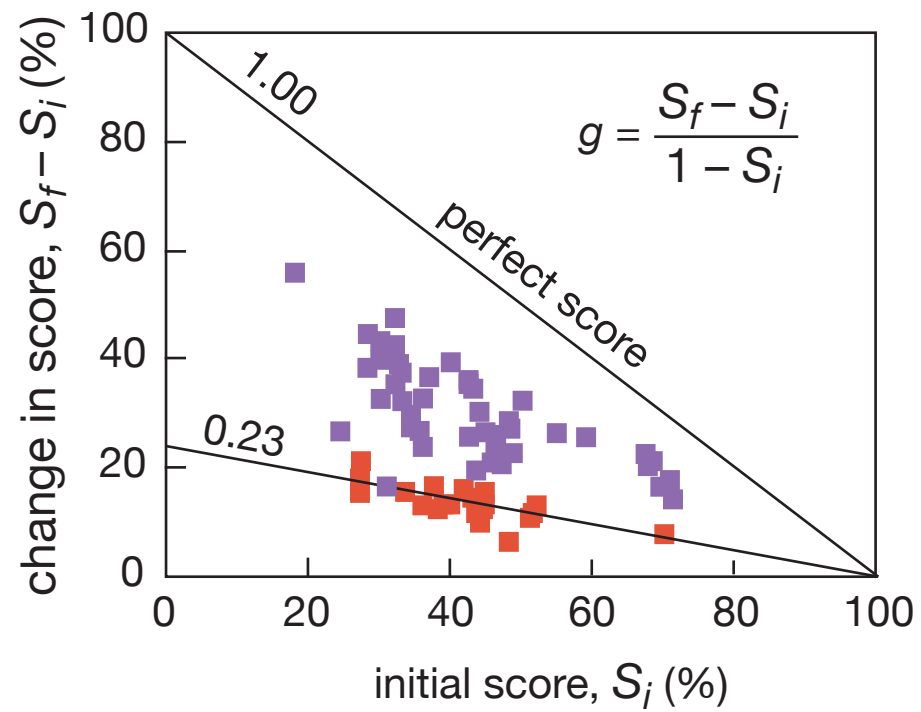
Results



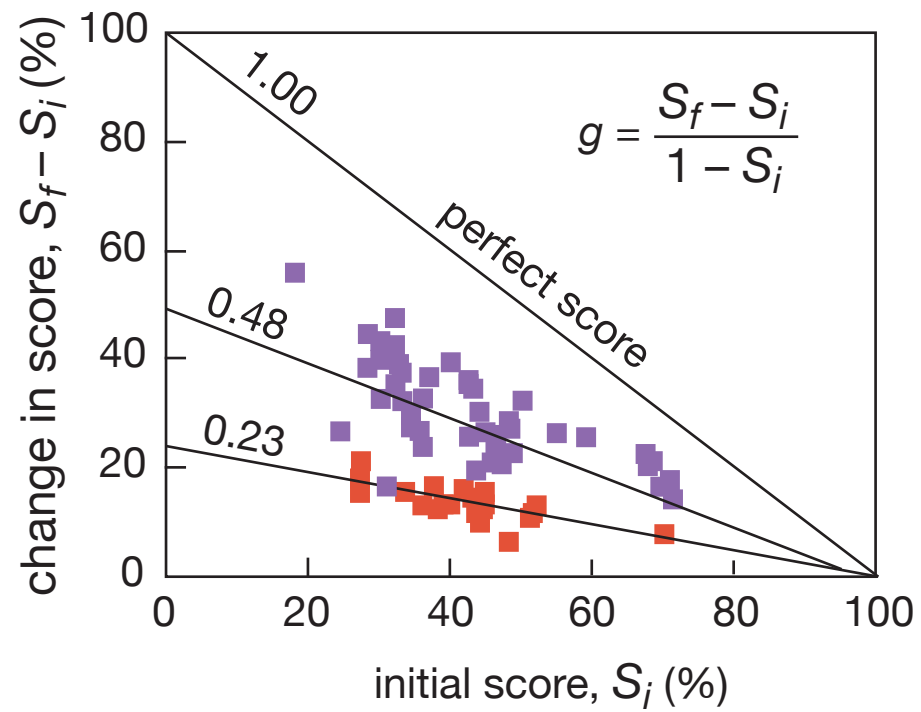
Results



Results



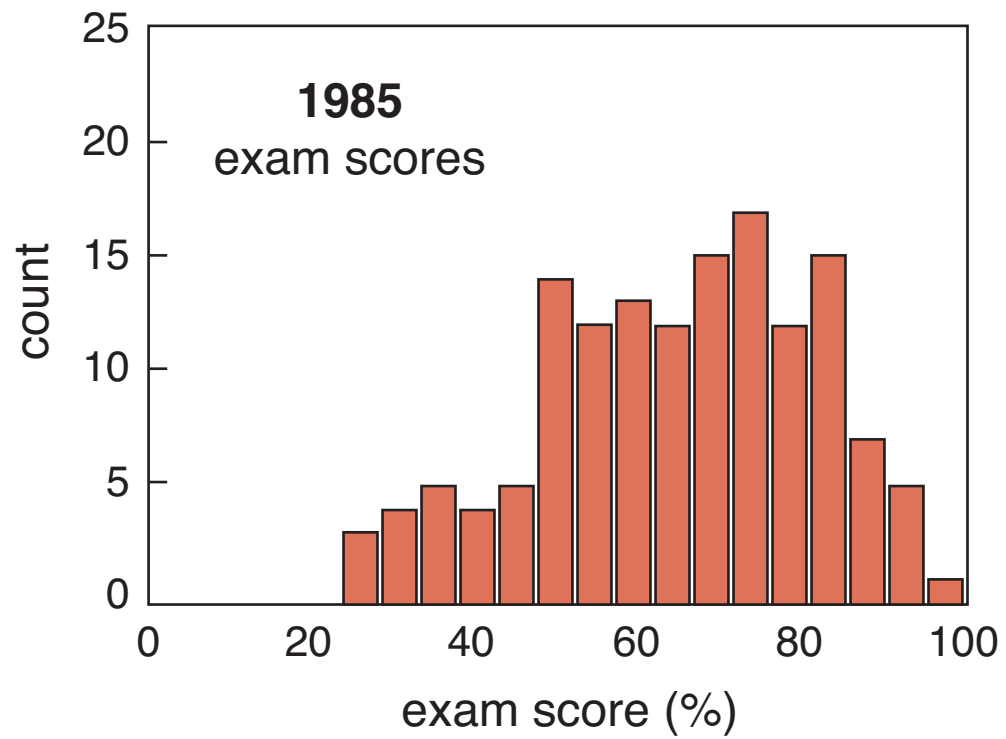
Results



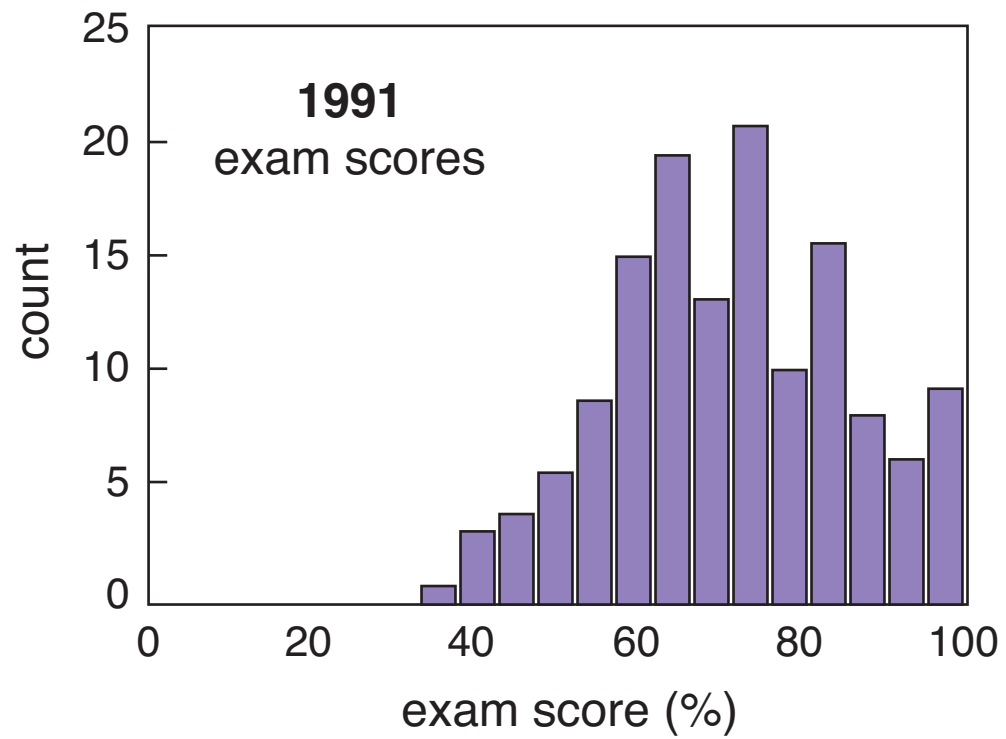
Results

what about problem solving?

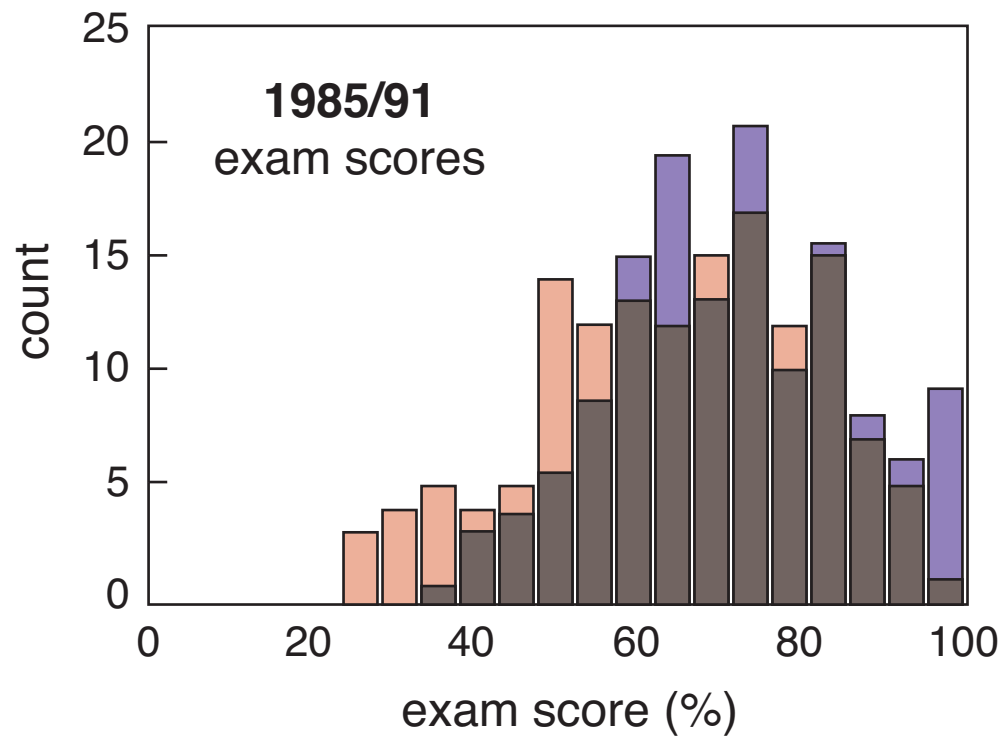
Results



Results



Results



Conclusion

**So better understanding leads to better
problem solving!**

Conclusion

So better understanding leads to better problem solving!

(but “good” problem solving doesn’t always indicate understanding!)

