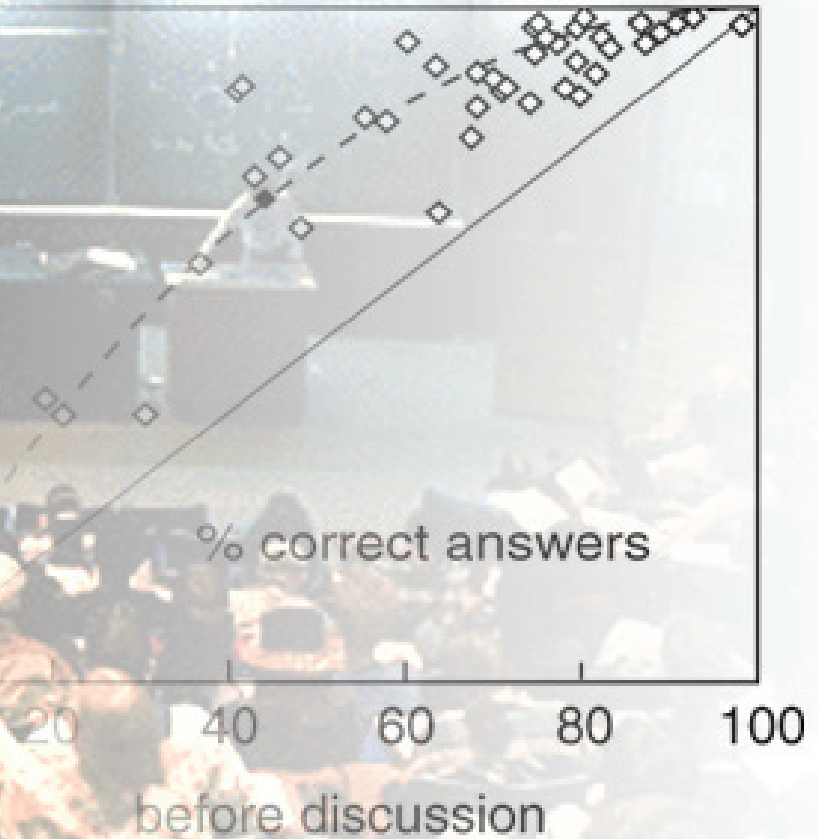


# The scientific approach to teaching: research as a basis for course design



Nuevas Tendencias en la Enseñanza de la Física  
Benemerita Universidad Autónoma de Puebla  
Puebla, Mexico, 19 septiembre 2009



# Education



# Education

lectures focus on delivery of information

A large lecture hall filled with students seated at desks, facing a stage. A lecturer is standing at a podium on the stage, addressing the class. A large screen or chalkboard is visible behind the lecturer, displaying text. The room is dimly lit, with the stage area being the primary light source.

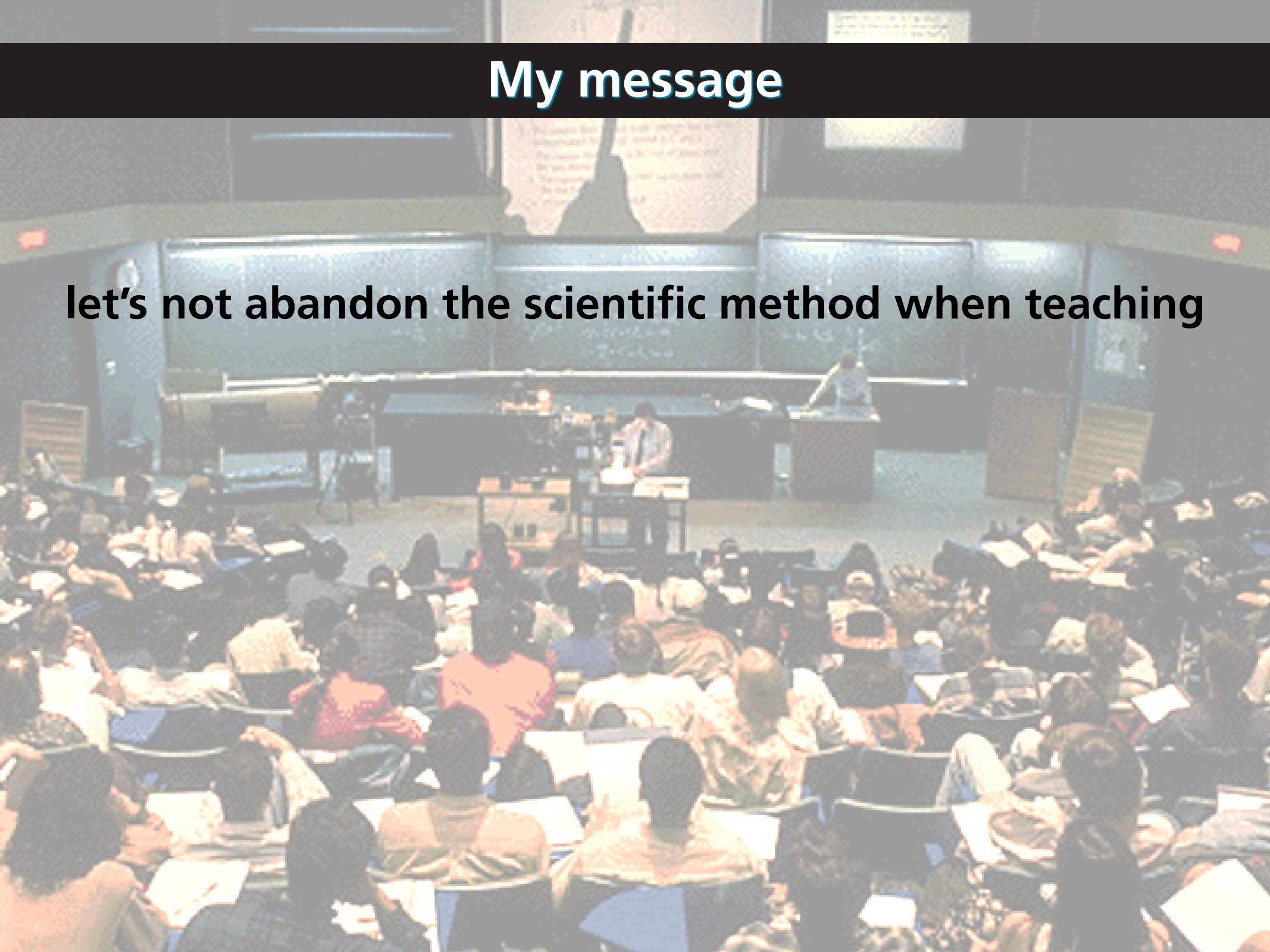
# Education

**not transfer but assimilation of information is key**

A large lecture hall filled with students seated at desks, facing a stage. A lecturer is standing at a podium on the stage, and a large screen displays text. The room is dimly lit, with the stage area being the primary light source. The students are mostly seen from behind, looking towards the front of the room.