Summary

Traditional indicators of success misleading

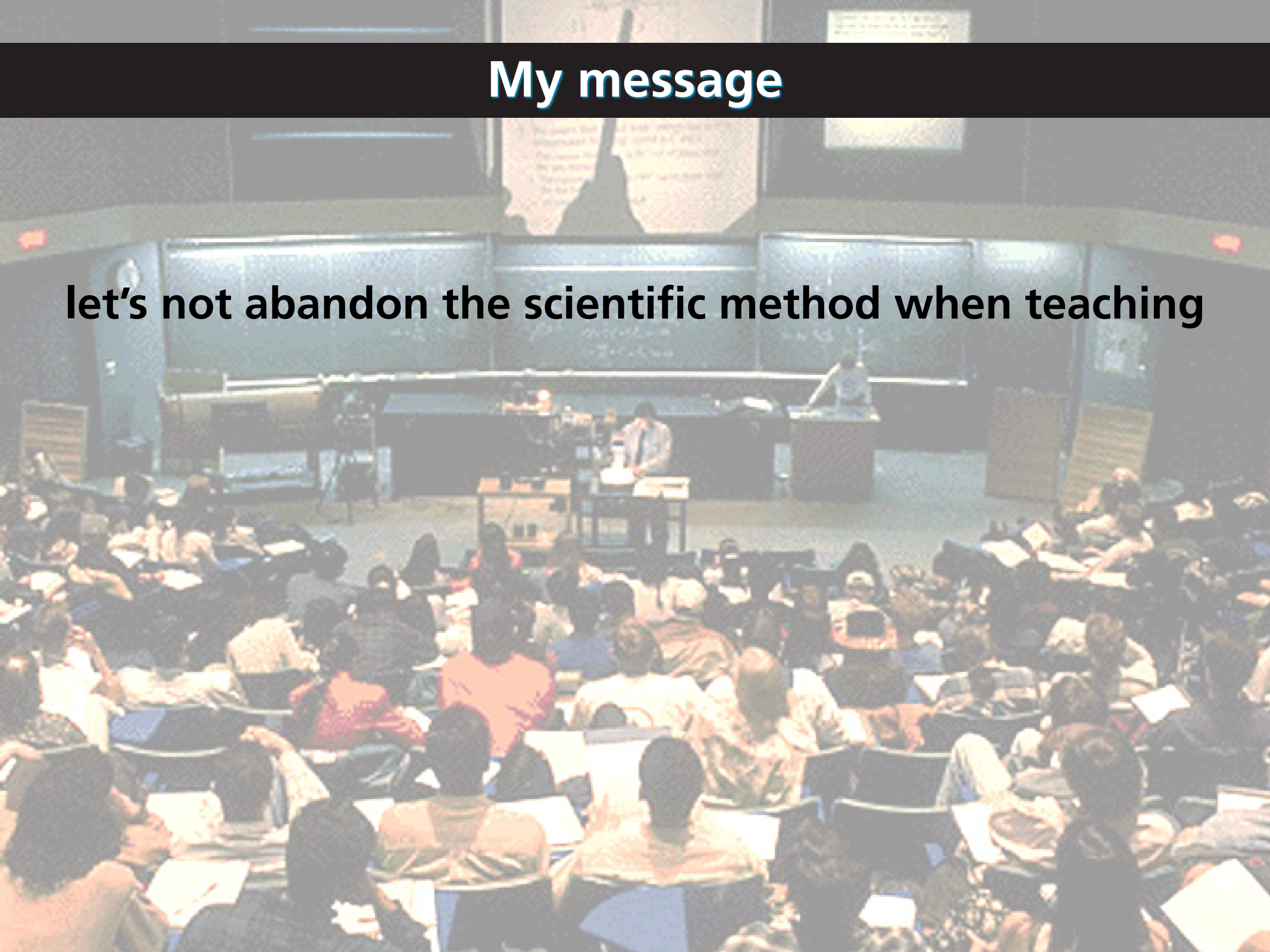
Summary

Traditional indicators of success misleading

Education is no longer about information

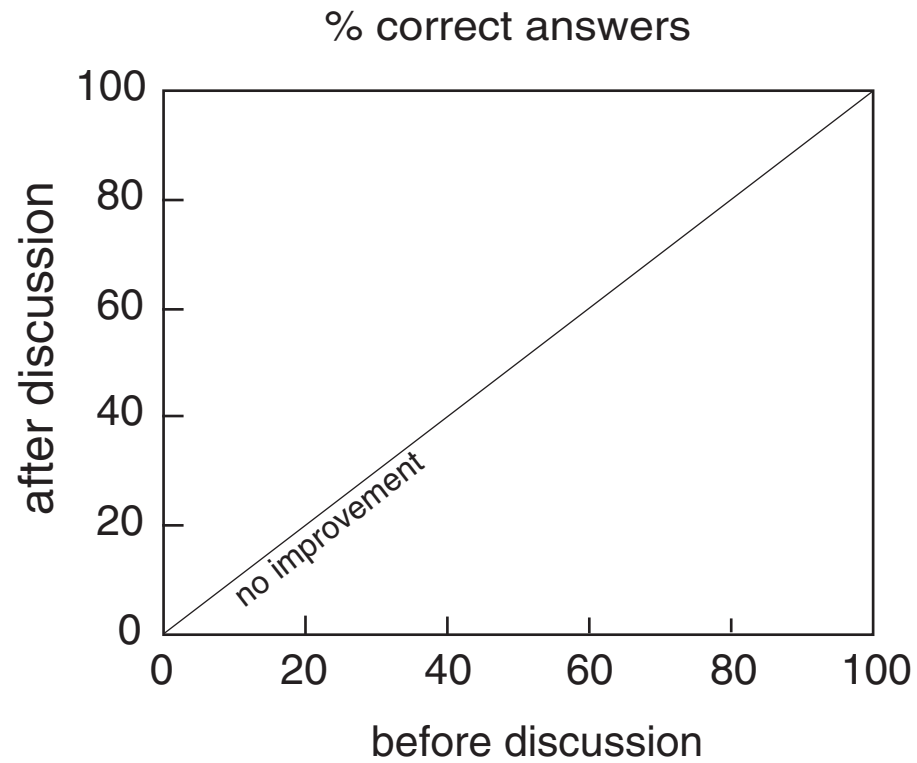
My message

let's not abandon the scientific method when teaching



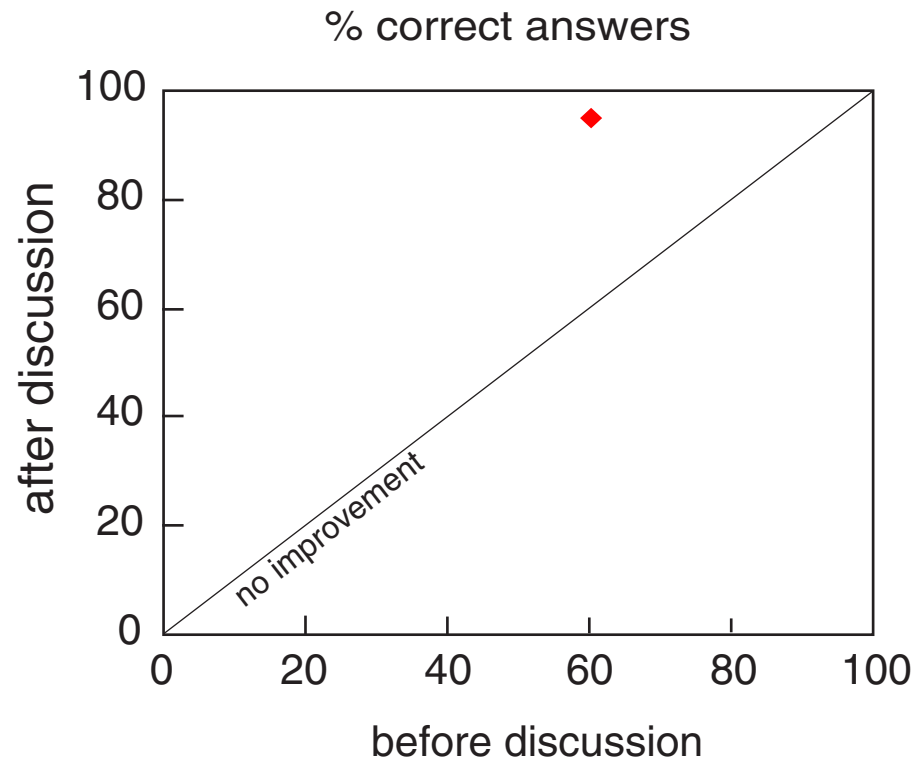
Making it happen

ConceptTest data



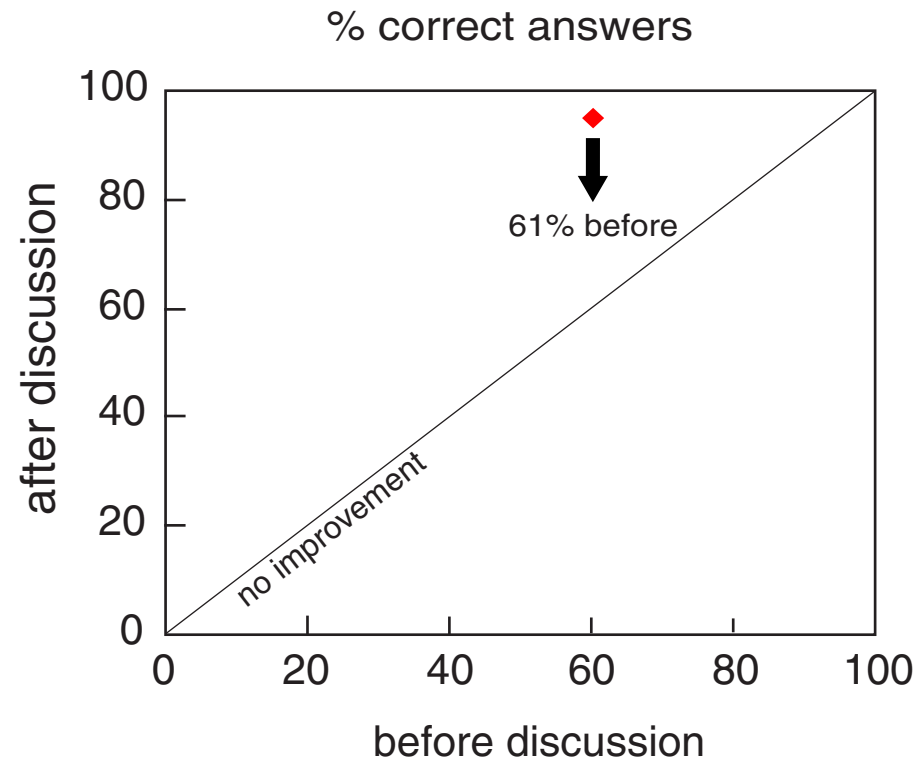
Making it happen

ConceptTest data



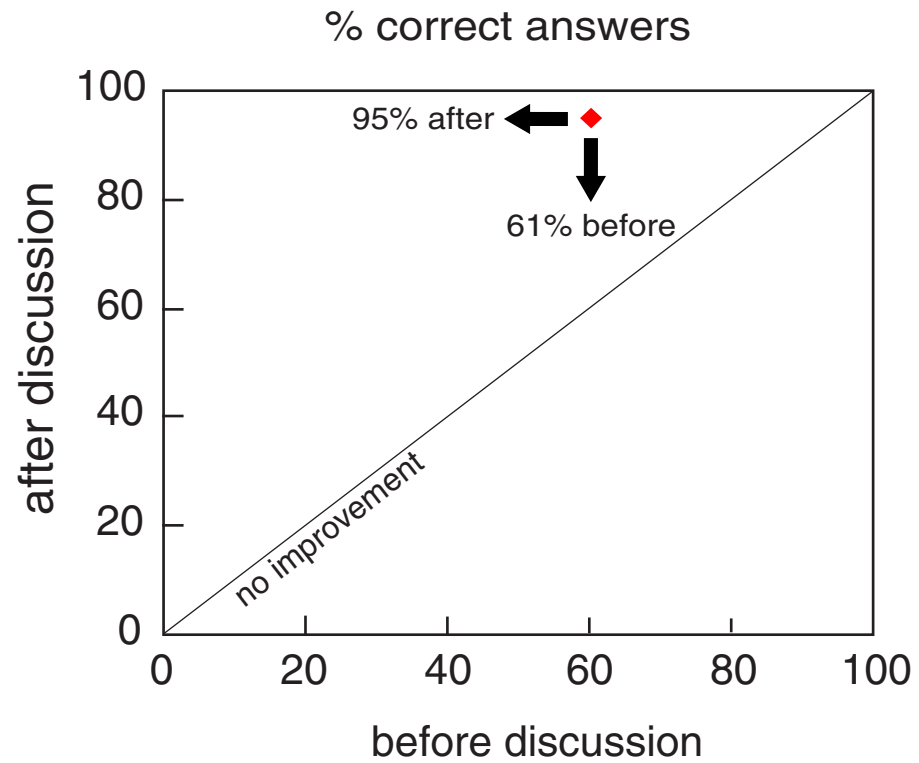
Making it happen

ConceptTest data



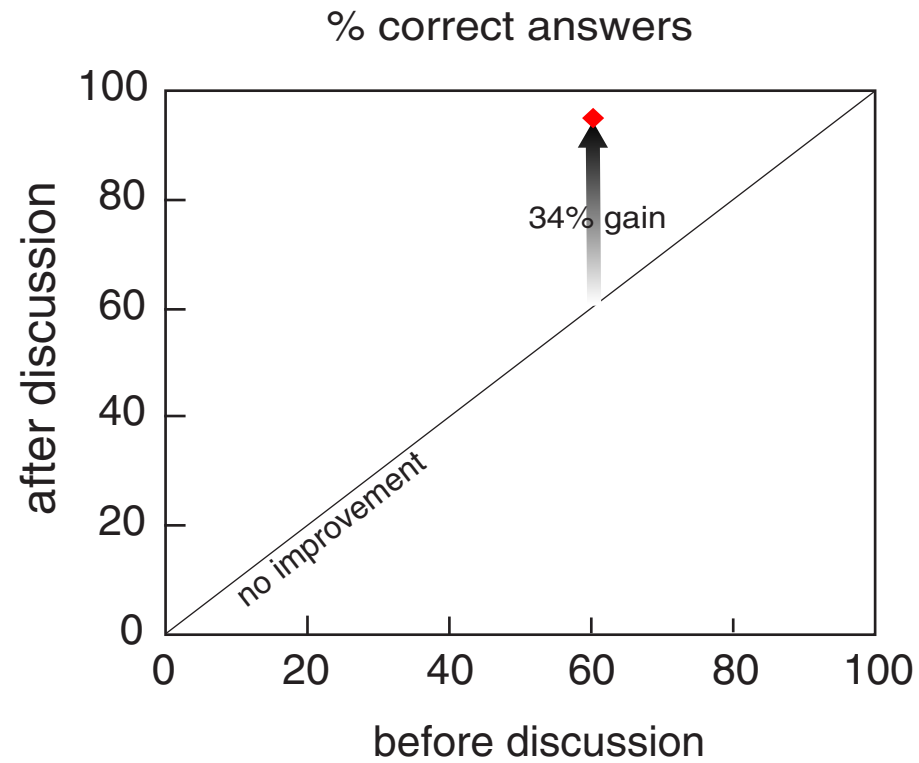
Making it happen

ConceptTest data



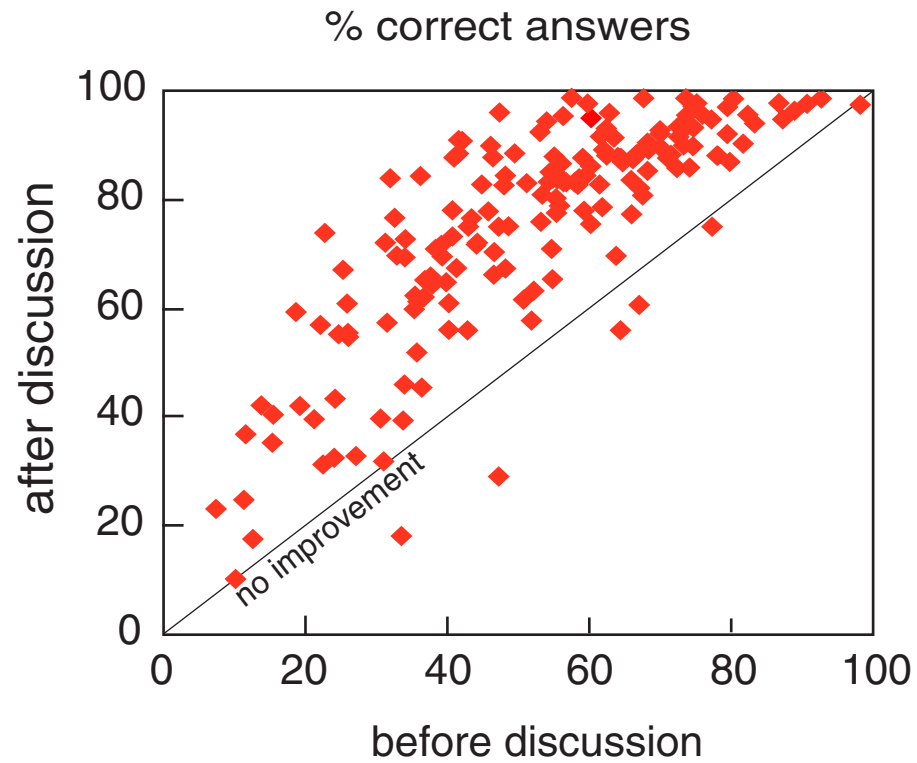
Making it happen

ConceptTest data



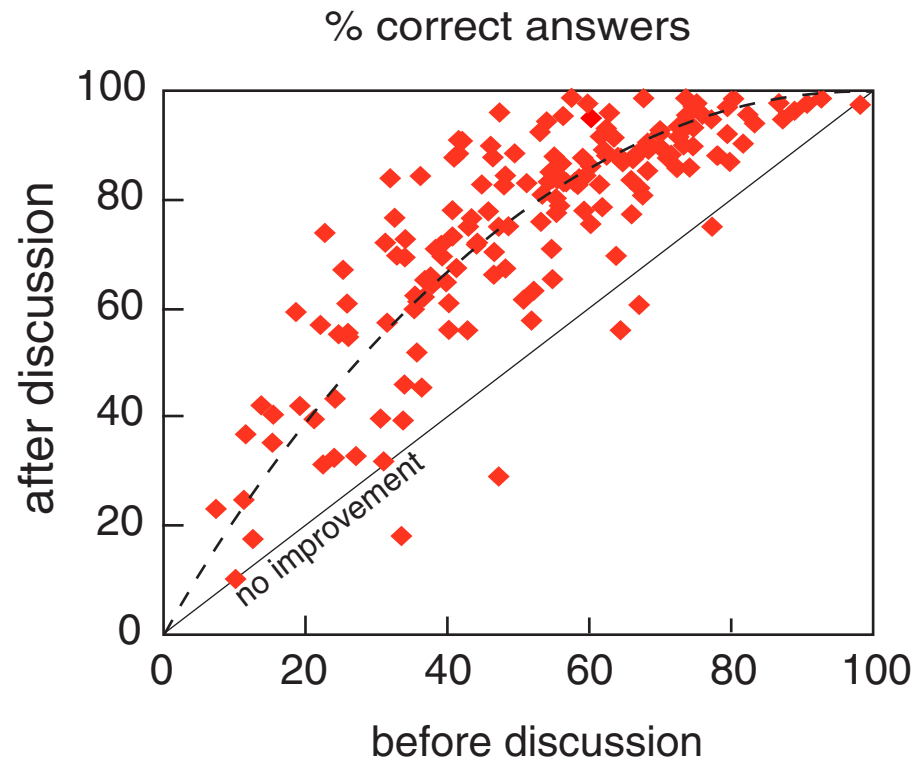
Making it happen

ConceptTest data



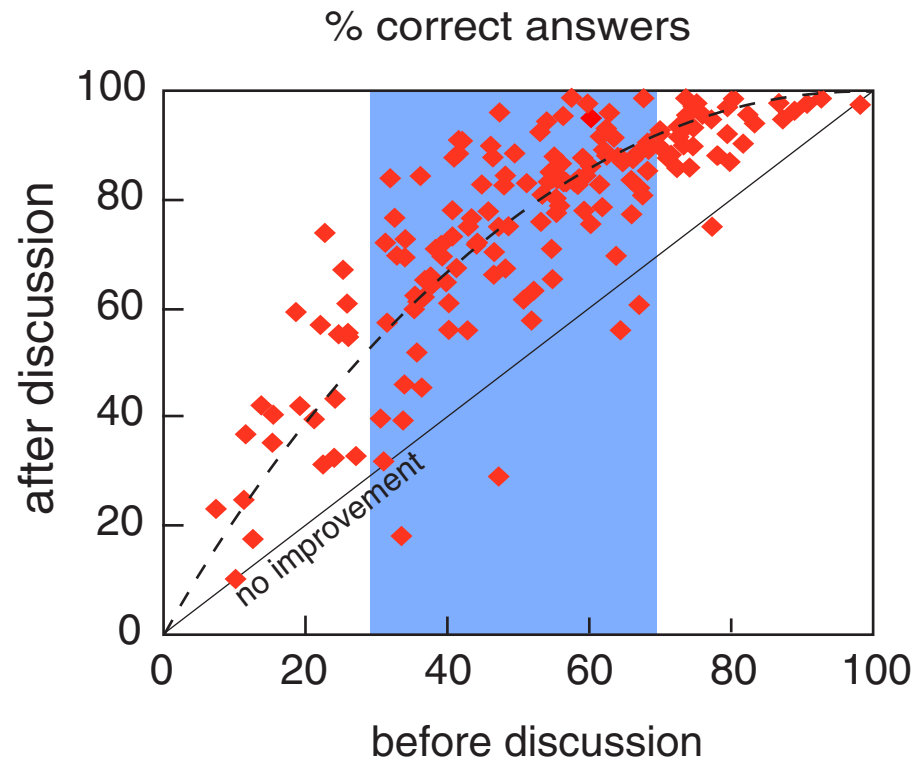
Making it happen

ConceptTest data



Making it happen

ConcepTest data



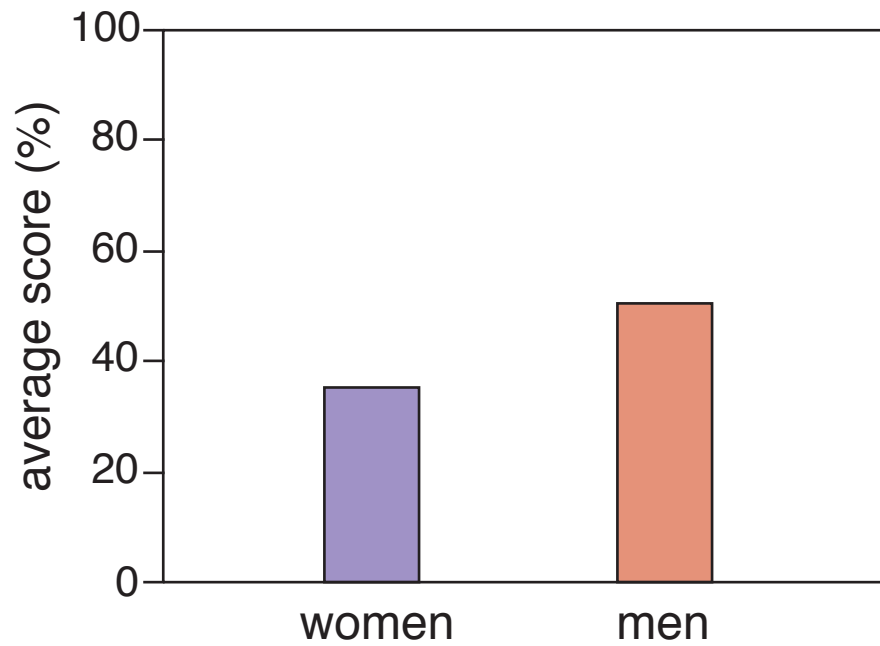
Outline

- Gender issues
- Lecture demonstrations
- Confusion



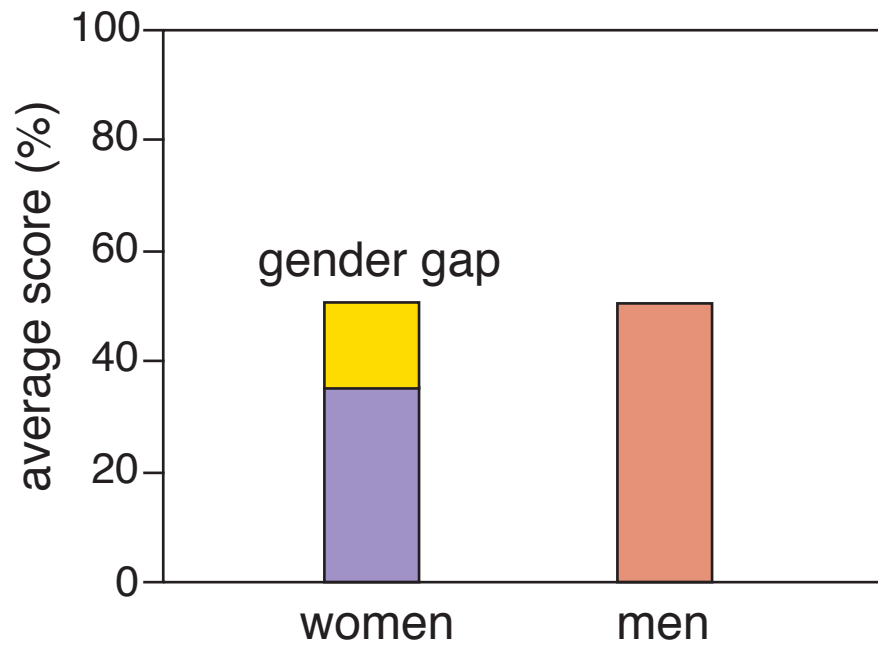
Gender issues

Force Concept Inventory posttest scores



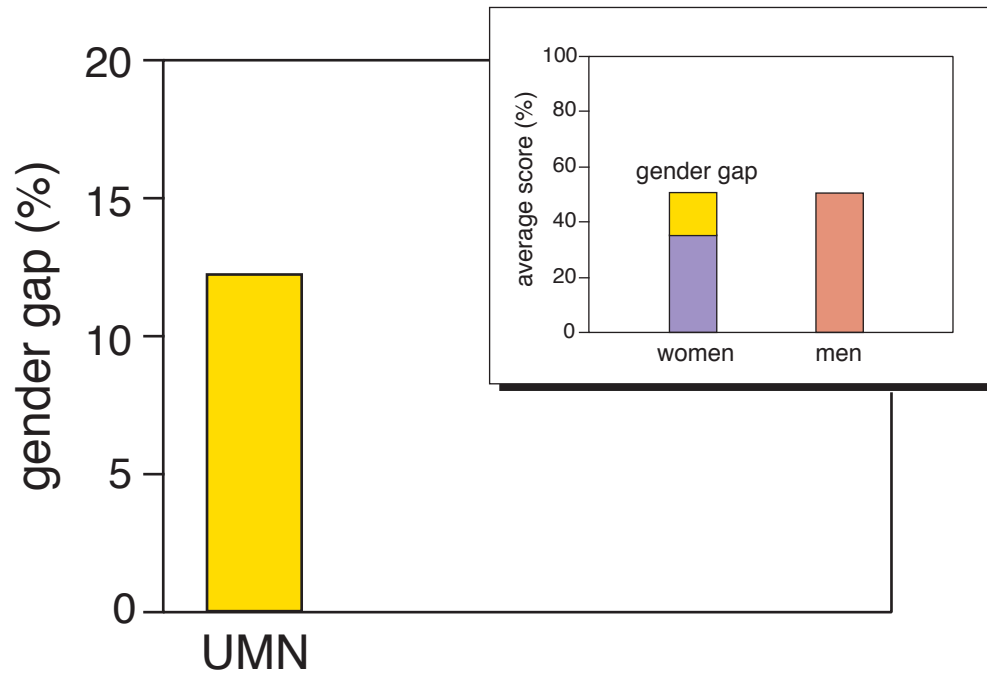
Gender issues

Force Concept Inventory posttest scores



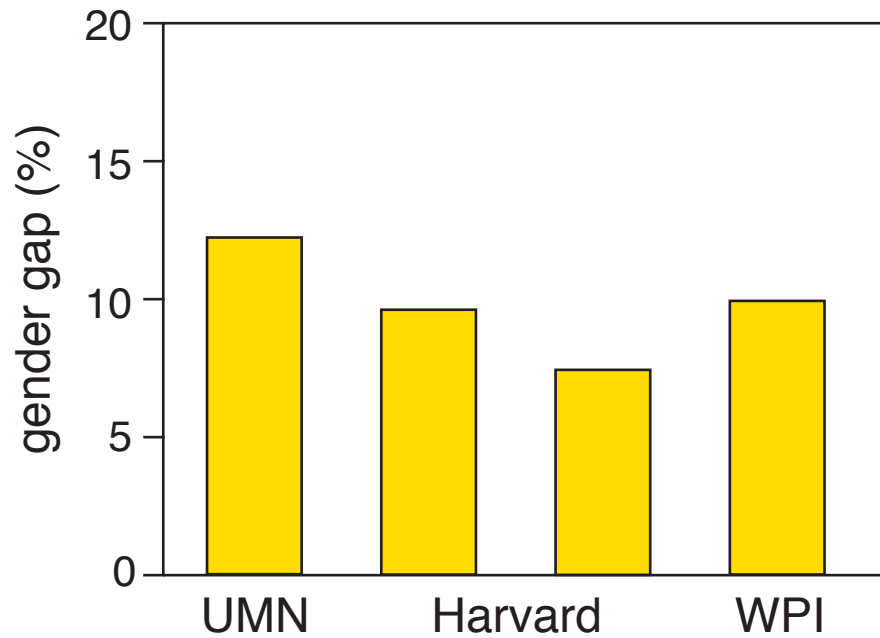
Gender issues

Force Concept Inventory posttest scores



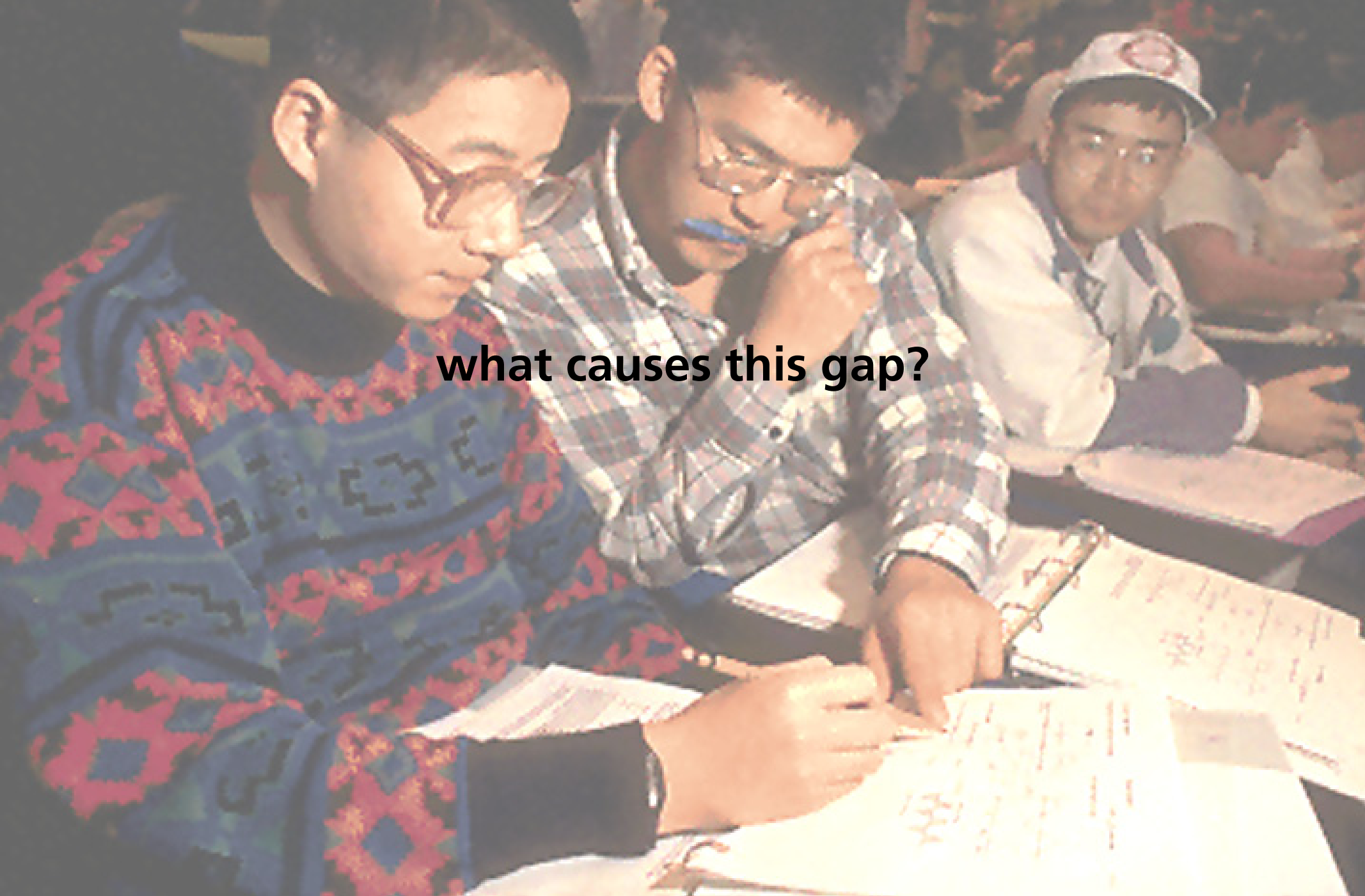
Gender issues

Force Concept Inventory posttest scores



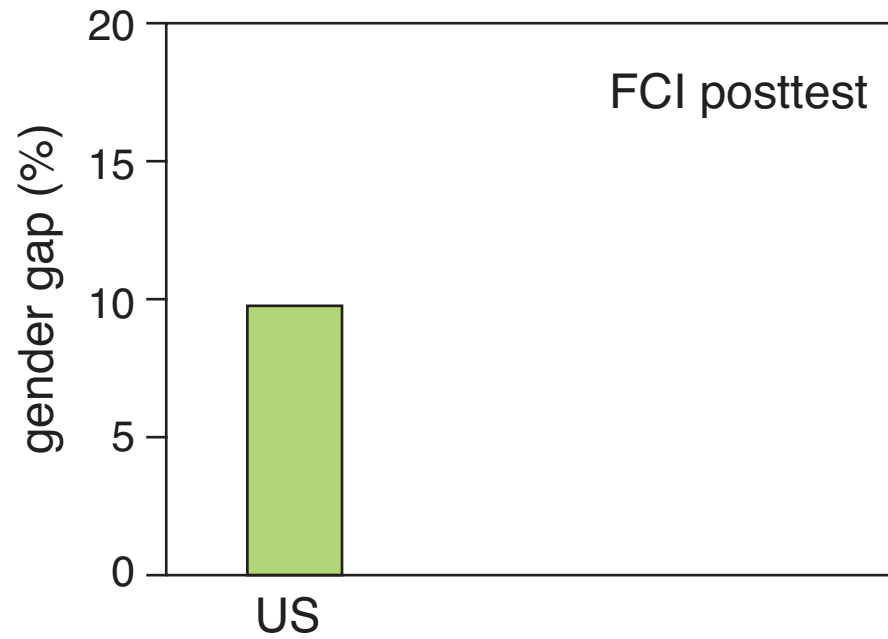
Gender issues

what causes this gap?

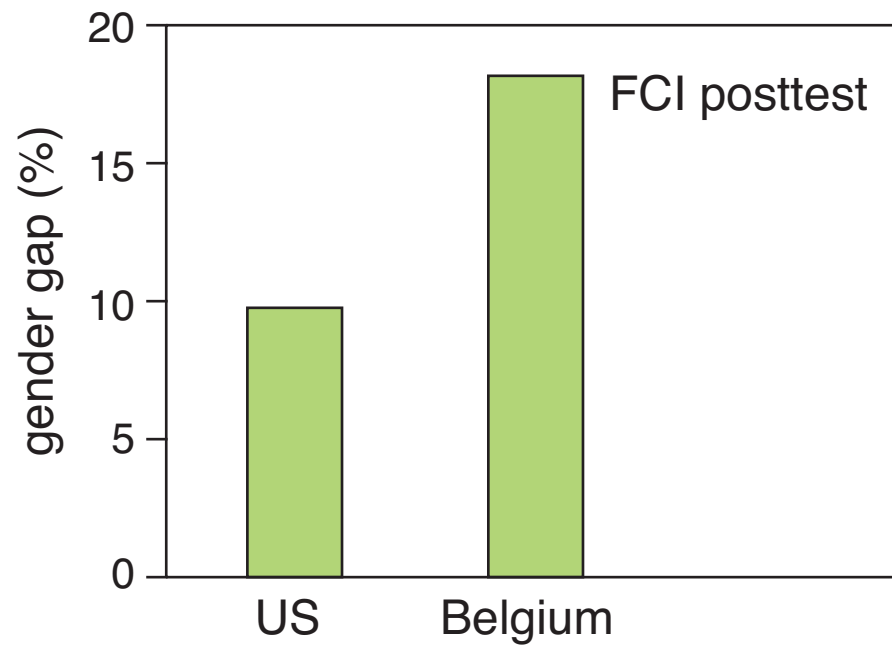


Gender issues

is it cultural?