# My message

**let's not abandon the scientific method when teaching**



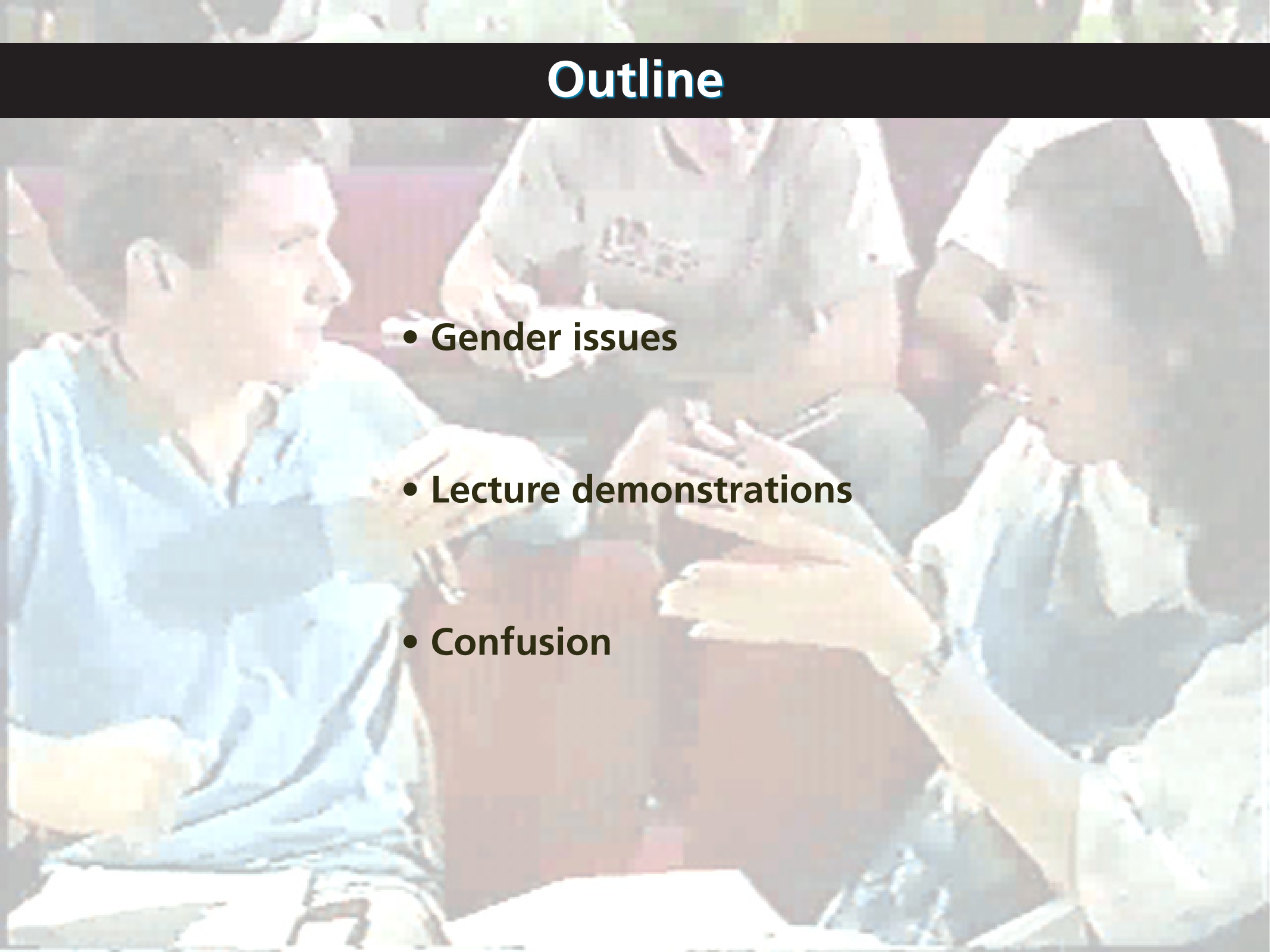
# My message

let's not abandon the scientific method when teaching

*The plural of anecdote is not data*

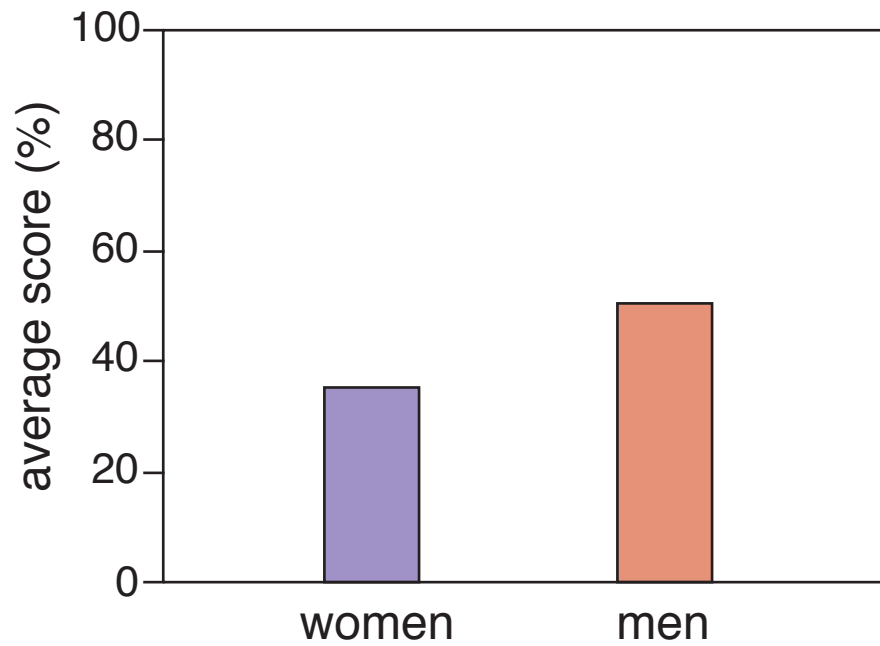
Lee Shulman

# Outline

- Gender issues
  - Lecture demonstrations
  - Confusion
- 

# Gender issues

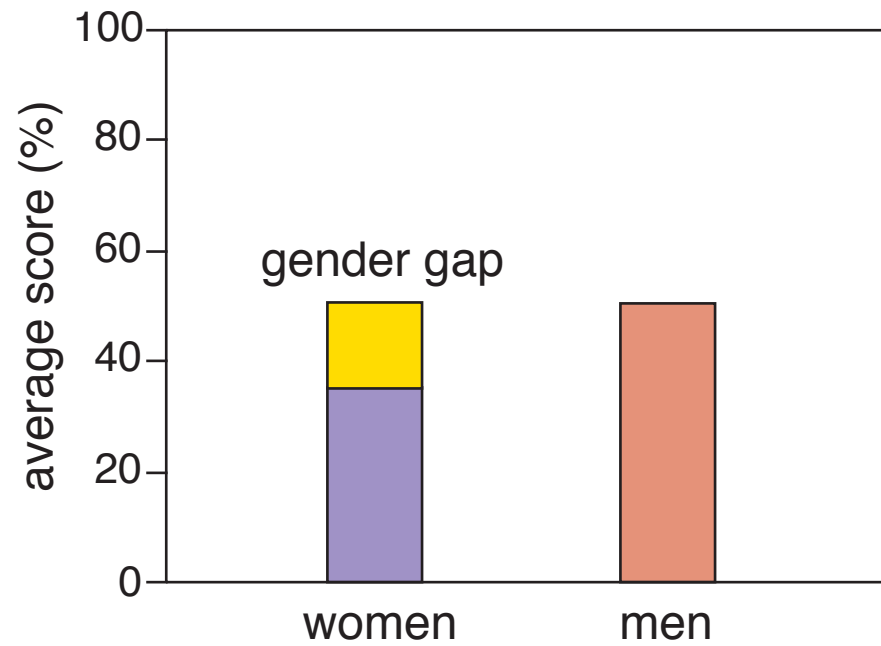
## Force Concept Inventory posttest scores





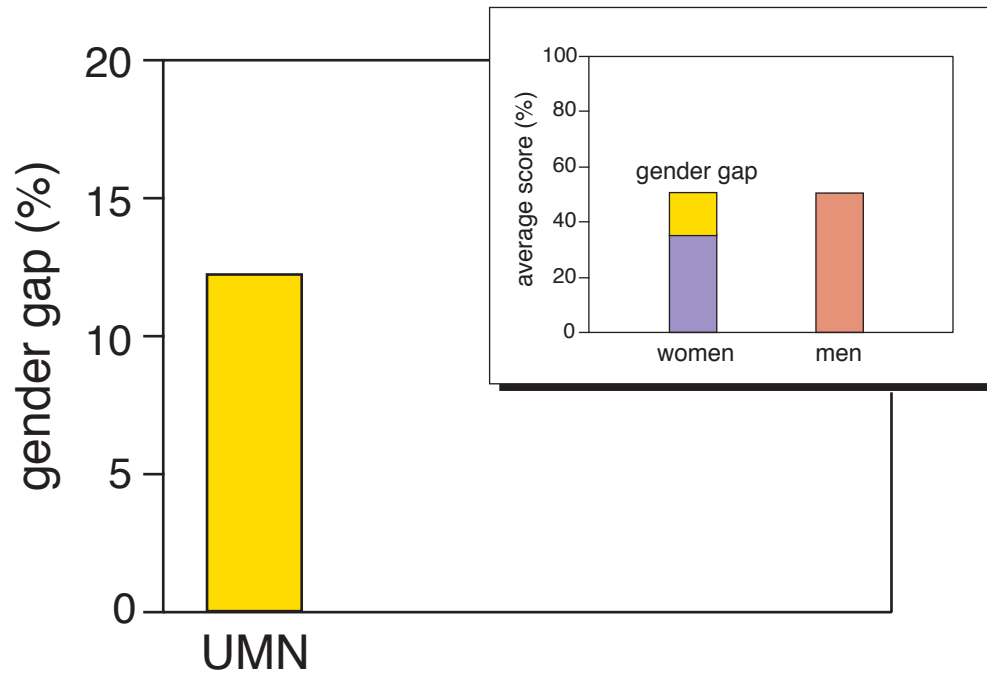
# Gender issues

## Force Concept Inventory posttest scores



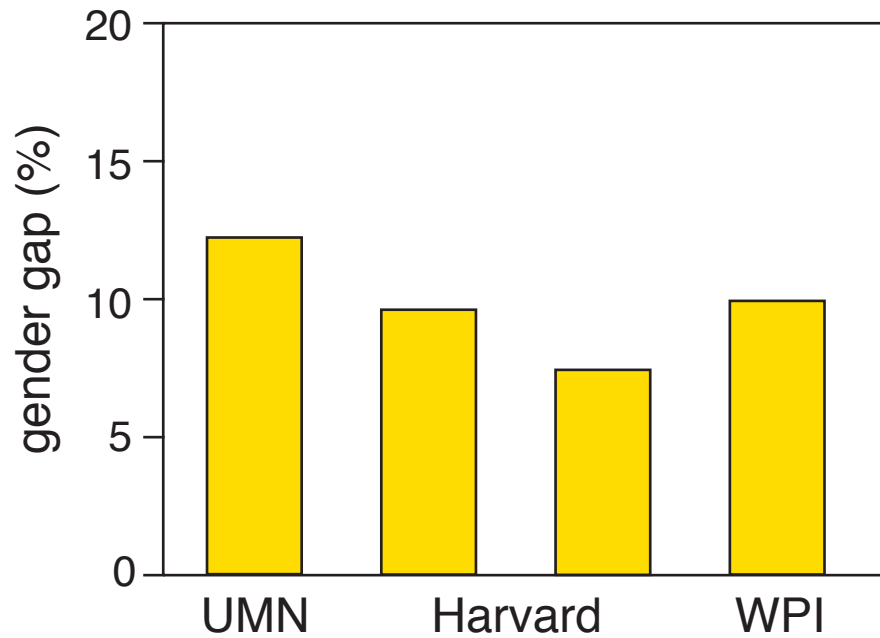
# Gender issues

## Force Concept Inventory posttest scores



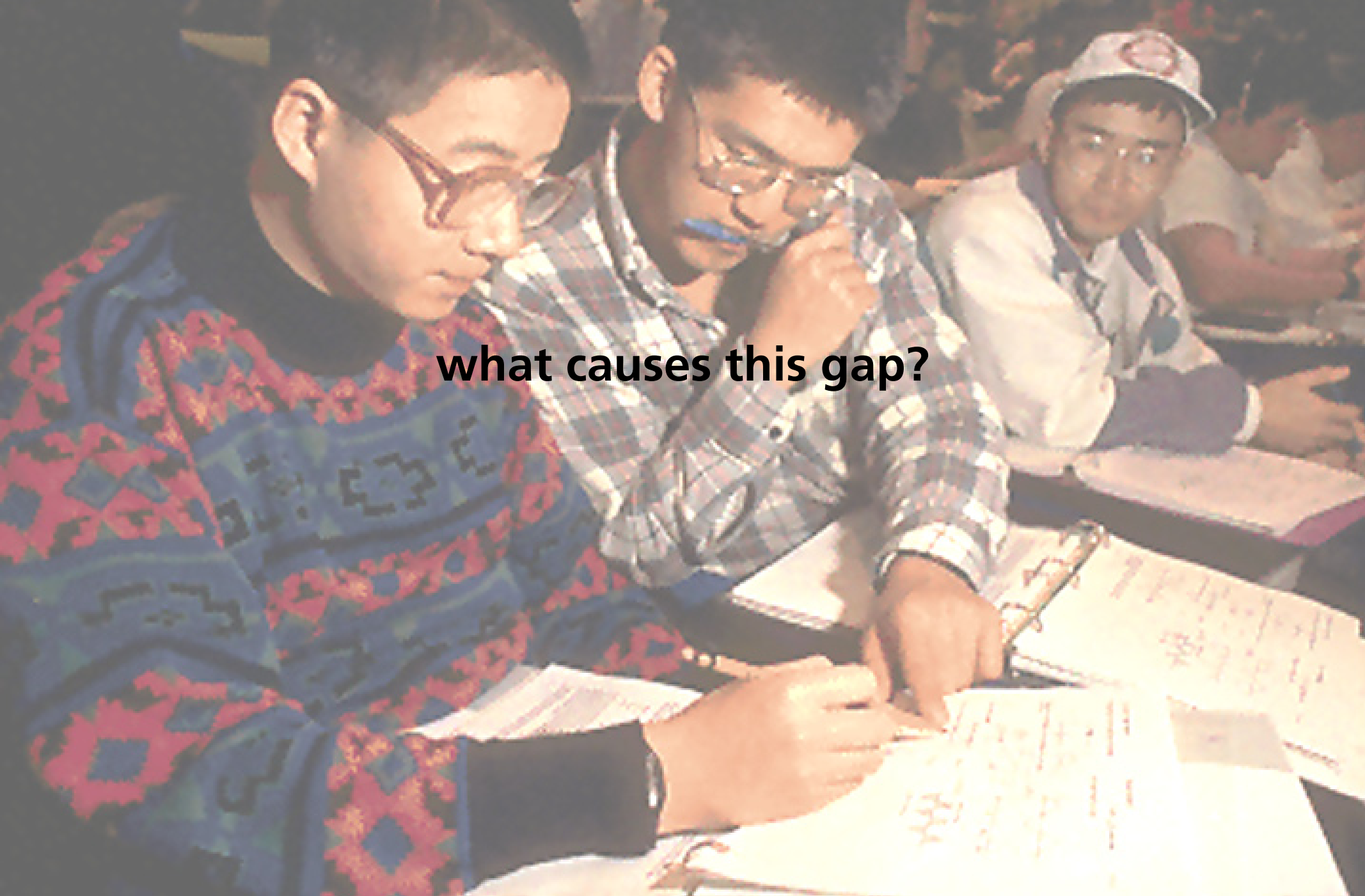
# Gender issues

## Force Concept Inventory posttest scores



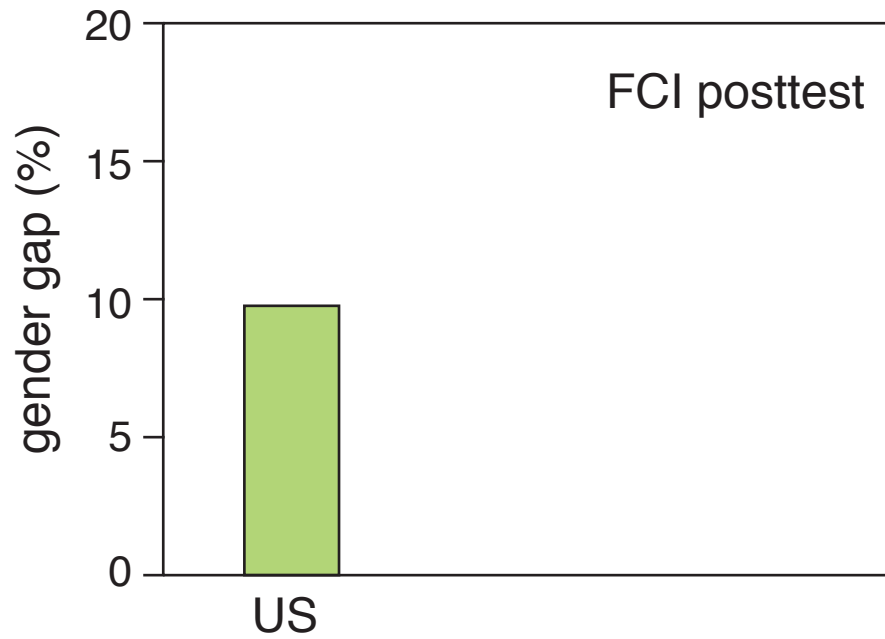
# Gender issues

what causes this gap?