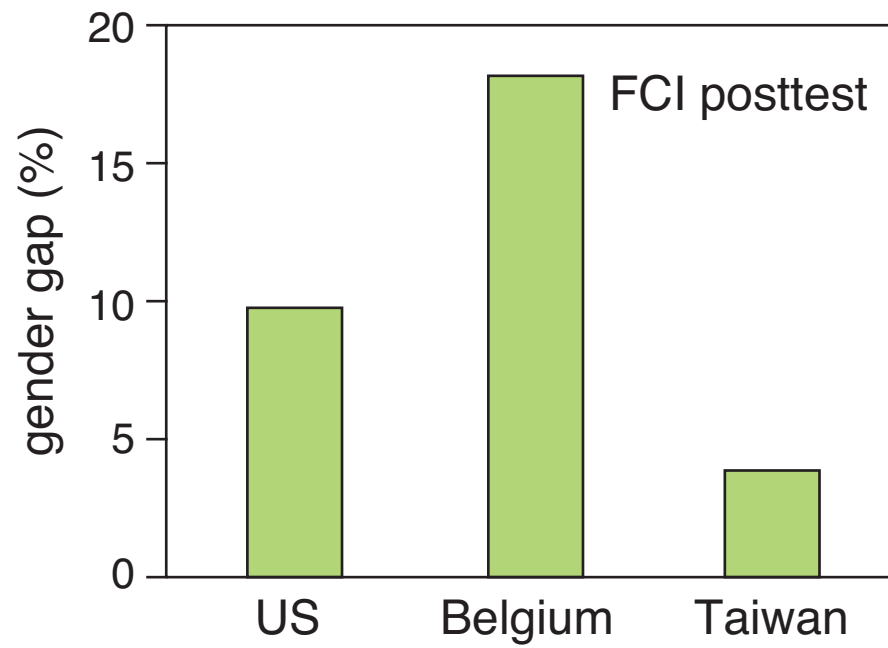


Gender issues



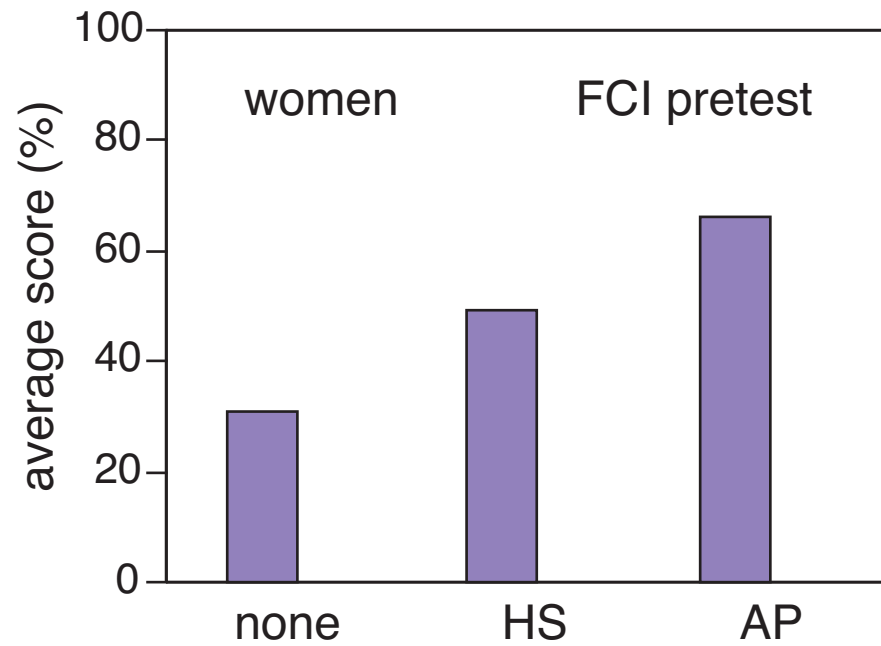
Gender issues

strong dependence on culture!



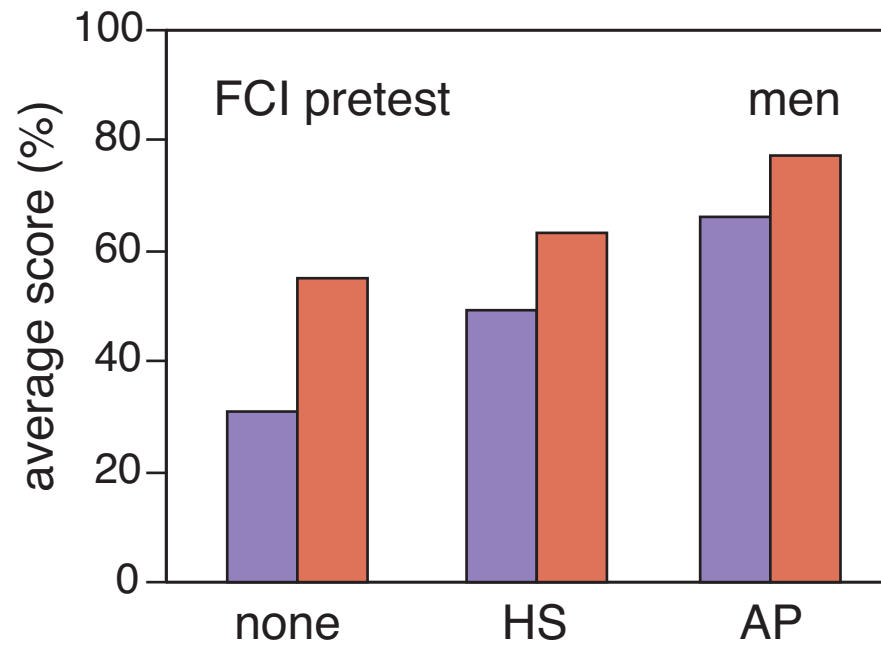
Gender issues

effect of precollege education



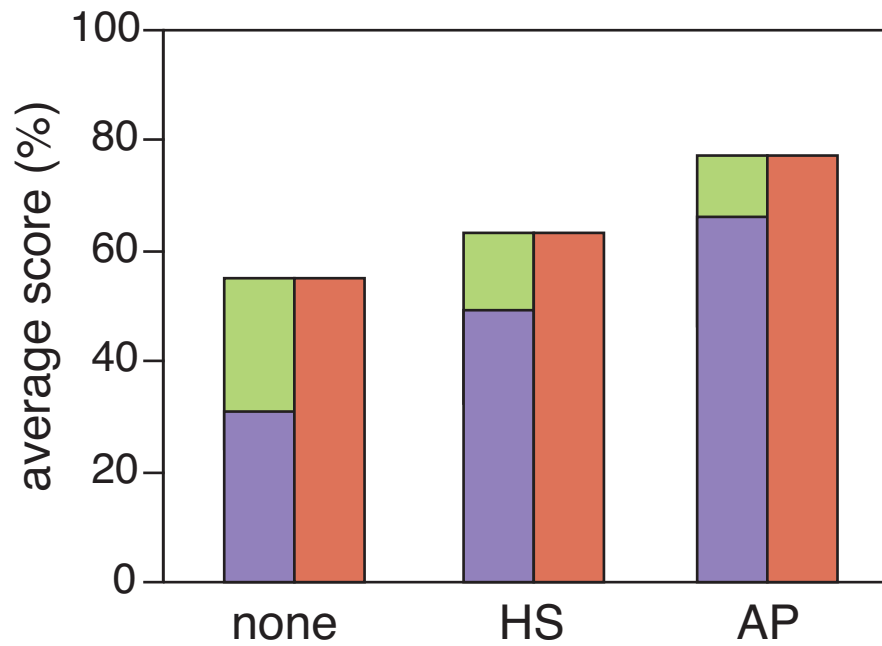
Gender issues

everyone gains...



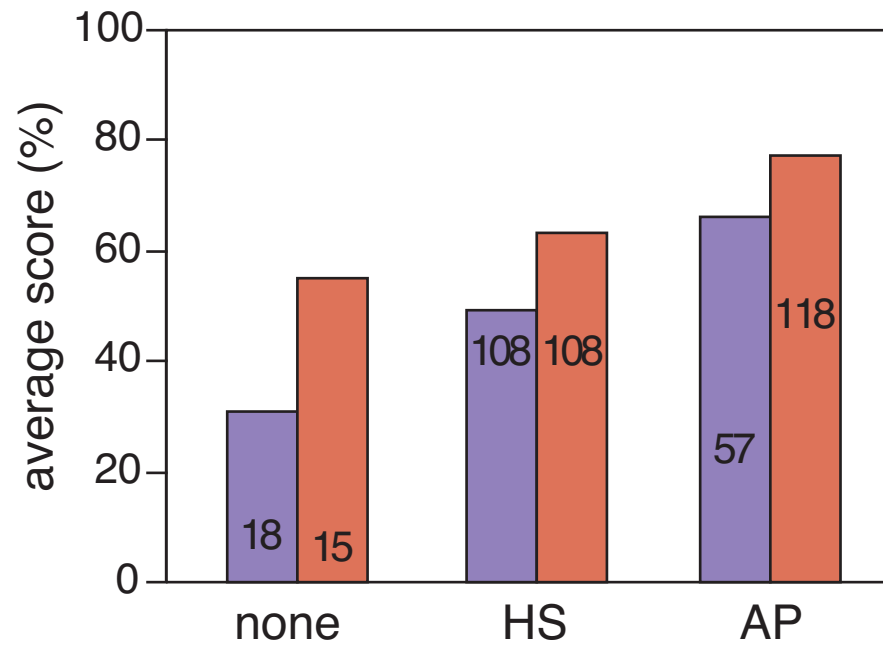
Gender issues

...but gap persists...



Gender issues

...and women underrepresented



Gender issues

what can we do?



Gender issues

increase collaboration and interactivity

A group of women are seated around a table in a meeting room, engaged in a collaborative discussion. One woman in the foreground is wearing a red and orange patterned top and blue jeans, looking towards the right. Another woman to her right is wearing a white top with a blue and red patterned vest. In the background, another woman with long dark hair is looking towards the camera. The table has several papers and a pen on it. The setting appears to be a professional or educational environment.

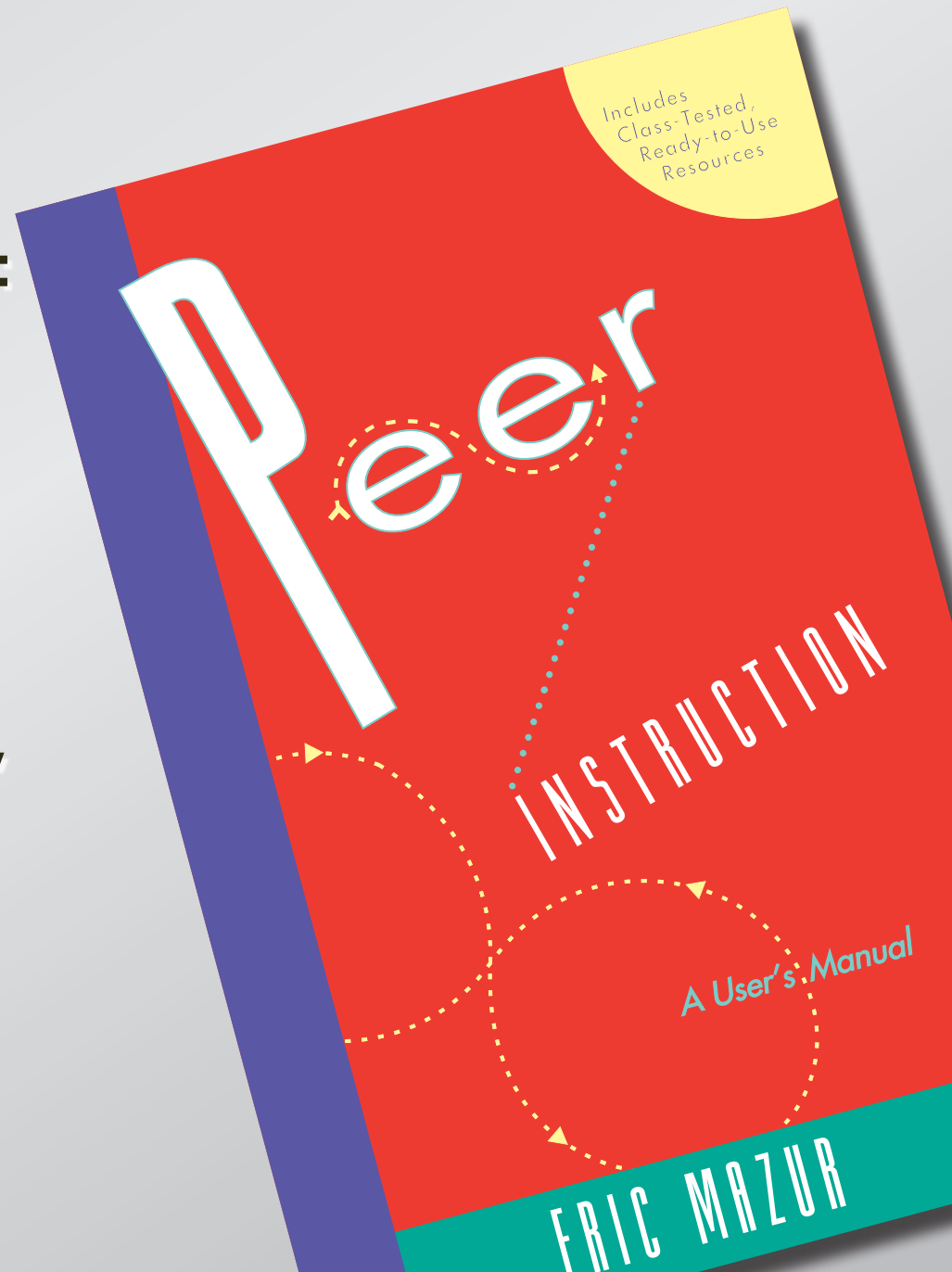
Gender issues

Compare three pedagogies:

T: traditional lectures

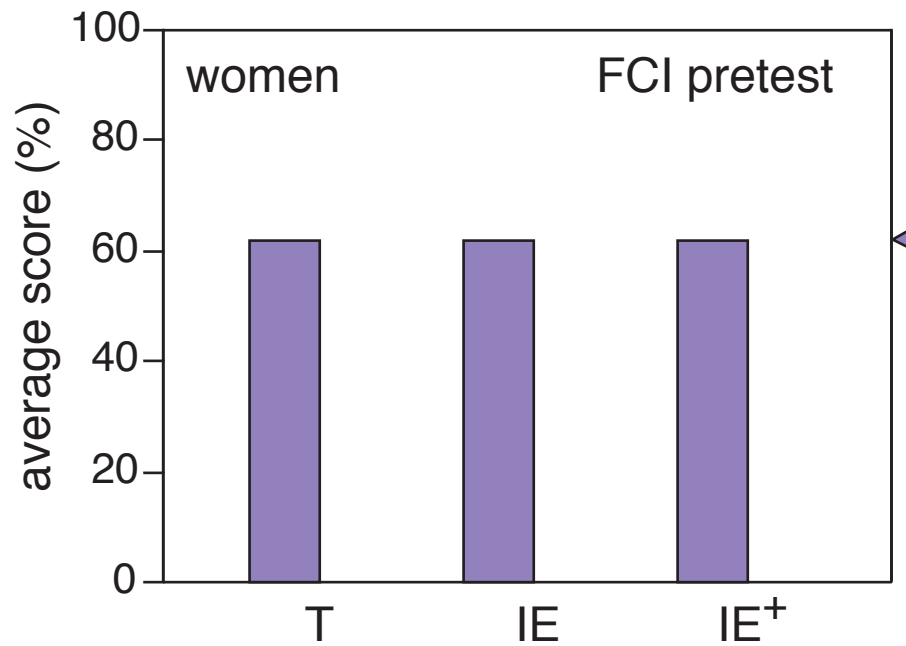
I: interactive lectures

I⁺: interactive assignments,
lectures, and tutorials



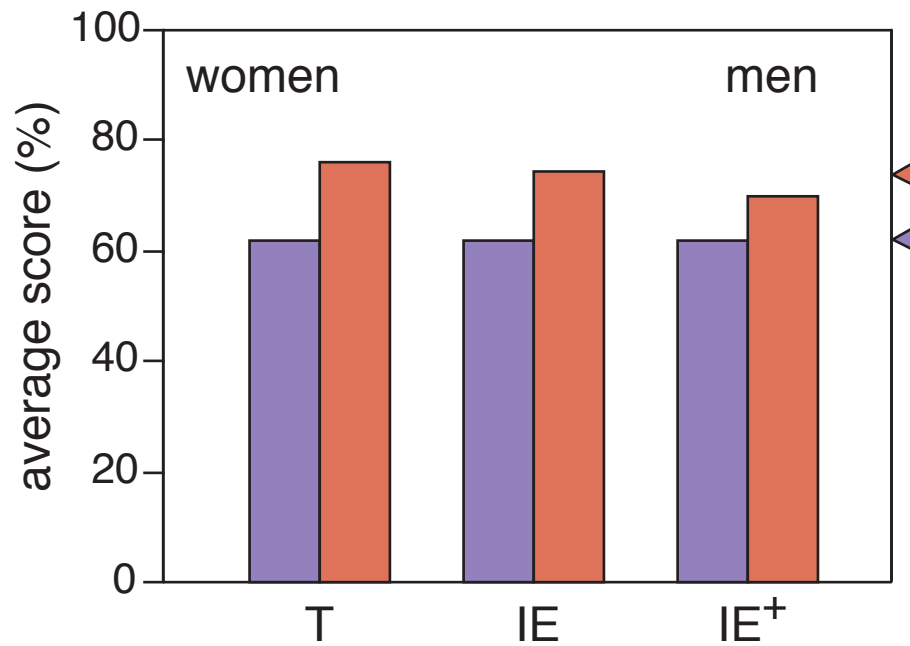
Gender issues

does pedagogy help?