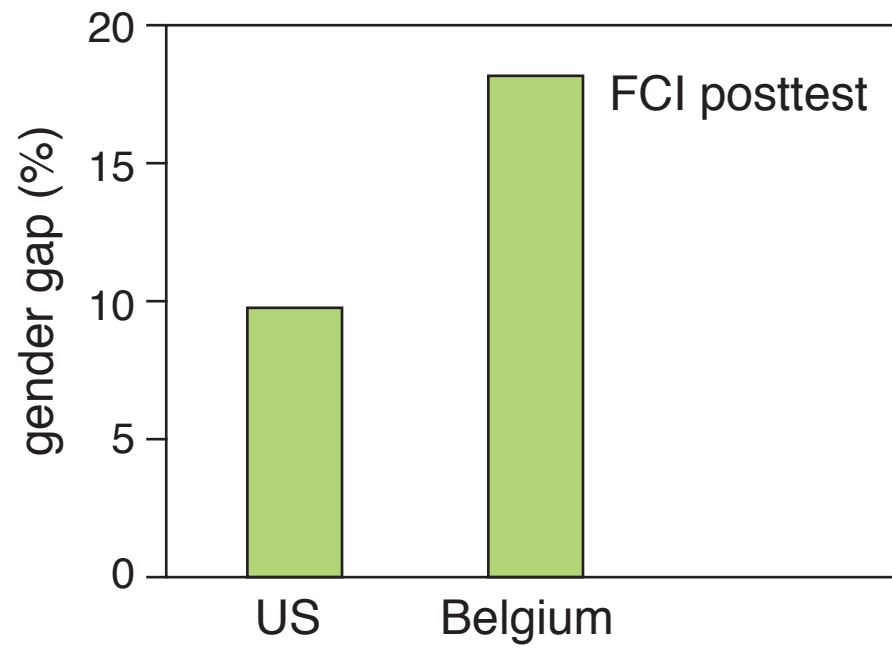


# Gender issues

is it cultural?

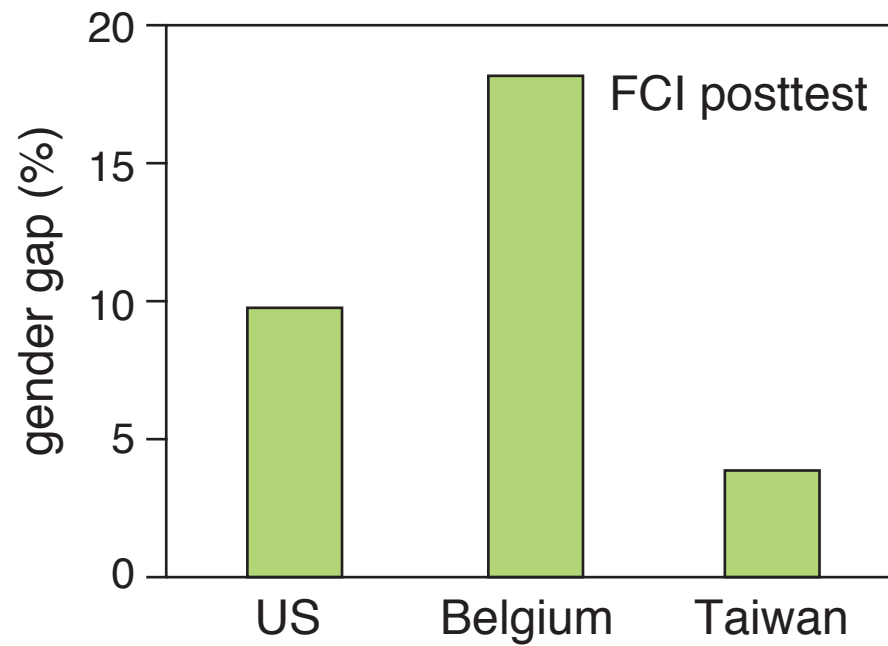


# Gender issues



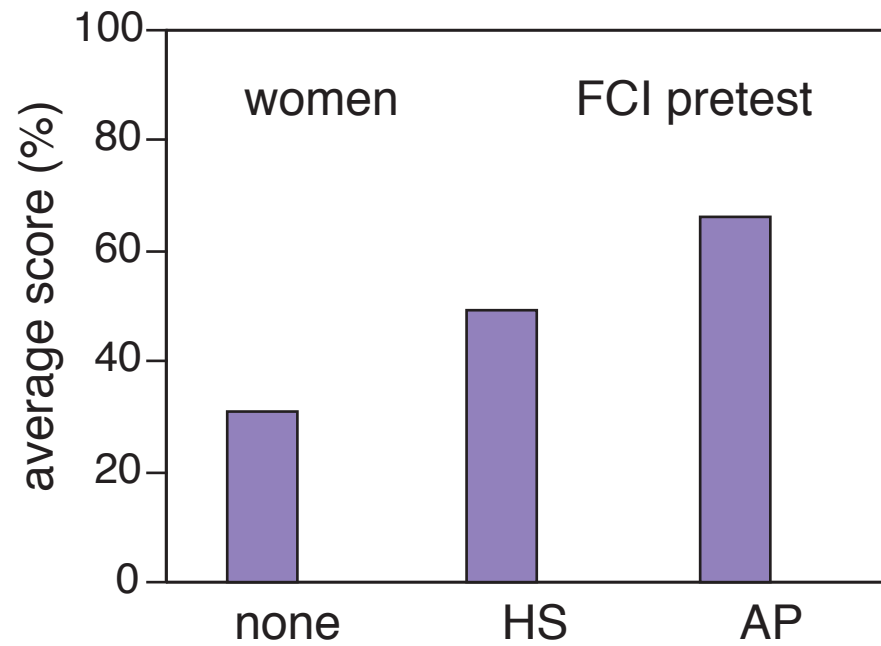
# Gender issues

**strong dependence on culture!**



# Gender issues

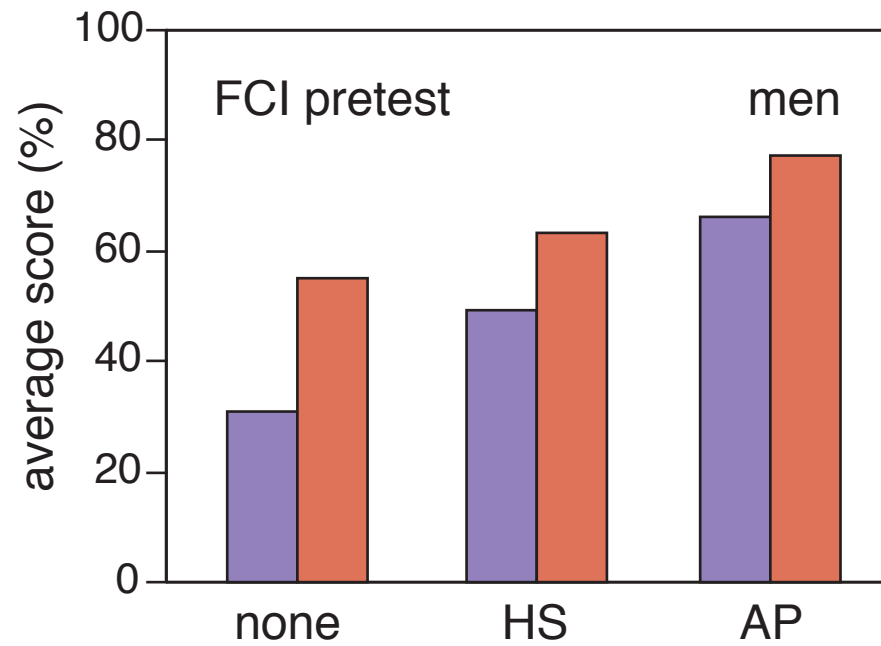
## effect of precollege education





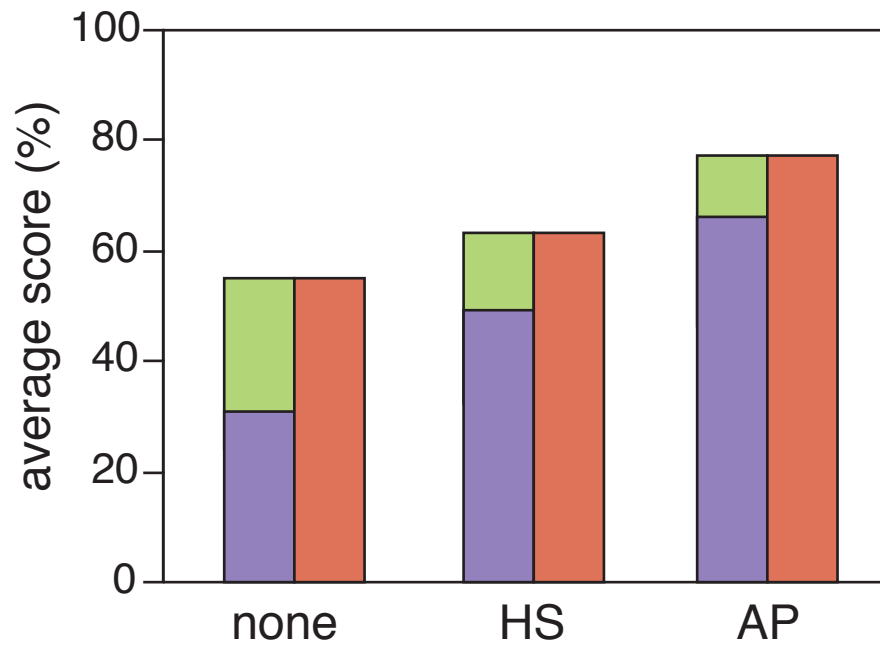
# Gender issues

everyone gains...



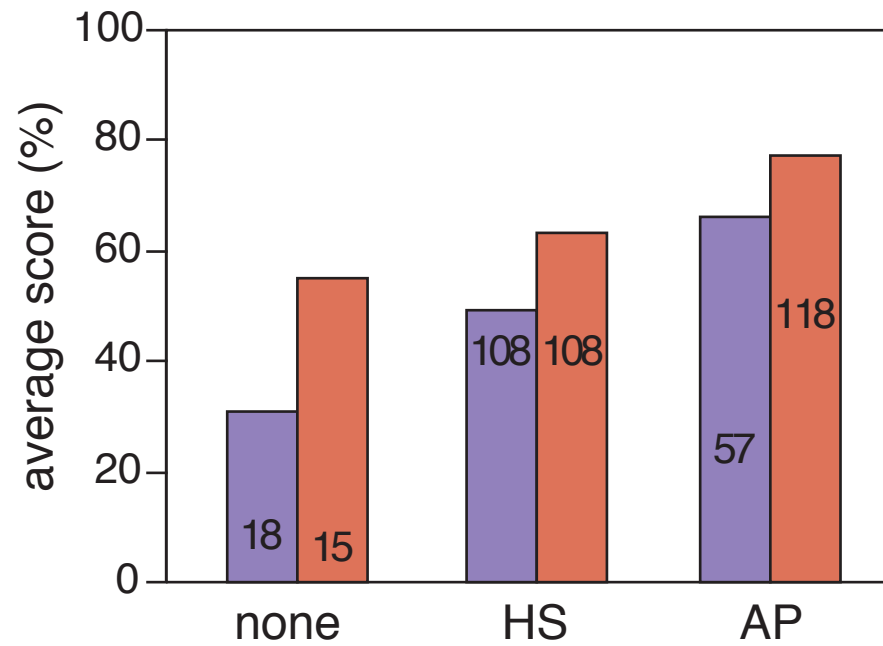
# Gender issues

...but gap persists...



# Gender issues

...and women underrepresented



# Gender issues

what can we do?

A group of women are seated around a table in what appears to be a meeting or workshop. The woman in the center, wearing a red patterned top, is speaking and gesturing with her hand. To her left, a woman with long dark hair and glasses is looking towards her. To her right, another woman is partially visible, wearing a white top with a colorful pattern. On the table in front of them are several sheets of paper, a pen, and a small notebook. The background shows other people seated at tables, suggesting a larger gathering.

# Gender issues

**increase collaboration and interactivity**

A group of women are seated around a table in a room with green chairs. They appear to be in a collaborative meeting or workshop. One woman in the foreground is wearing a red and orange patterned top and is writing in a notebook. Other women are looking towards her or at documents on the table. The atmosphere is focused and interactive.

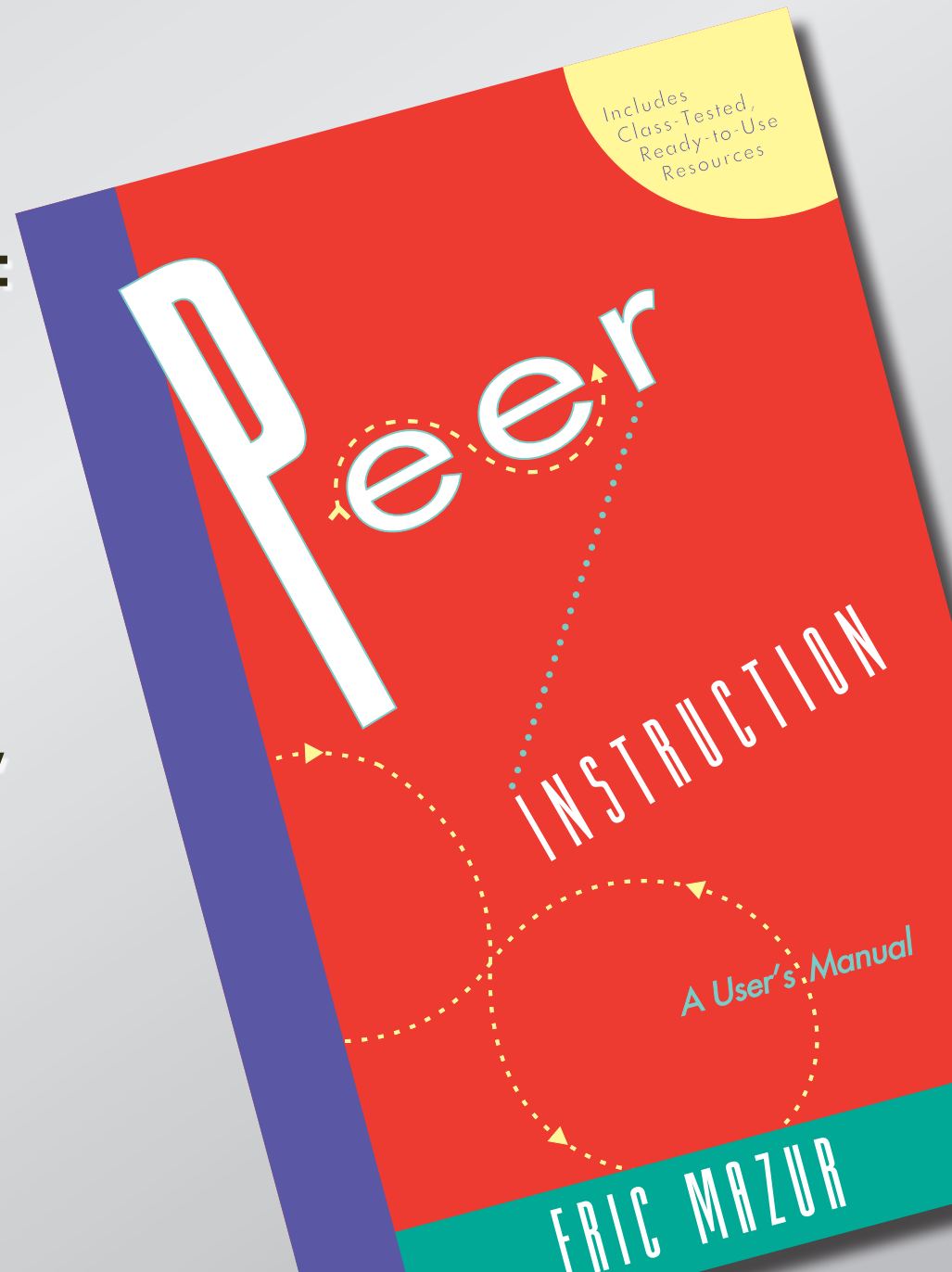
# Gender issues

Compare three pedagogies:

**T:** traditional lectures

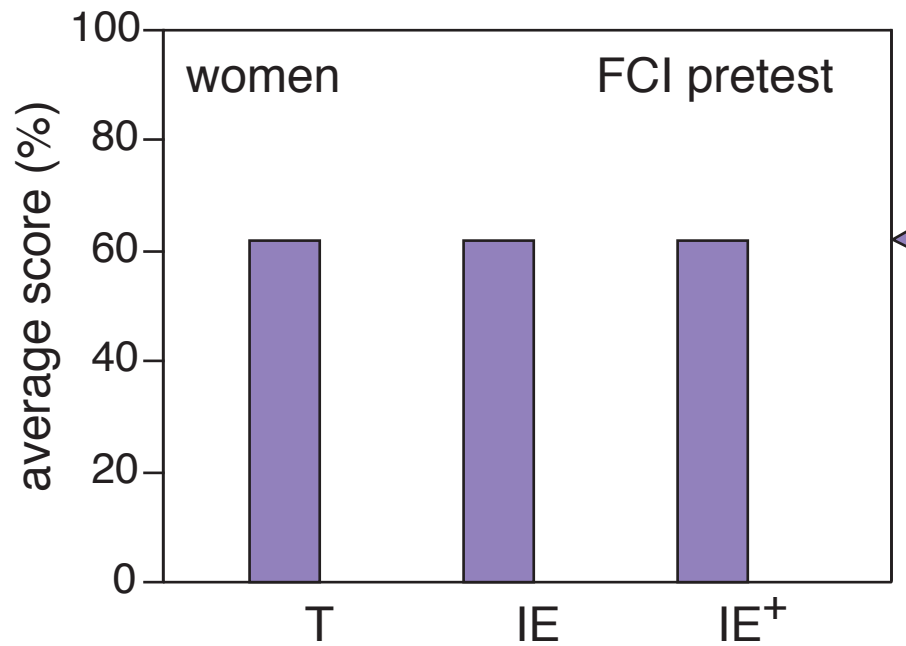
**I:** interactive lectures

**I<sup>+</sup>:** interactive assignments,  
lectures, and tutorials



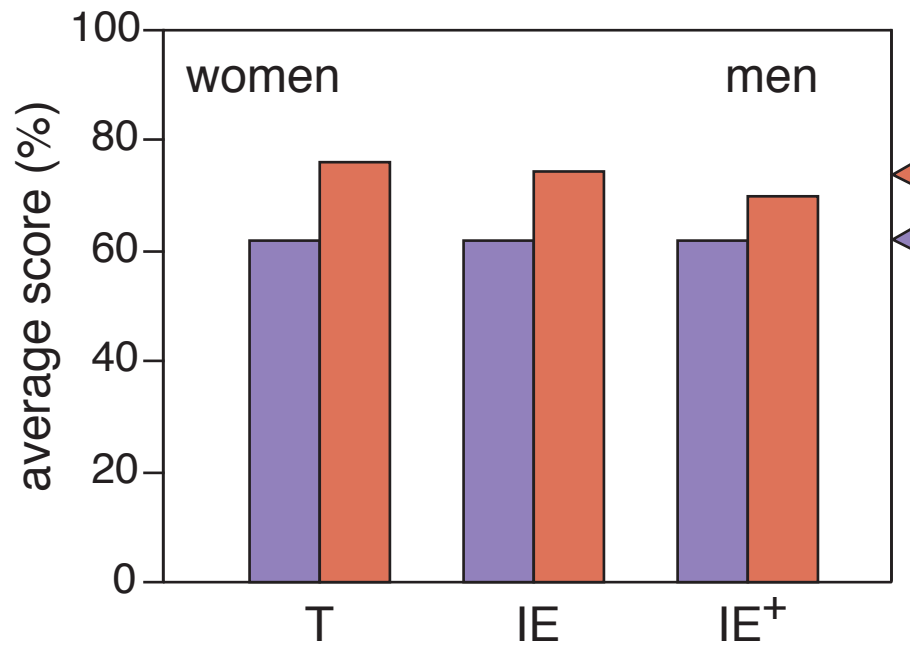
# Gender issues

does pedagogy help?



# Gender issues

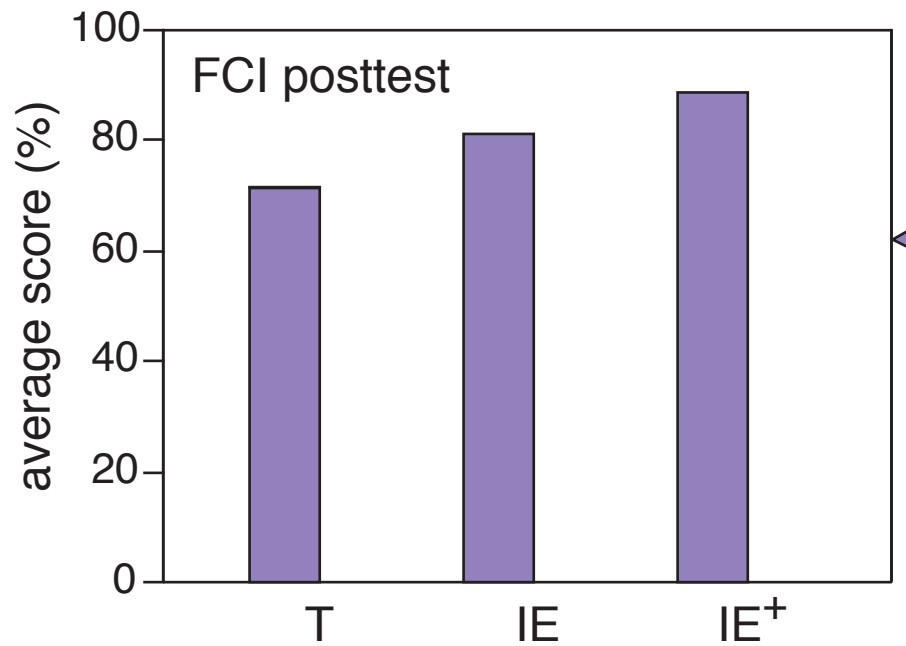
does pedagogy help?