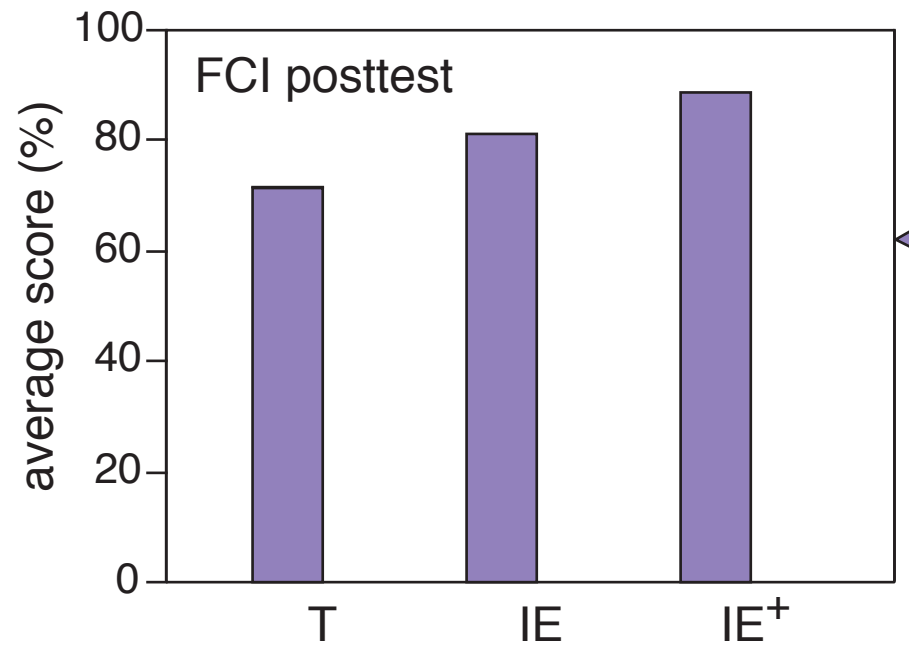
Gender issues

does pedagogy help?



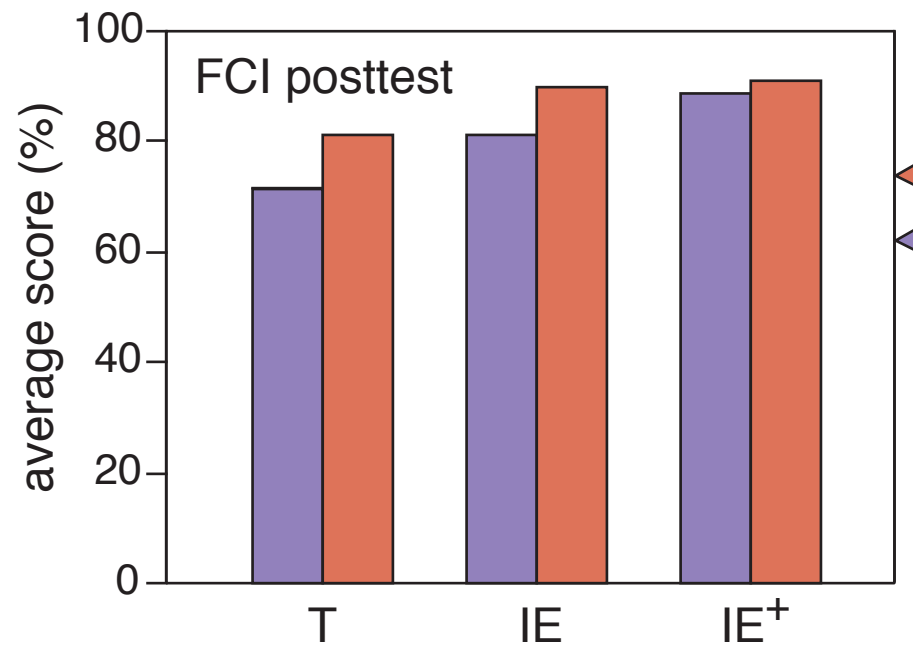
Gender issues

does pedagogy help?



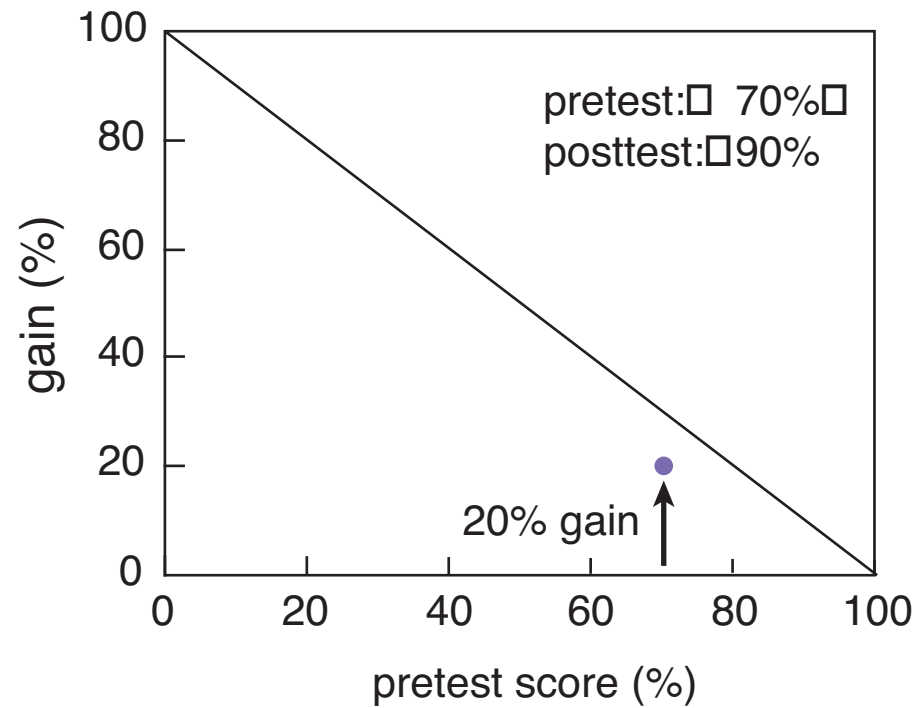
Gender issues

yes, pedagogy can eliminate gap!



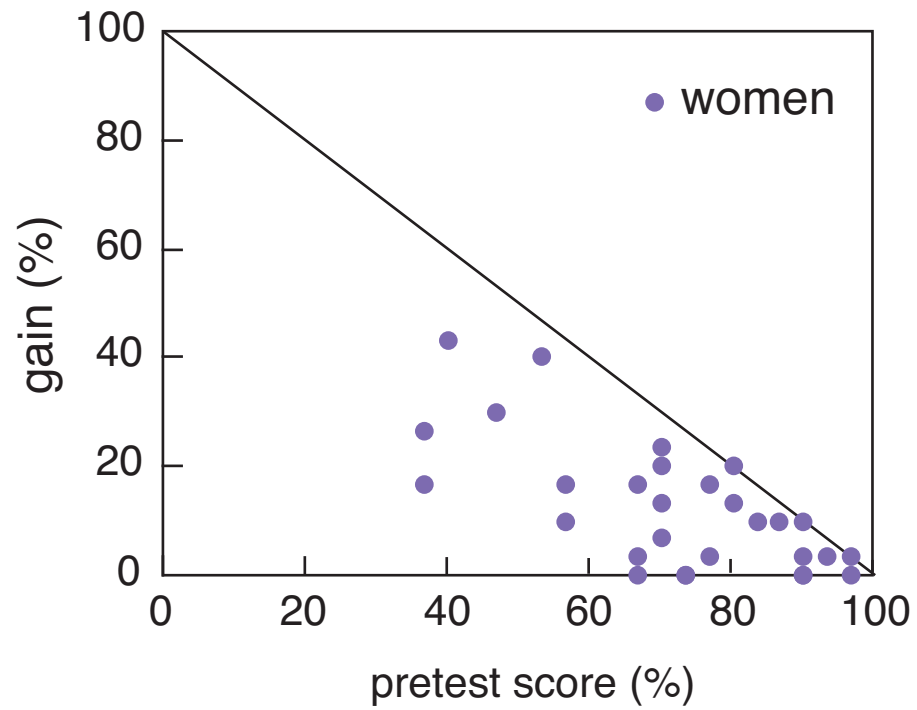
Gender issues

who are the low-gain students?



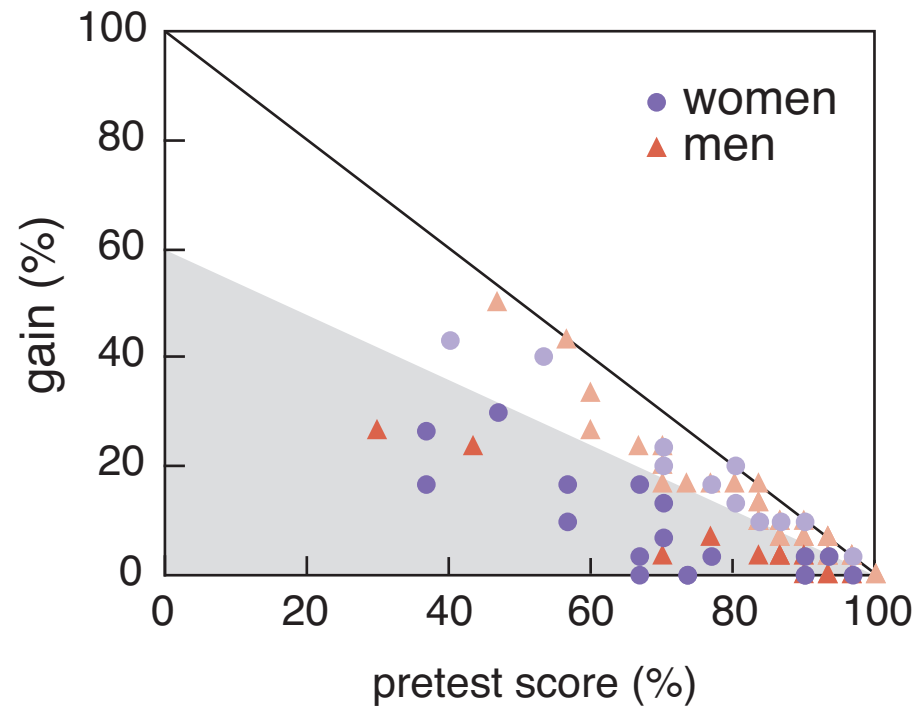
Gender issues

traditional class



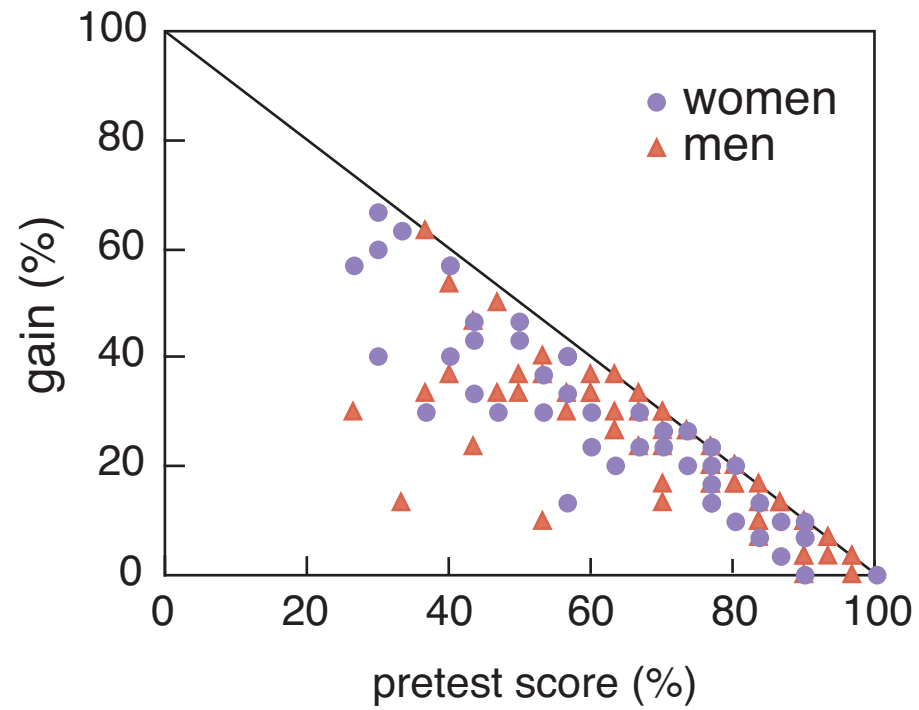
Gender issues

traditional class: gender imbalance



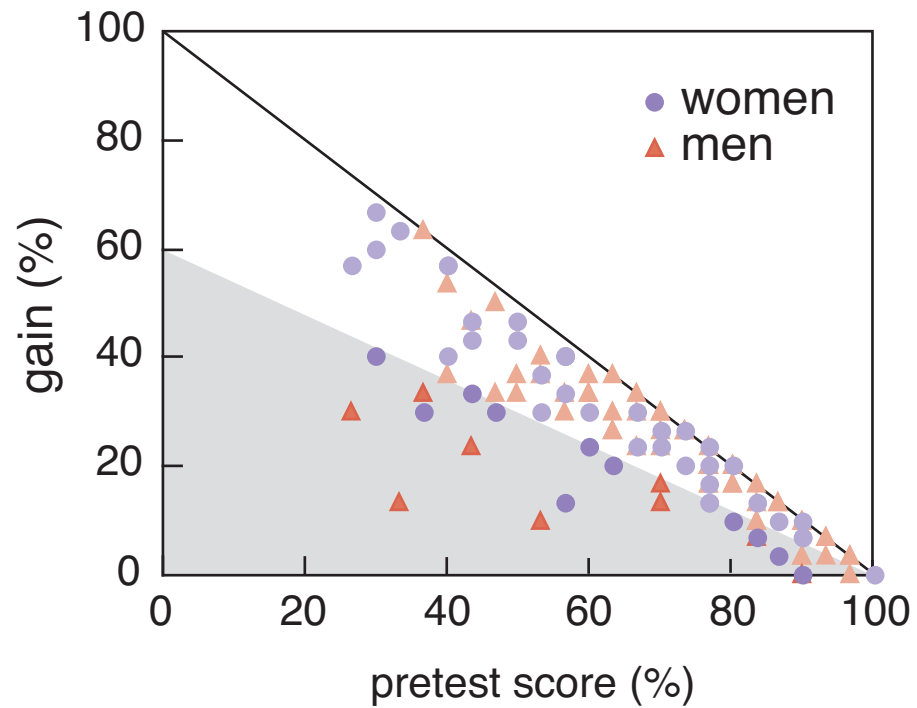
Gender issues

interactive class



Gender issues

interactive class: gender balance



Gender issues

Points to keep in mind:

- **gap comes from culture and background**
- **interactivity makes a difference**

Lecture demonstrations

how effective are lecture demonstrations?



Lecture demonstrations

Carry out seven demonstrations in four “modes”:

- no demo (control)
- observe
- predict
- discuss

Lecture demonstrations

Carry out seven demonstrations in four “modes”:

- no demo (control)
- observe
- predict (+2 mins.)
- discuss (+8 mins.)