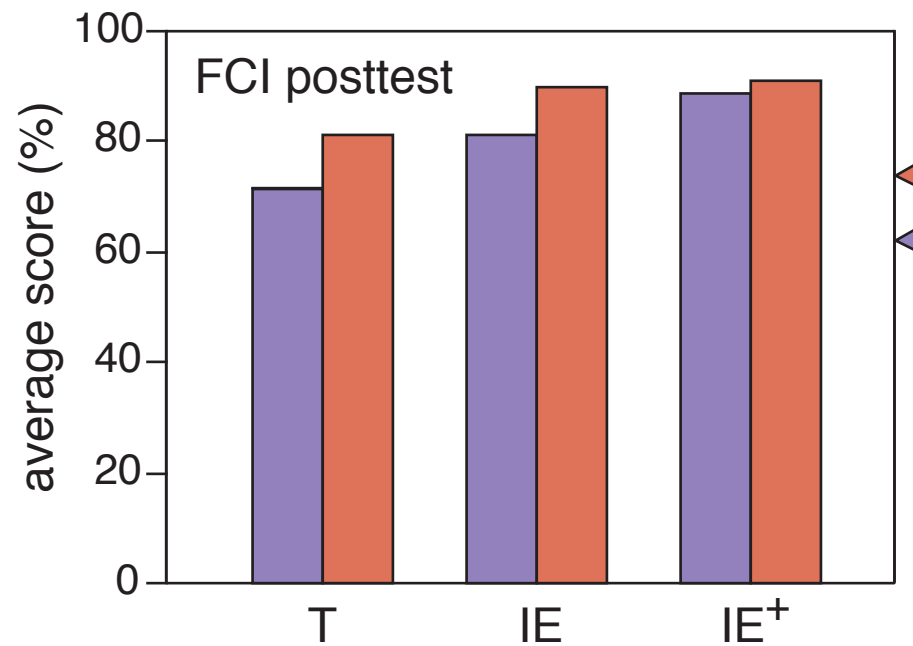
# Gender issues

does pedagogy help?



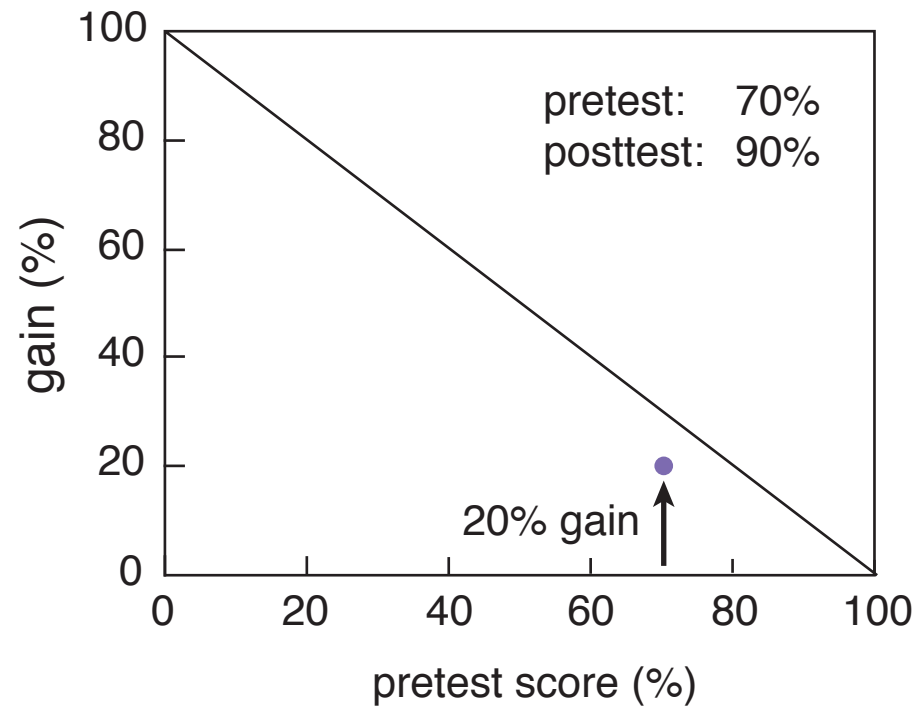
# Gender issues

yes, pedagogy can eliminate gap!



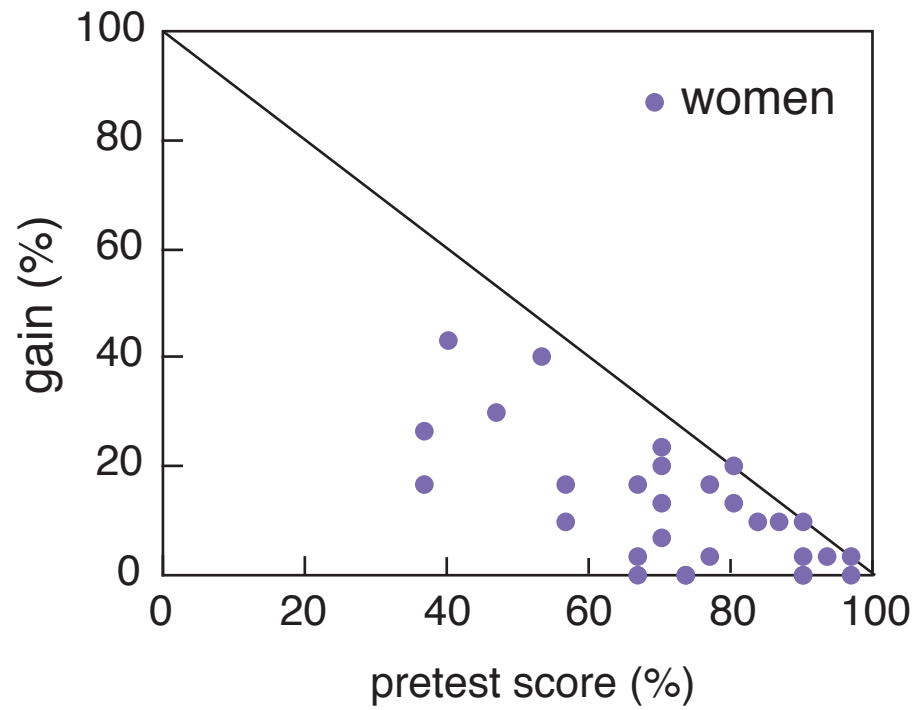
# Gender issues

who are the low-gain students?



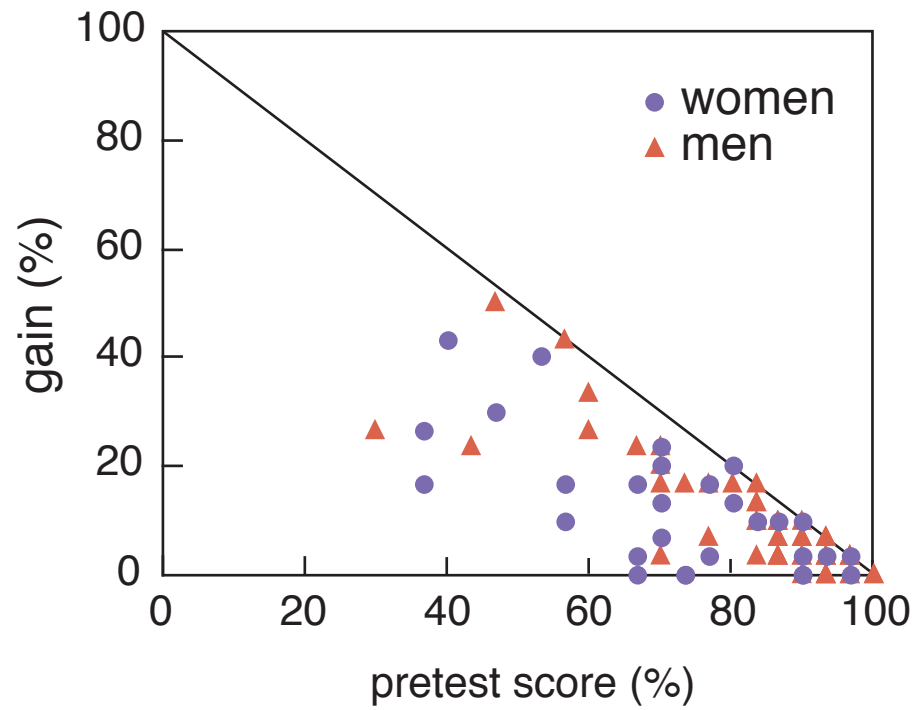
# Gender issues

## traditional class



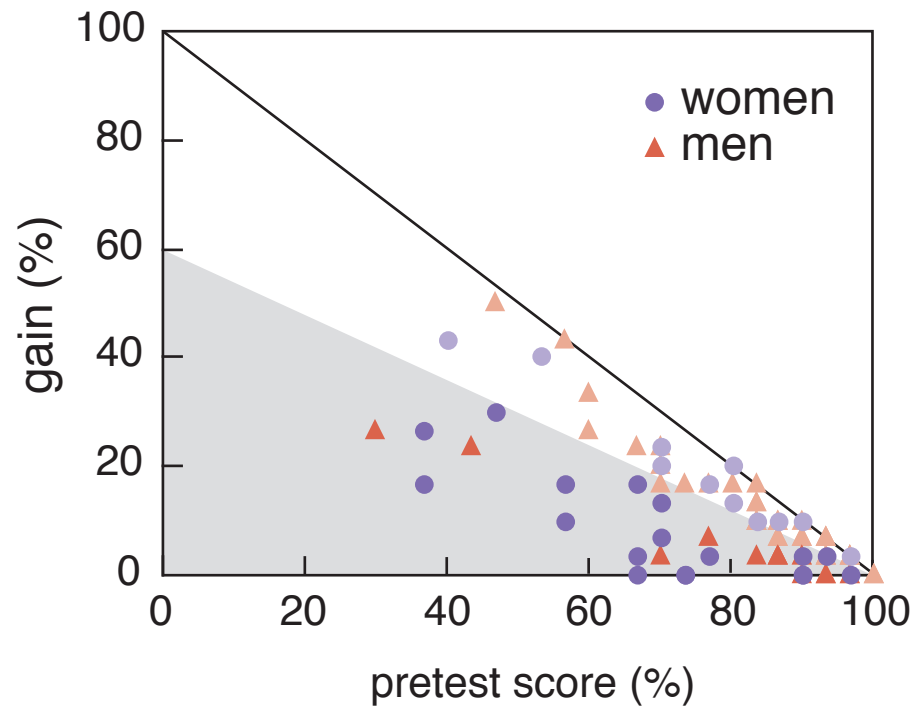
# Gender issues

traditional class



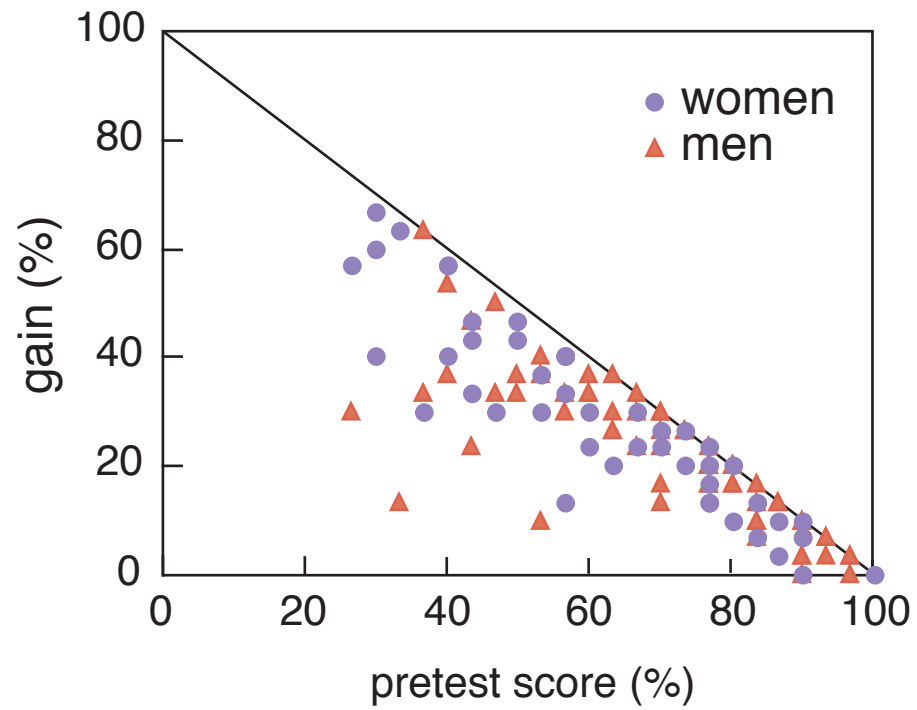
# Gender issues

traditional class: gender imbalance



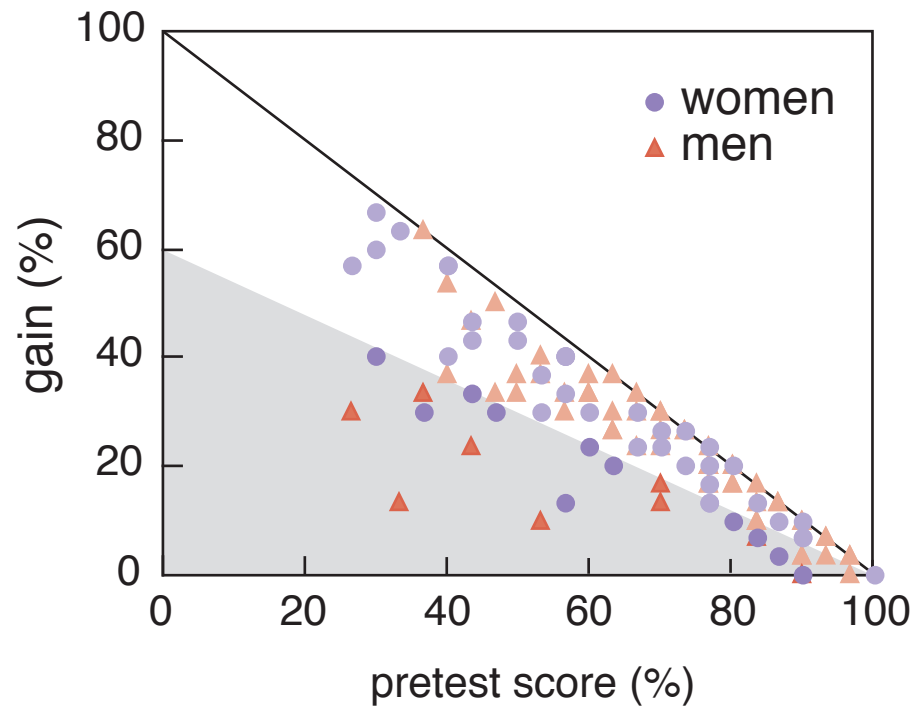
# Gender issues

## 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.)

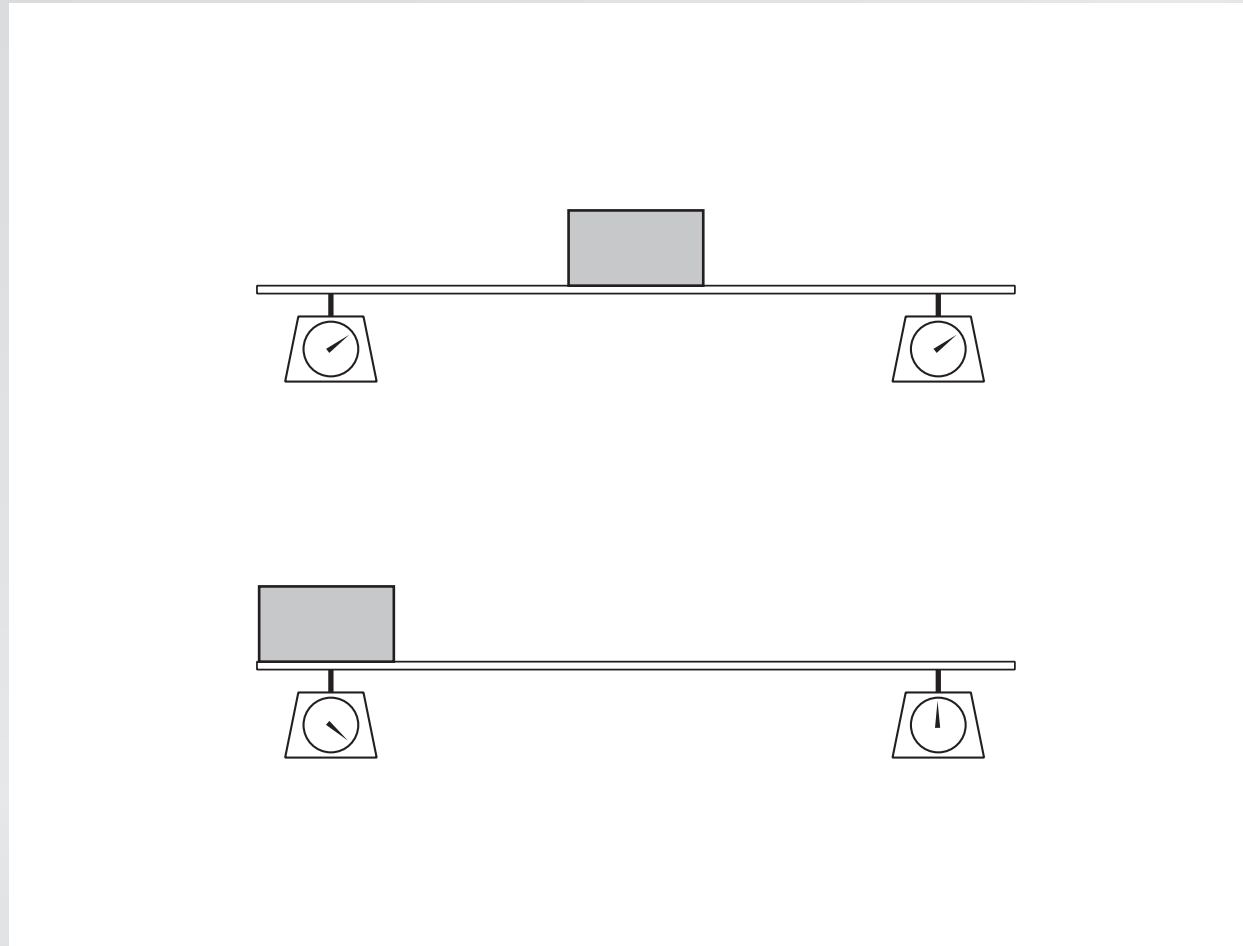
# Lecture demonstrations

**Follow up:**

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

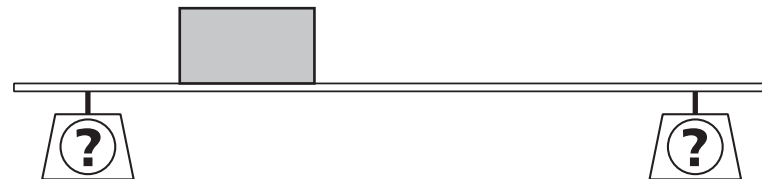
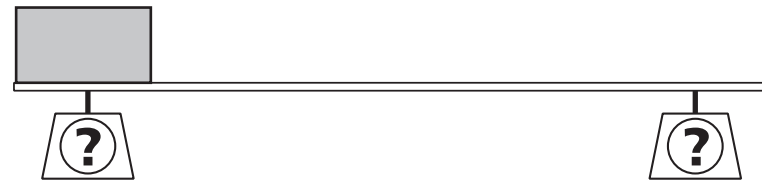
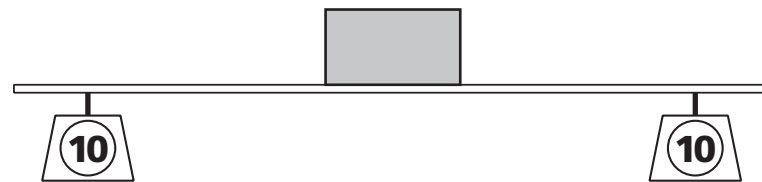
# Lecture demonstrations

## loaded beam demo



# Lecture demonstrations

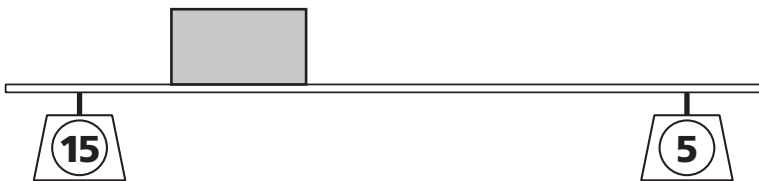
online test question



# Lecture demonstrations

answers given

24% of students



correct (mentions torque)



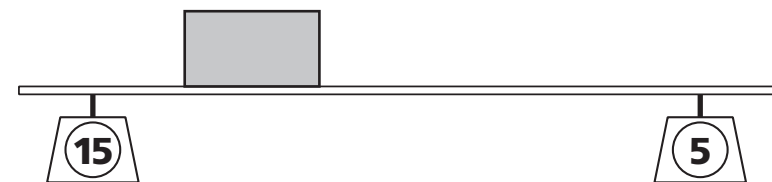
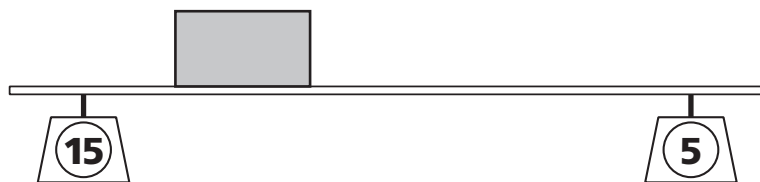
# Lecture demonstrations

answers given

24% of students



38% of students



correct (mentions torque)

proportional reasoning

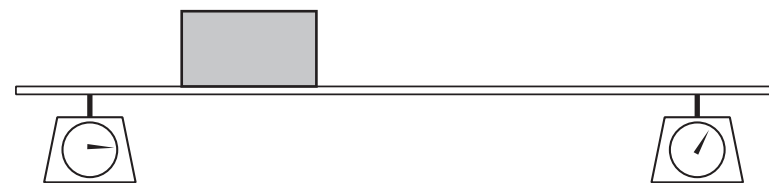
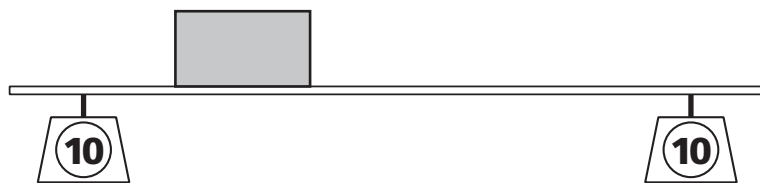
# Lecture demonstrations

answers given

20% of students



10% of students



independent of position

qualitative reasoning

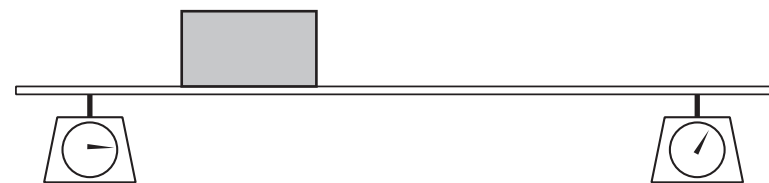
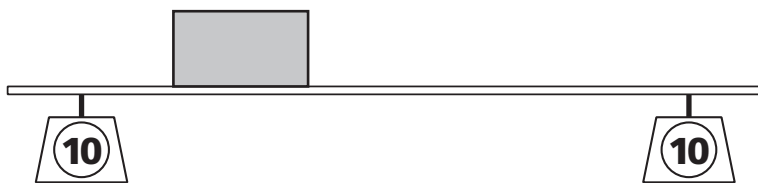
# Lecture demonstrations

answers given

20% of students



10% of students



independent of position

qualitative reasoning

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

# Lecture demonstrations

---

<b>mode</b>	<b>correct</b>	<b>incorrect</b>
<b>no demo</b>	<b>30%</b>	<b>70%</b>
<b>observe</b>	<b>18%</b>	<b>82%</b>
<b>predict</b>	<b>29%</b>	<b>71%</b>
<b>discuss</b>	<b>30%</b>	<b>70%</b>