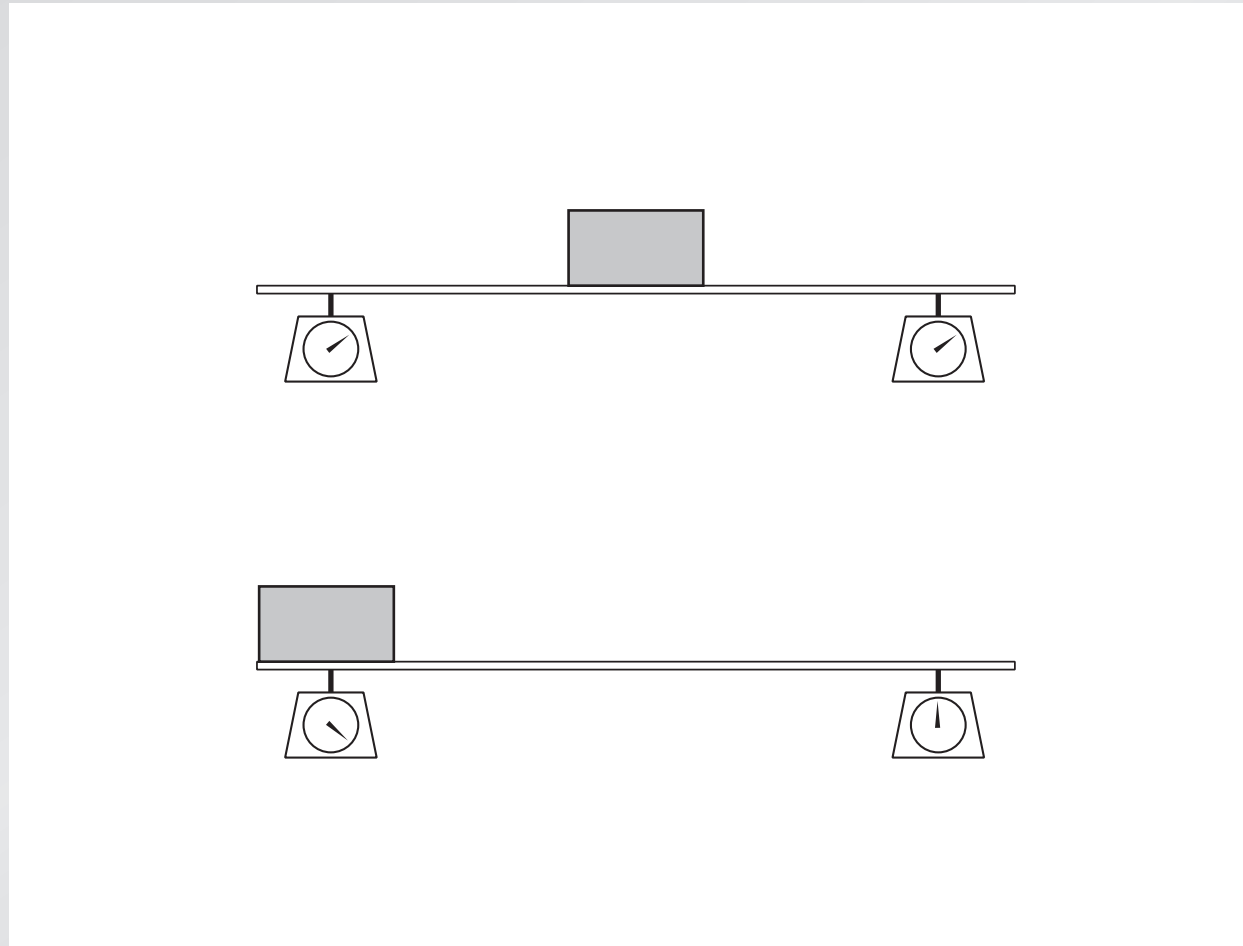
Lecture demonstrations

Follow up:

- **free-response test (online)**
- **exam questions**

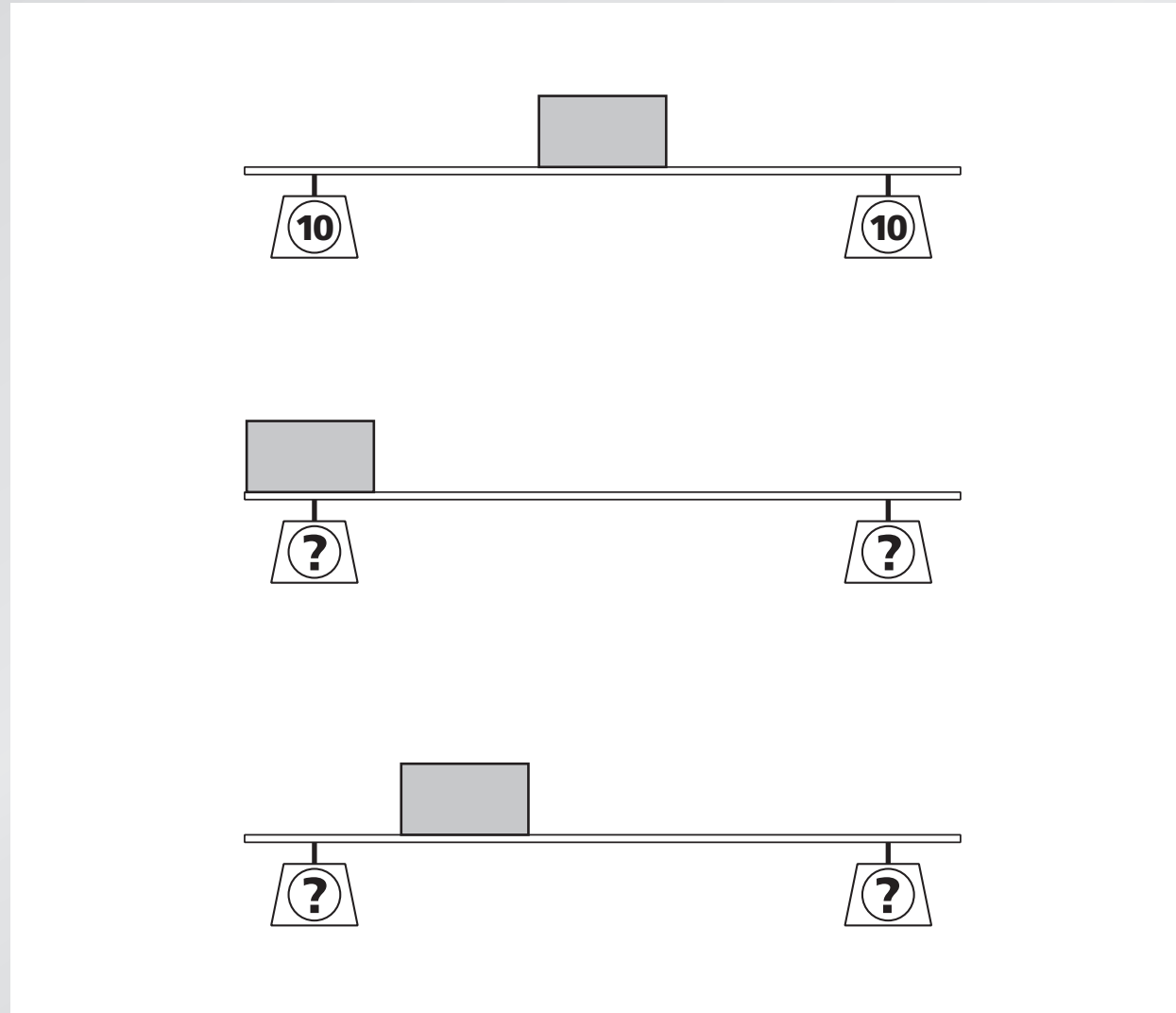
Lecture demonstrations

loaded beam demo



Lecture demonstrations

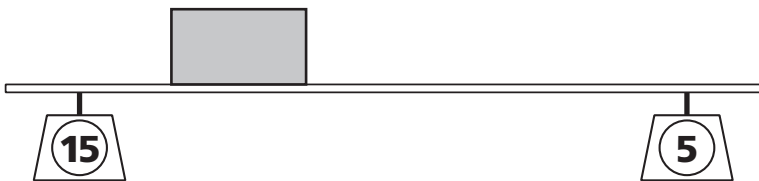
online test question



Lecture demonstrations

answers given

24% of students



correct (mentions torque)

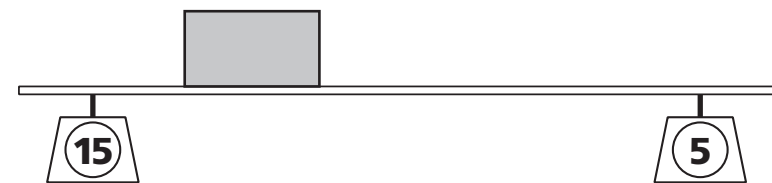
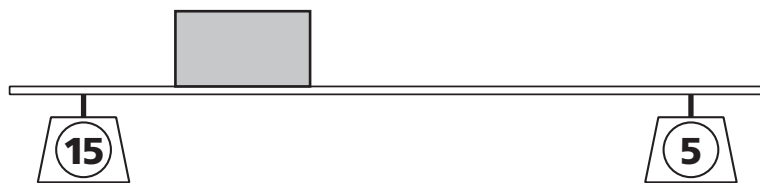
Lecture demonstrations

answers given

24% of students



38% of students



correct (mentions torque)

proportional reasoning

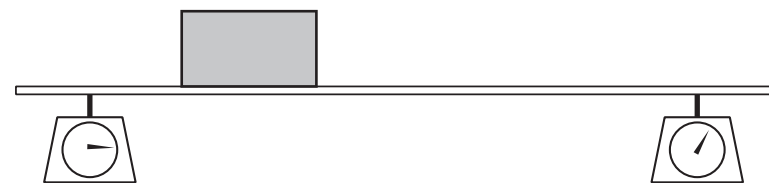
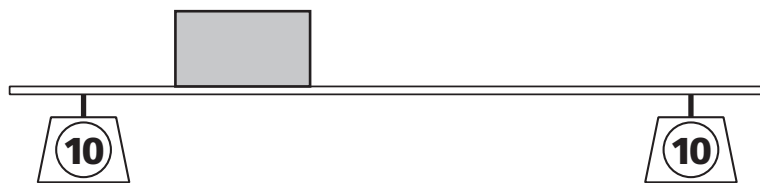
Lecture demonstrations

answers given

20% of students



10% of students



independent of position

qualitative reasoning

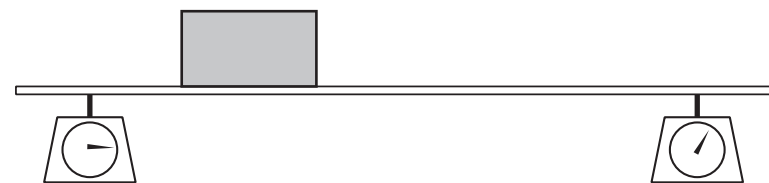
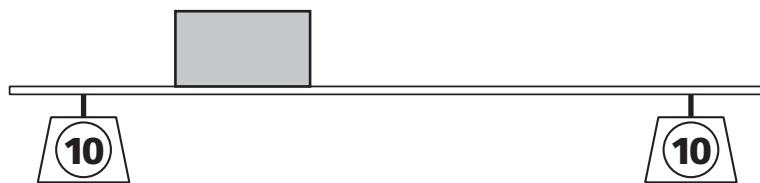
Lecture demonstrations

answers given

20% of students



10% of students



independent of position

qualitative reasoning

6%: forces not balanced; 2%: other incorrect

Lecture demonstrations

mode	correct	incorrect
no demo	30%	70%
observe	18%	82%
predict	29%	71%
discuss	30%	70%

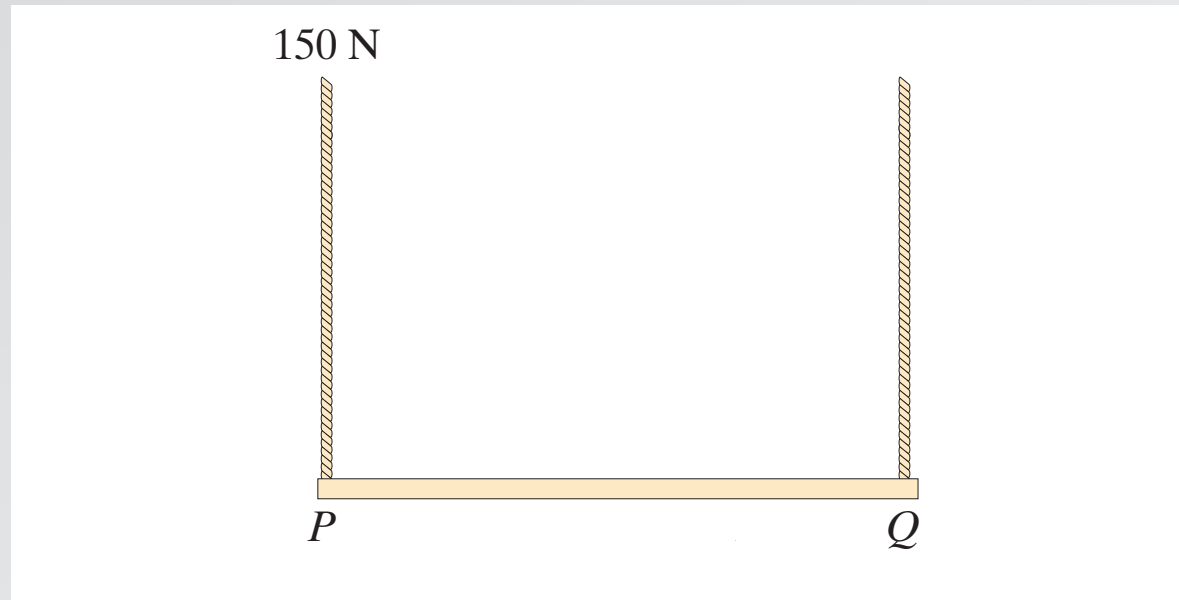
Lecture demonstrations

mode	correct	incorrect
no demo	30%	70%
observe	18%	82%
predict	29%	71%
discuss	30%	70%

just presenting harmful?

Lecture demonstrations

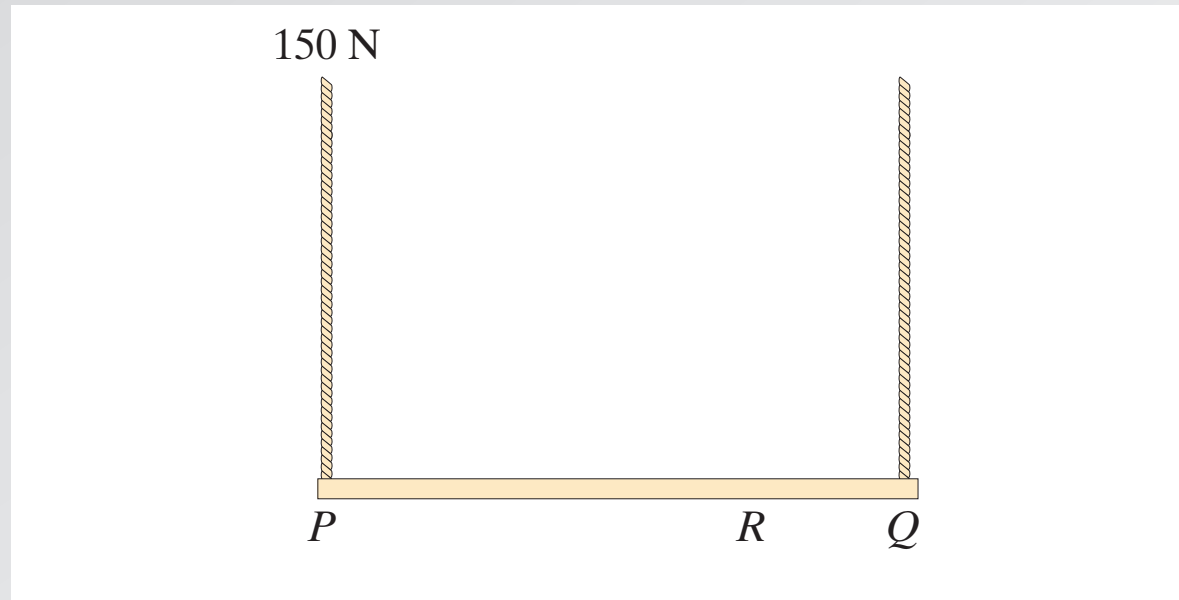
exam question



A uniform plank is supported by two ropes at points P and Q . The tension in the rope at P is 150 N .