---

# Lecture demonstrations

---

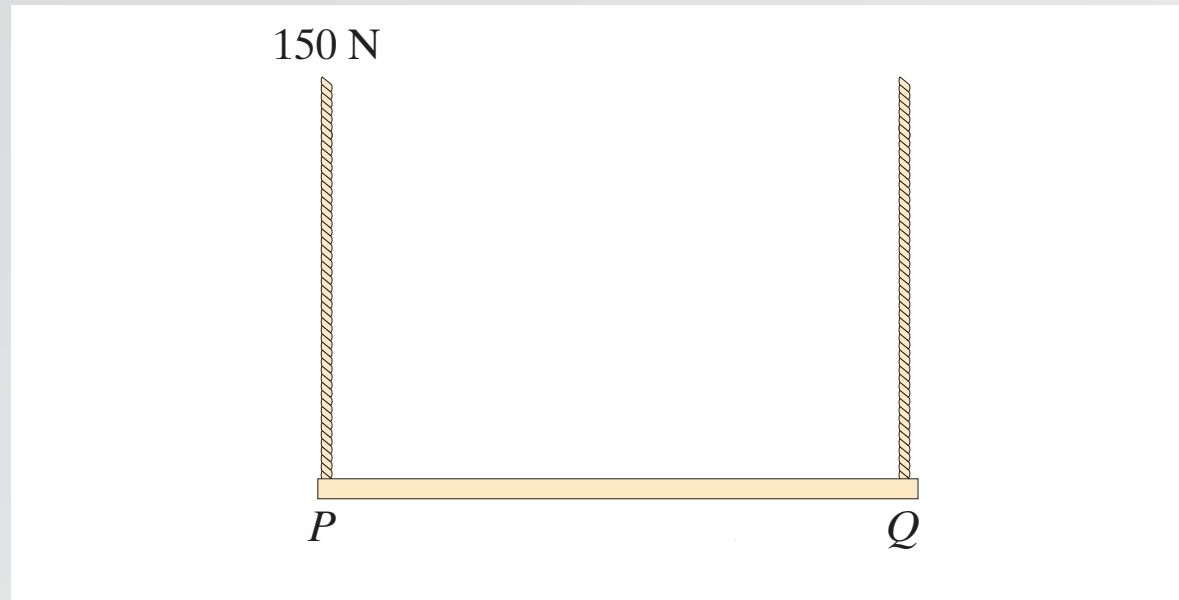
mode	correct	incorrect
no demo	30%	70%
<b>observe</b>	<b>18%</b>	<b>82%</b>
predict	29%	71%
discuss	30%	70%

---

**just presenting harmful?**

# Lecture demonstrations

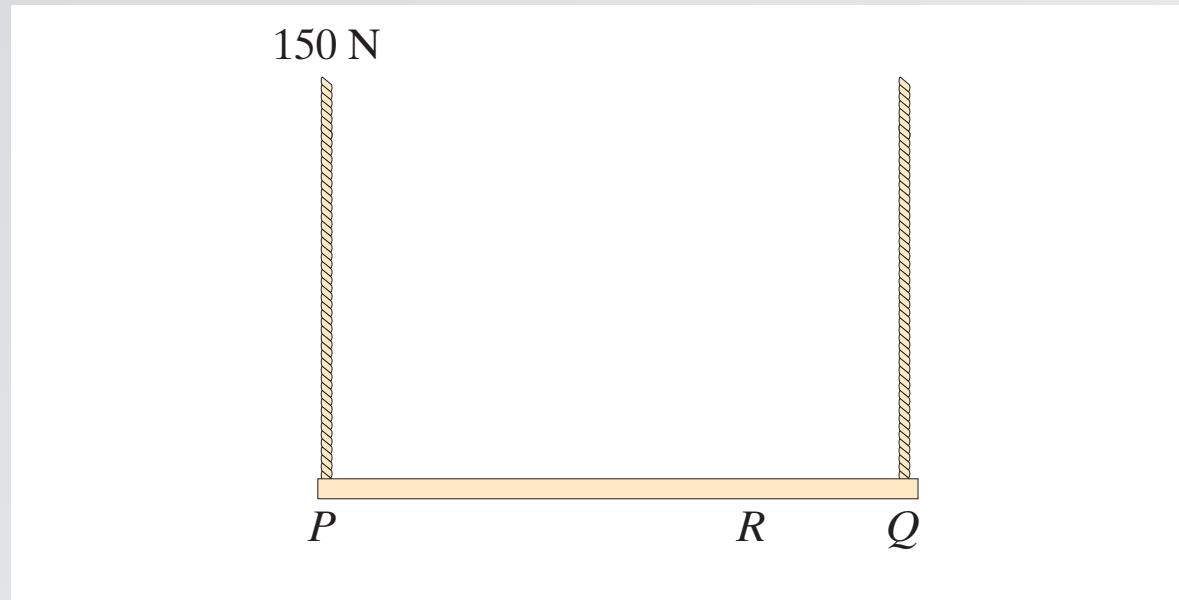
## exam question



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

# Lecture demonstrations

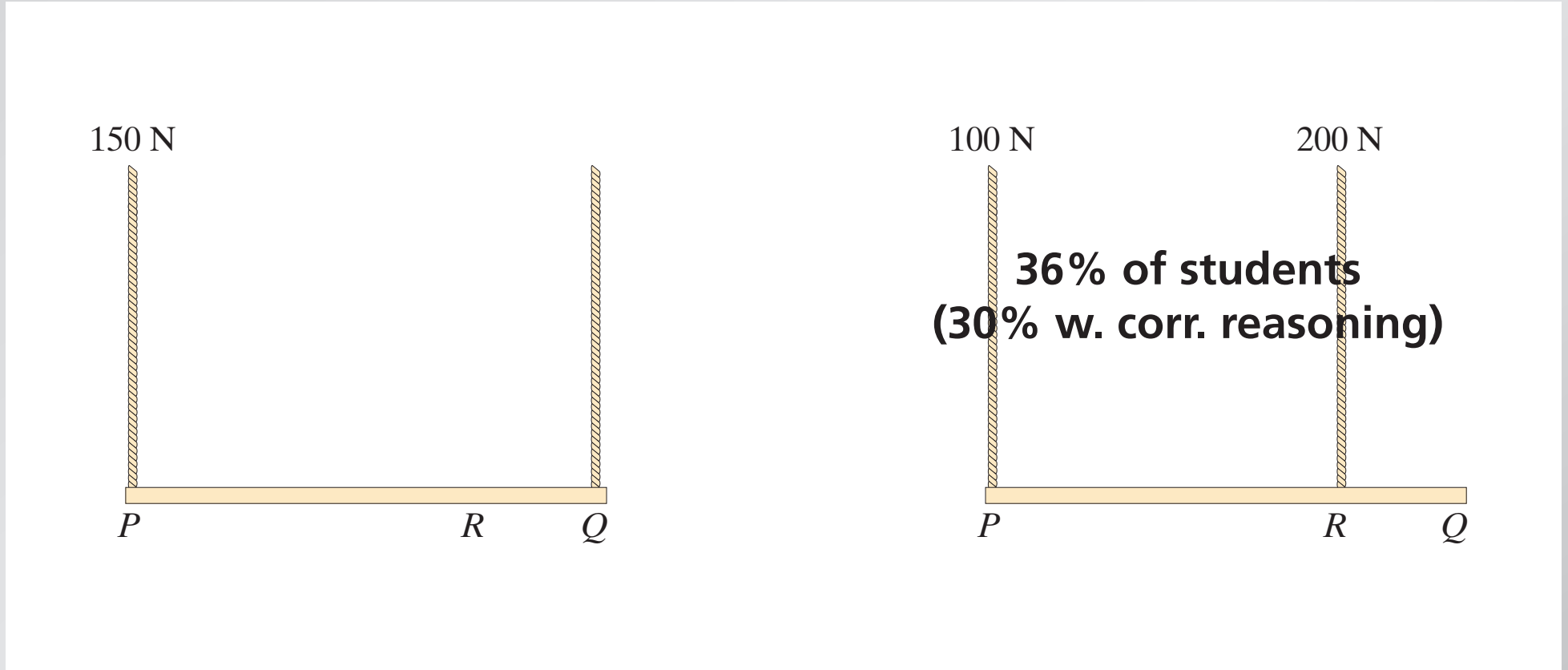
## exam question



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

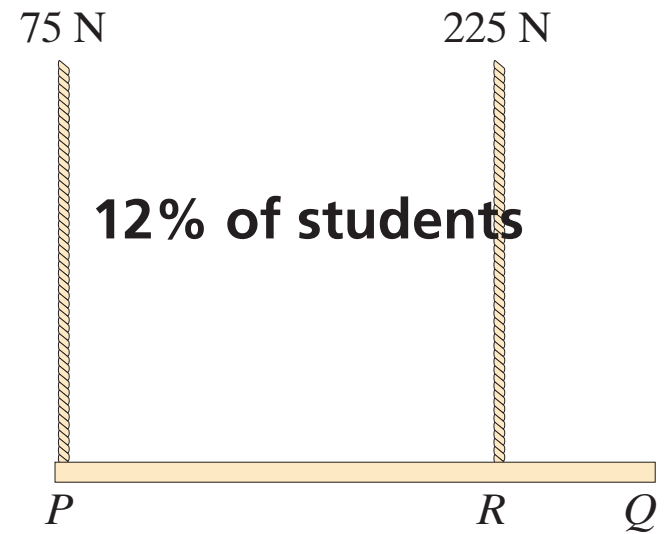
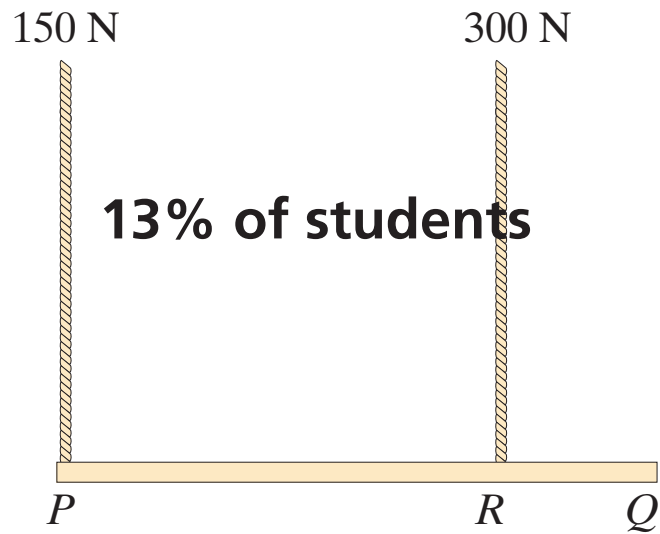