Lecture demonstrations

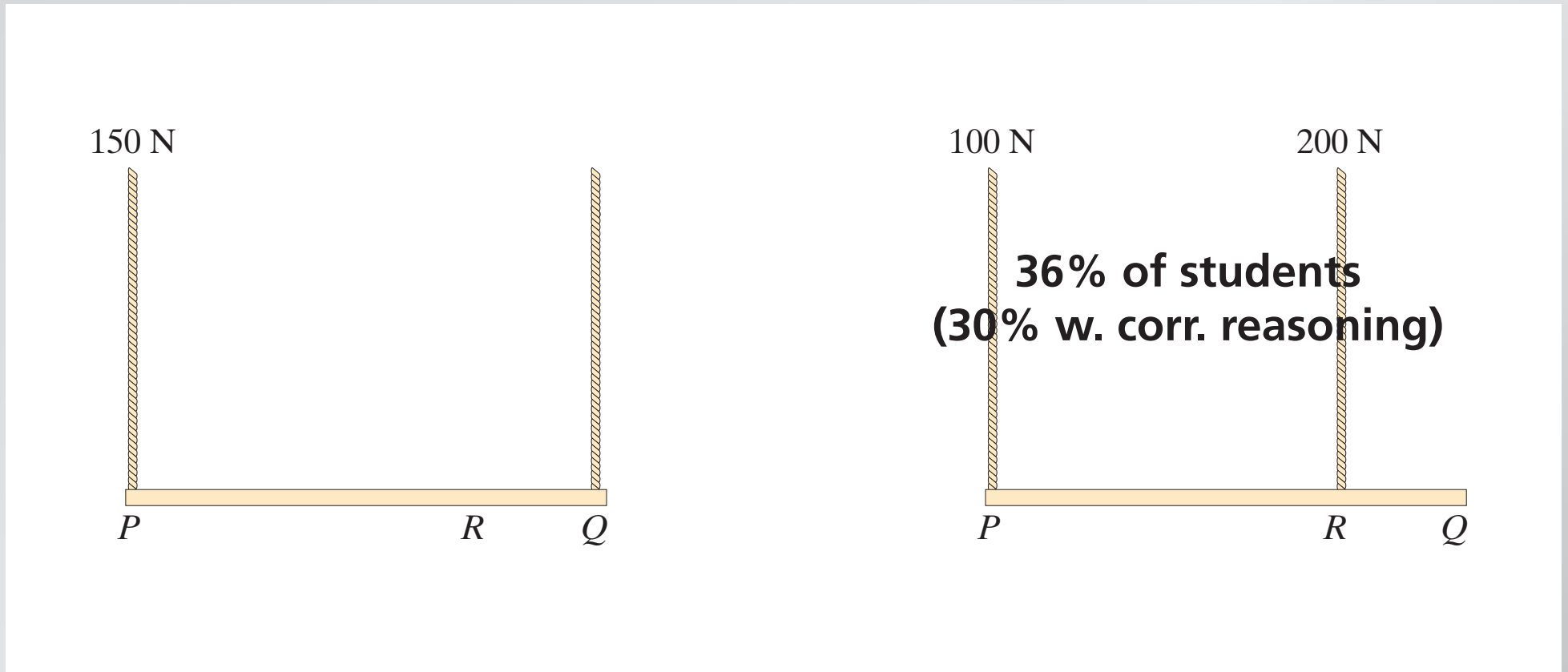
exam question



A uniform plank is supported by two ropes at points P and Q . The tension in the rope at P is 150 N . The point at which the other rope is attached to the plank is now moved to point R halfway between Q and the center of the plank. What are the tensions in the two ropes?

Lecture demonstrations

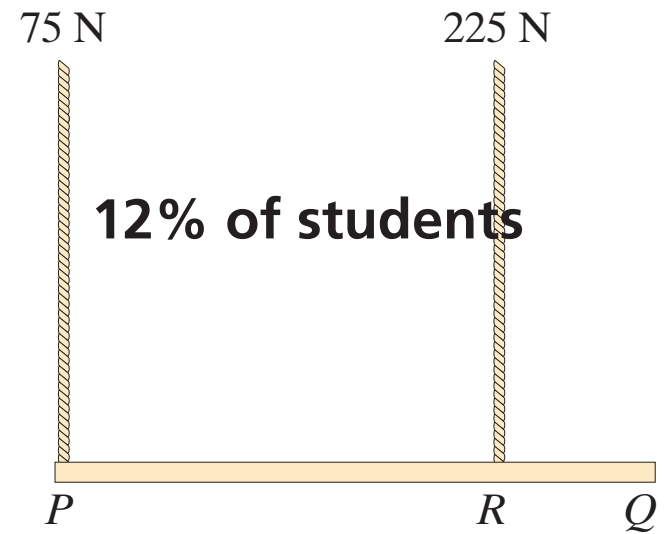
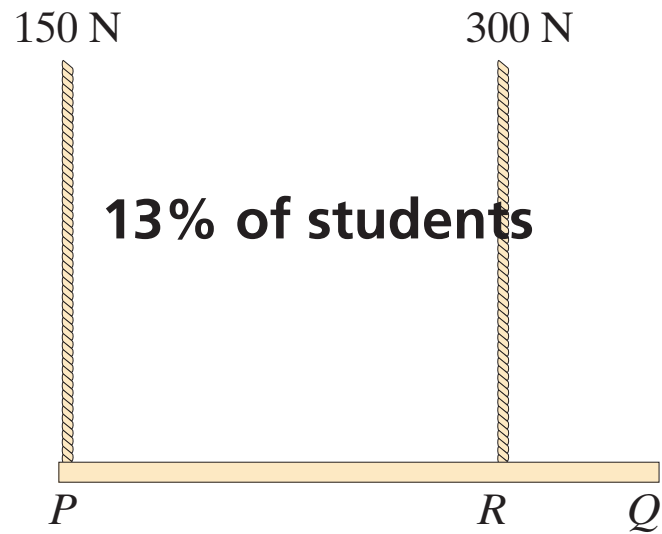
correct answer



considerable improvement from online test

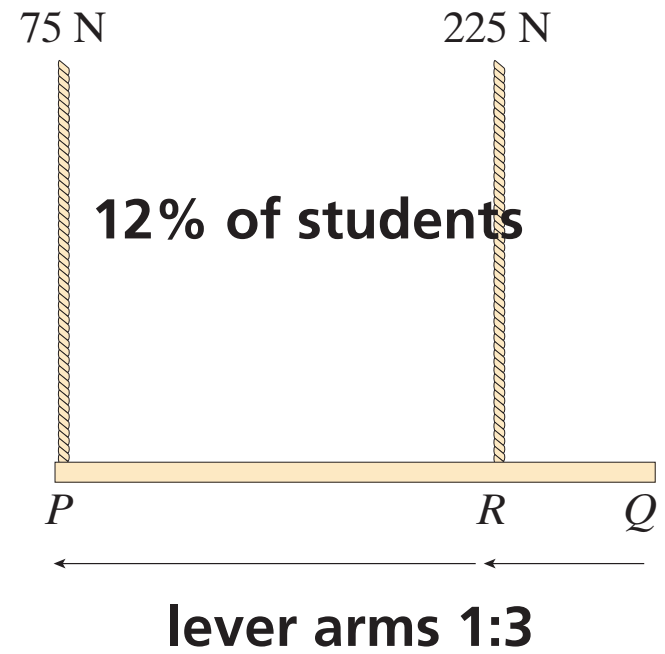
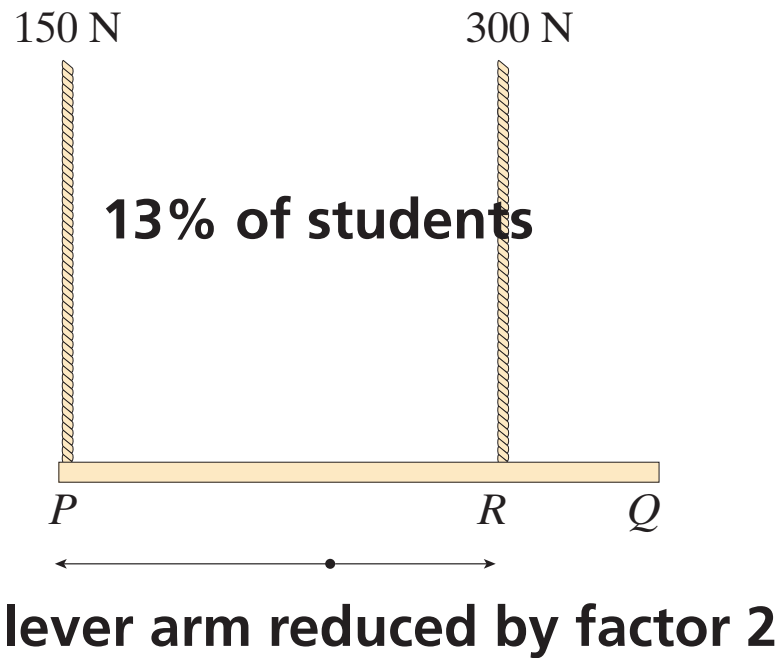
Lecture demonstrations

incorrect answers



Lecture demonstrations

incorrect answers

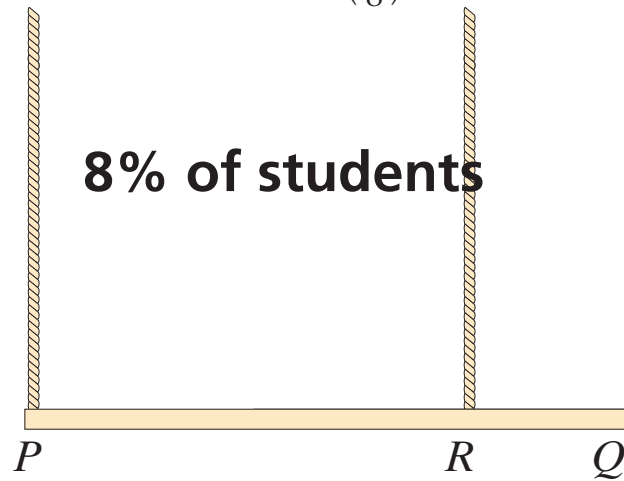


Lecture demonstrations

incorrect answers

$$\left(\frac{3}{8}\right) 300 \text{ N} = 112.5 \text{ N} \quad \left(\frac{5}{8}\right) 300 \text{ N} = 187.5 \text{ N}$$

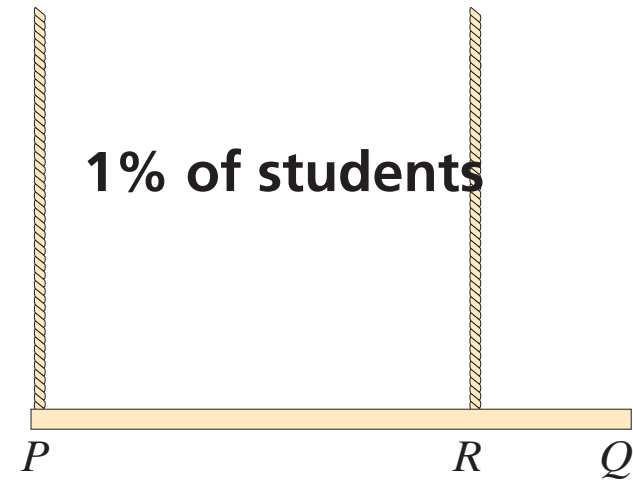
8% of students



$$112.5 \text{ N}$$

$$112.5 \text{ N}$$

1% of students

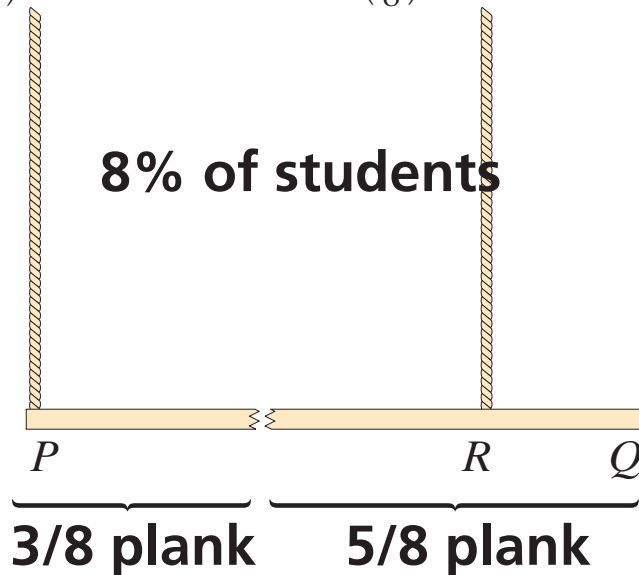


Lecture demonstrations

incorrect answers

$$\left(\frac{3}{8}\right) 300 \text{ N} = 112.5 \text{ N} \quad \left(\frac{5}{8}\right) 300 \text{ N} = 187.5 \text{ N}$$

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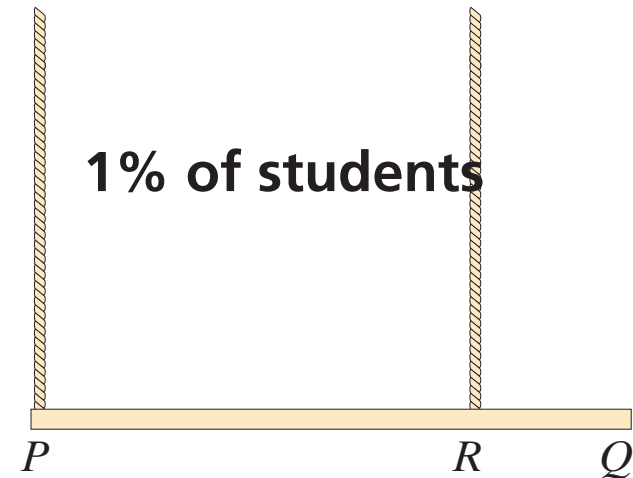


$$112.5 \text{ N}$$

$$112.5 \text{ N}$$

1% of students

only 3/4 of plank supported



who would have thought??

Lecture demonstrations

mode	correct	balances torques	no clear reasoning
no demo	31%	53%	42%
observe	42%	55%	42%
predict	41%	65%	32%
discuss	46%	85%	15%

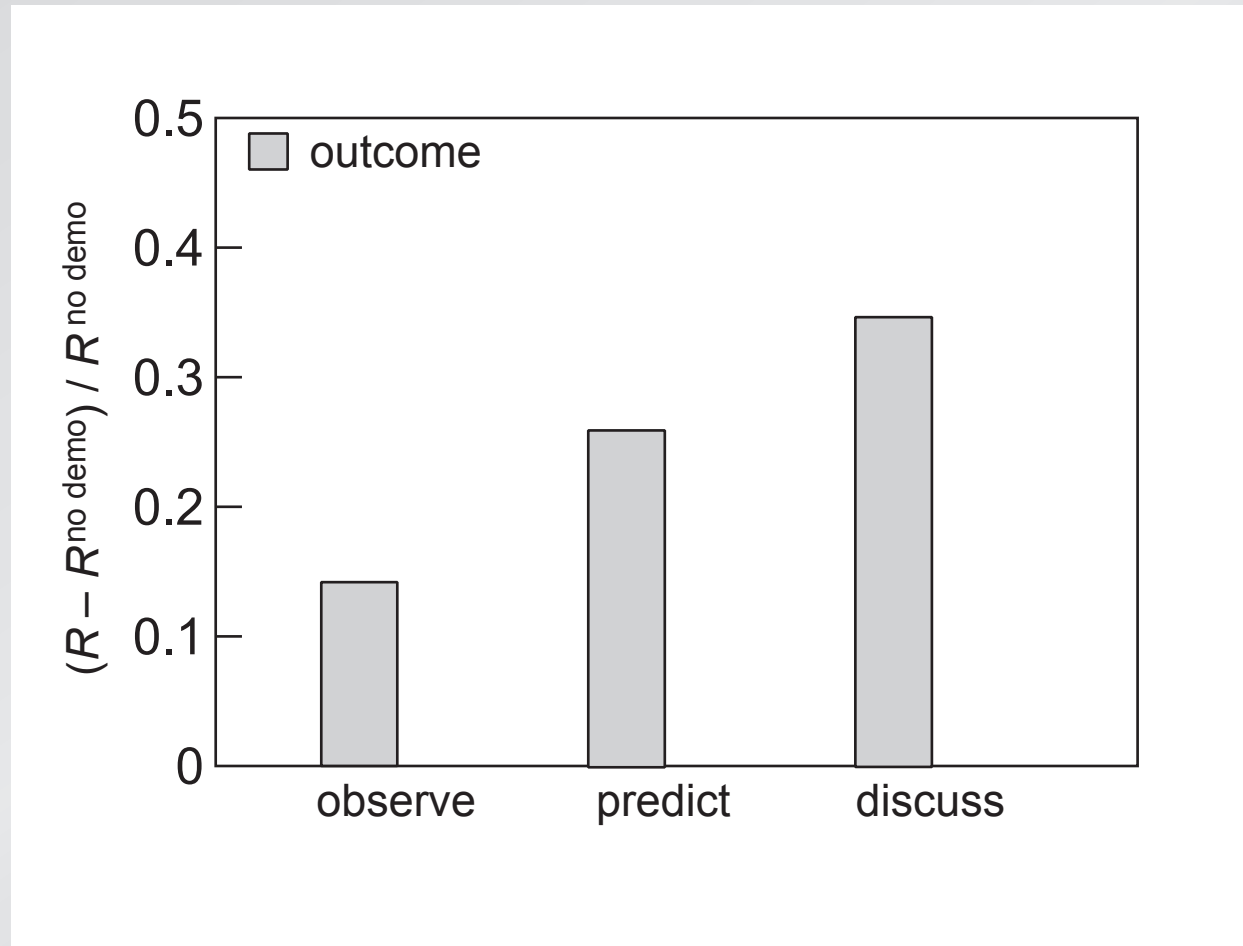
Lecture demonstrations

aggregate results for seven demonstrations

mode	N	R_{outcome}	$R_{\text{explanation}}$
no demo	297	61%	22%
observe	220	70%	24%
predict	179	77%	30%
discuss	158	82%	32%

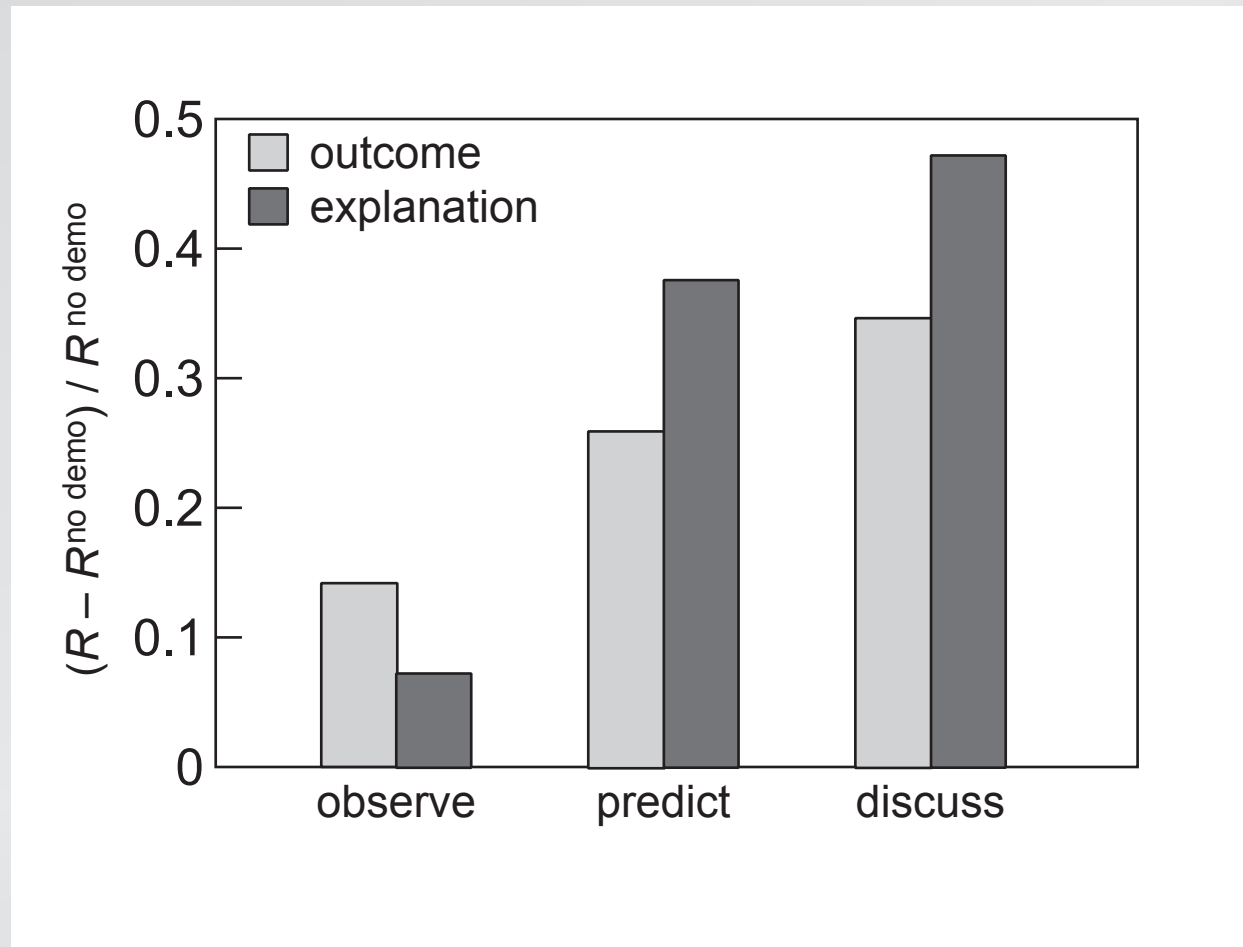
Lecture demonstrations

improvement correlates with engagement



Lecture demonstrations

improvement correlates with engagement



Lecture demonstrations

Points to keep in mind:

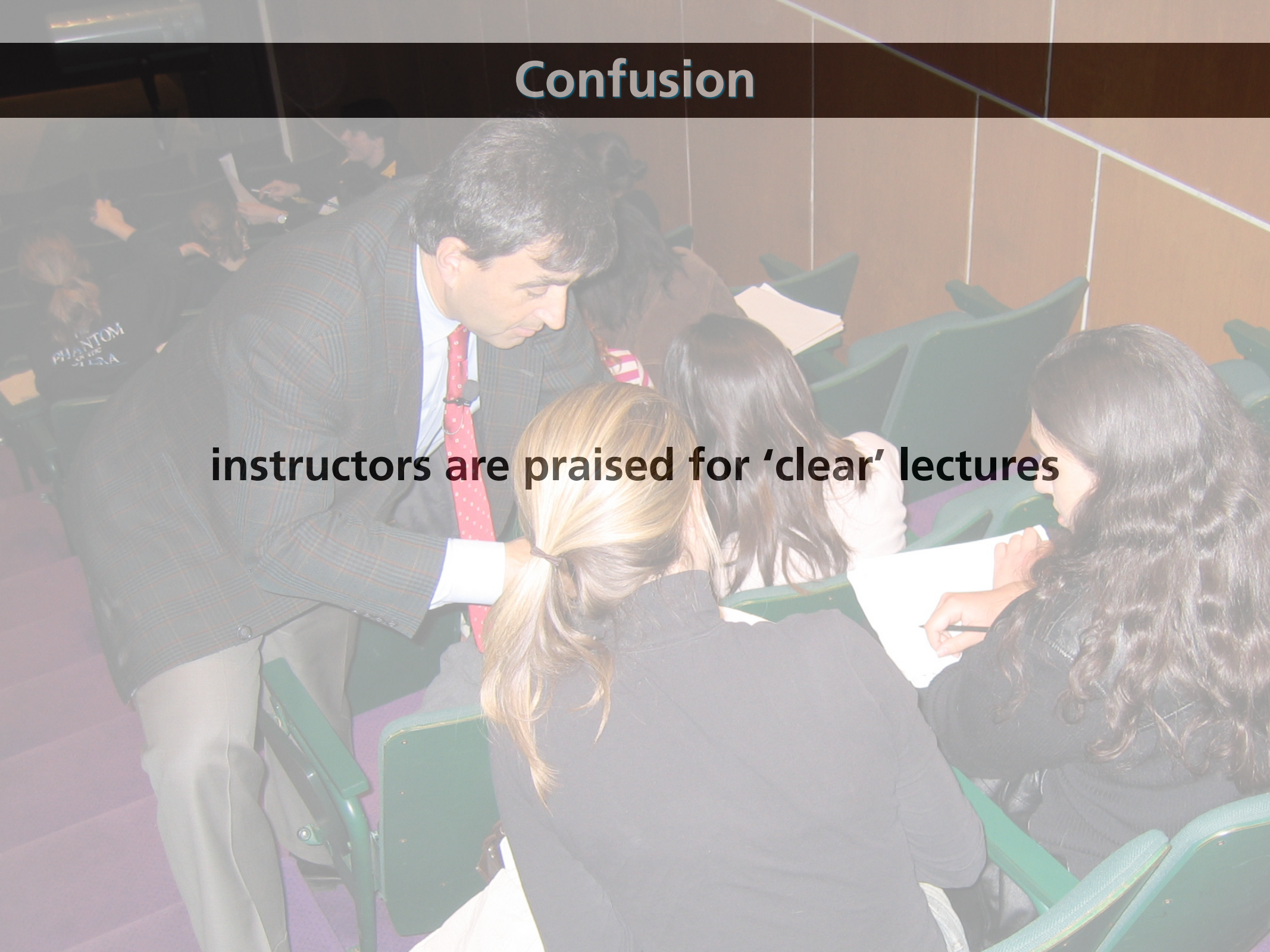
- **demonstrations without engagement not very helpful**
- **results can be improved by having students predict outcome**

Confusion



Confusion

instructors are praised for 'clear' lectures



Confusion

confusion is discouraging, but...

A photograph of a man in a dark plaid suit and red tie leaning over a desk to assist students. The students are seated at green desks in a classroom or lecture hall. The man is looking down at a book or paper on the desk. The students are focused on their work. The background shows other students and a wooden wall.

Confusion

A photograph of a man in a dark plaid suit and red tie leaning over a desk to assist students. The students are seated at green desks in a classroom. The man is looking down at a book or paper on the desk. The students are looking at the same material. The background shows other students and a wooden wall.

**confusion is discouraging, but...
"to wonder is to begin to understand"**

Confusion

does confusion indicate lack of understanding?

A photograph of a man in a dark plaid suit and red tie leaning over a desk to assist students. The students are seated at green desks in a classroom or lecture hall. The man is looking down at a document on the desk. The students are also looking at the document. The background shows other students and a wooden wall.

Confusion

or, alternatively:

does lack of confusion indicate understanding?



Confusion

Web-based free-response reading assignment:

- **two questions on content (difficult!)**
- **one feedback question**

Novak et al., Just-in-Time Teaching: Blending active learning with web technology (Prentice Hall, 1999).

Confusion

Web-based free-response reading assignment:

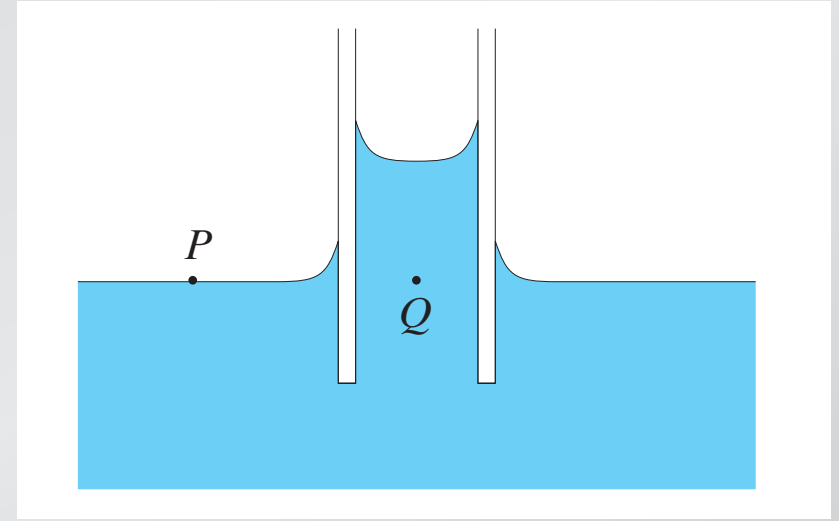
- **two questions on content (difficult!)**
- **one feedback question**

analyze understanding and confusion

Novak et al., Just-in-Time Teaching: Blending active learning with web technology (Prentice Hall, 1999).

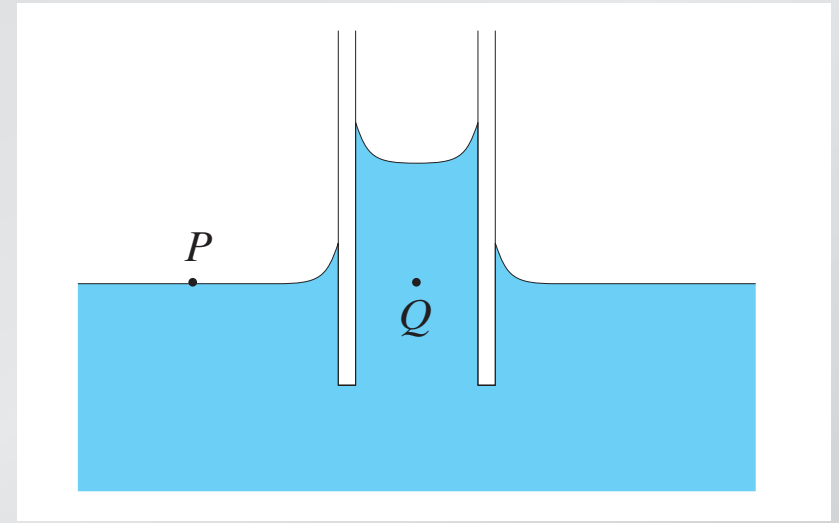
Confusion

1. Consider the capillary rise of a liquid in a glass tube. How does the pressure at point P at the surface of the liquid compare to the pressure at point Q at equal height?

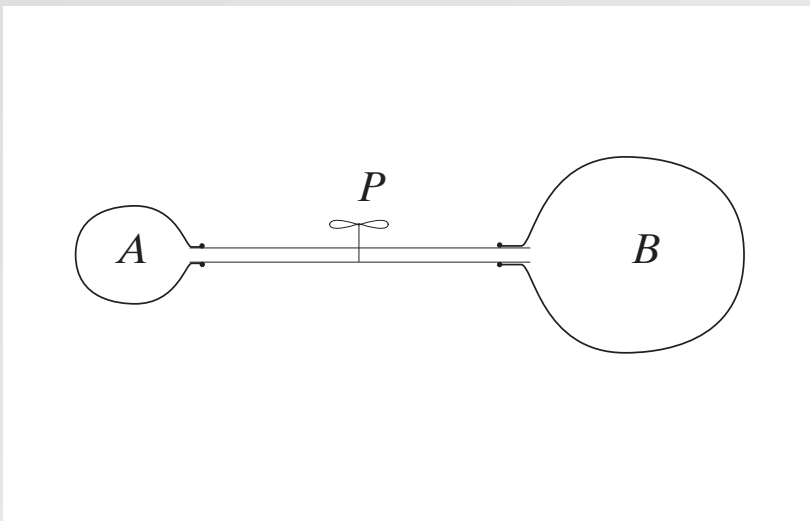


Confusion

1. Consider the capillary rise of a liquid in a glass tube. How does the pressure at point P at the surface of the liquid compare to the pressure at point Q at equal height?



2. Two identical balloons are connected to a tube as shown below. Balloon B is inflated more than balloon A . Which way does the air flow when valve P is opened?



Confusion

3. Please tell us briefly what points of the reading you found most difficult or confusing. If you did not find any part of it difficult or confusing, please tell us what parts you found most interesting.

Confusion

sample answer

- 1. Capillary action is due to the cohesion between water molecules, and the adhesion of water to the surface of the glass tube. Negative pressures can result from the cohesive forces of water. At the same height, the pressure inside the tube is much less due to negative pressures.**
- 2. The air flows from high pressure to low pressure. The fully blown up balloon has higher pressure than the 1/2 blown up balloon. So the air flows from the fully blown balloon to the half filled balloon.**
- 3. Nothing was difficult or confusing. The sections on the surfactant in the lungs and the heart as a pump were interesting because they relate physics to biology.**

Confusion

sample answer

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Confusion

1. The water rises because of an interaction between the water and the walls of the tube. This interaction creates an upward force which causes the water to rise. The force is due to surface tension between the water and the walls of the tube. The pressure at the point inside the tube must be the same as the pressure at the point of equal height outside the tube, because if there was a pressure difference, then there would be a net flow of water, into or out of the tube, until the pressure difference was equalized.

2. Laplace's law tells us that it requires a greater pressure difference to maintain a small sphere than a larger one. So, the pressure in the small balloon must be greater, and the air will flow from the small balloon into the large one.

3. I found the explanation of Laplace's law to be inadequate, and while I can understand the conclusion drawn, I don't understand the reasoning which led to the conclusion.

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Confusion

Analysis

Coding of responses:

- Q1 and Q2: correct or incorrect
- Q3: confusion expressed on topic of Q1/Q2

Correlate confusion with correctness

Confusion

traditional textbook on Laplace's law and capillarity

capillarity	correct	incorrect
confused	44%	56%
not confused	25%	75%

Confusion

traditional textbook on Laplace's law and capillarity

capillarity	correct	incorrect
confused	44%	56%
not confused	25%	75%

Laplace	correct	incorrect
confused	49%	51%
not confused	21%	79%

Confusion

“Confused” students twice as likely correct!

Confusion

using research-based text

torque	correct	incorrect
confused	45%	55%
not confused	43%	57%

Confusion

using research-based text

torque	correct	incorrect
confused	45%	55%
not confused	43%	57%

text compels students to think while reading

Confusion

**More confusion among students who understand!
(especially when students are not pushed to think)**

Confusion

Confusion...

- **doesn't correlate with understanding**
- **is not (necessarily) the result of poor teaching**
- **is part of the learning process**

Conclusion

classroom data vital to improving education!

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