considerable improvement from online test



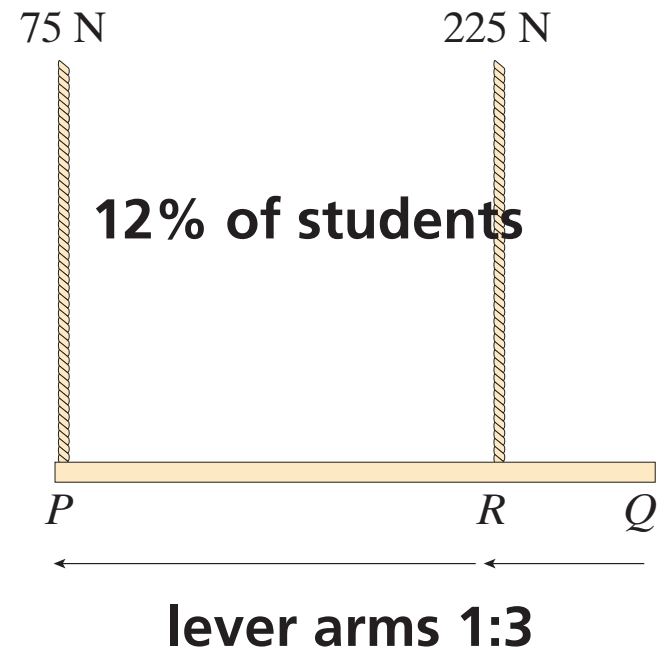
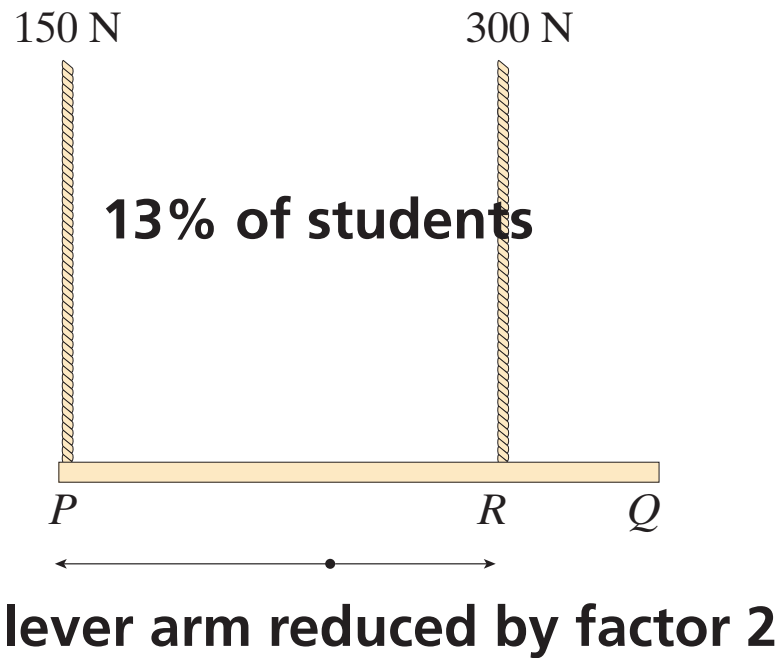
# Lecture demonstrations

incorrect answers



# Lecture demonstrations

incorrect answers

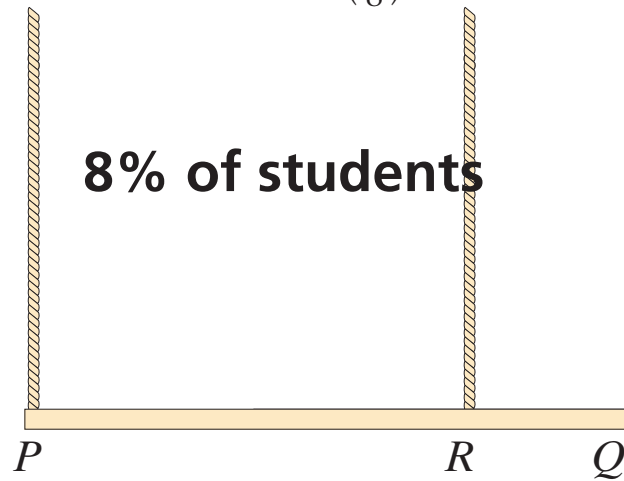


# Lecture demonstrations

## incorrect answers

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

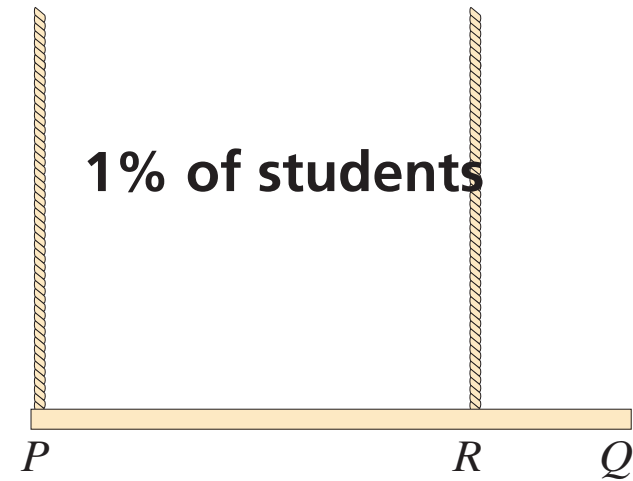
**8% of students**



$$112.5 \text{ N}$$

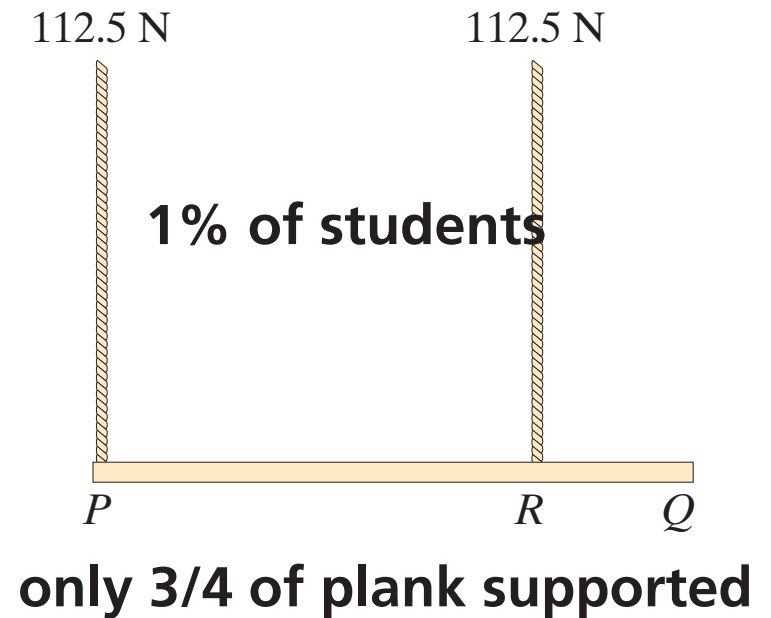
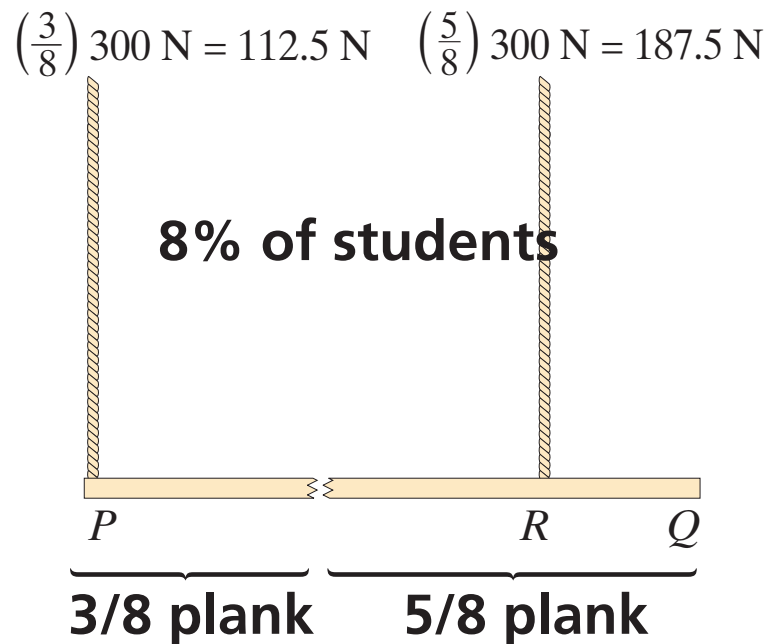
$$112.5 \text{ N}$$

**1% of students**



# Lecture demonstrations

incorrect answers



who would have thought??

# Lecture demonstrations

---

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

---

# Lecture demonstrations

aggregate results for seven demonstrations

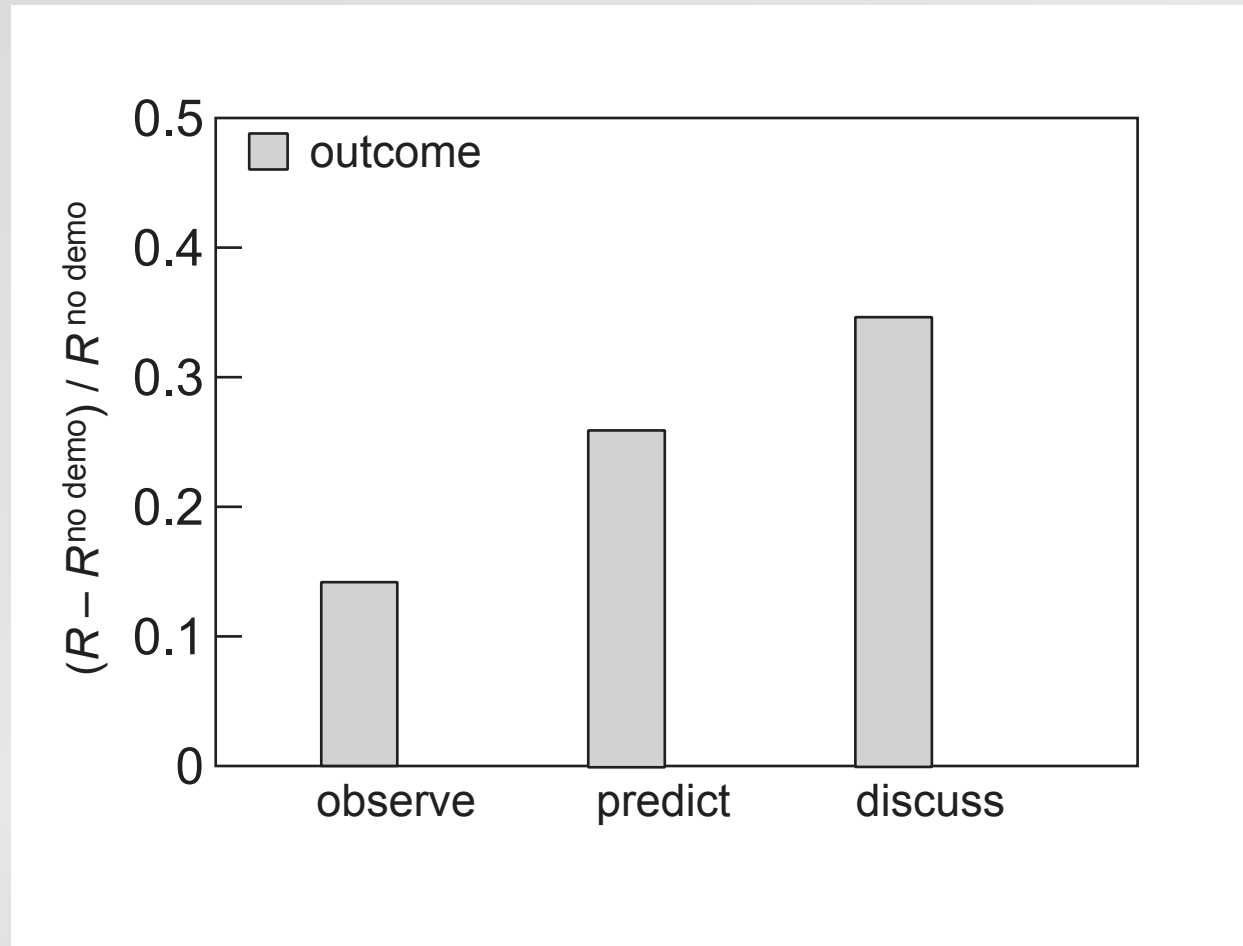
---

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

---

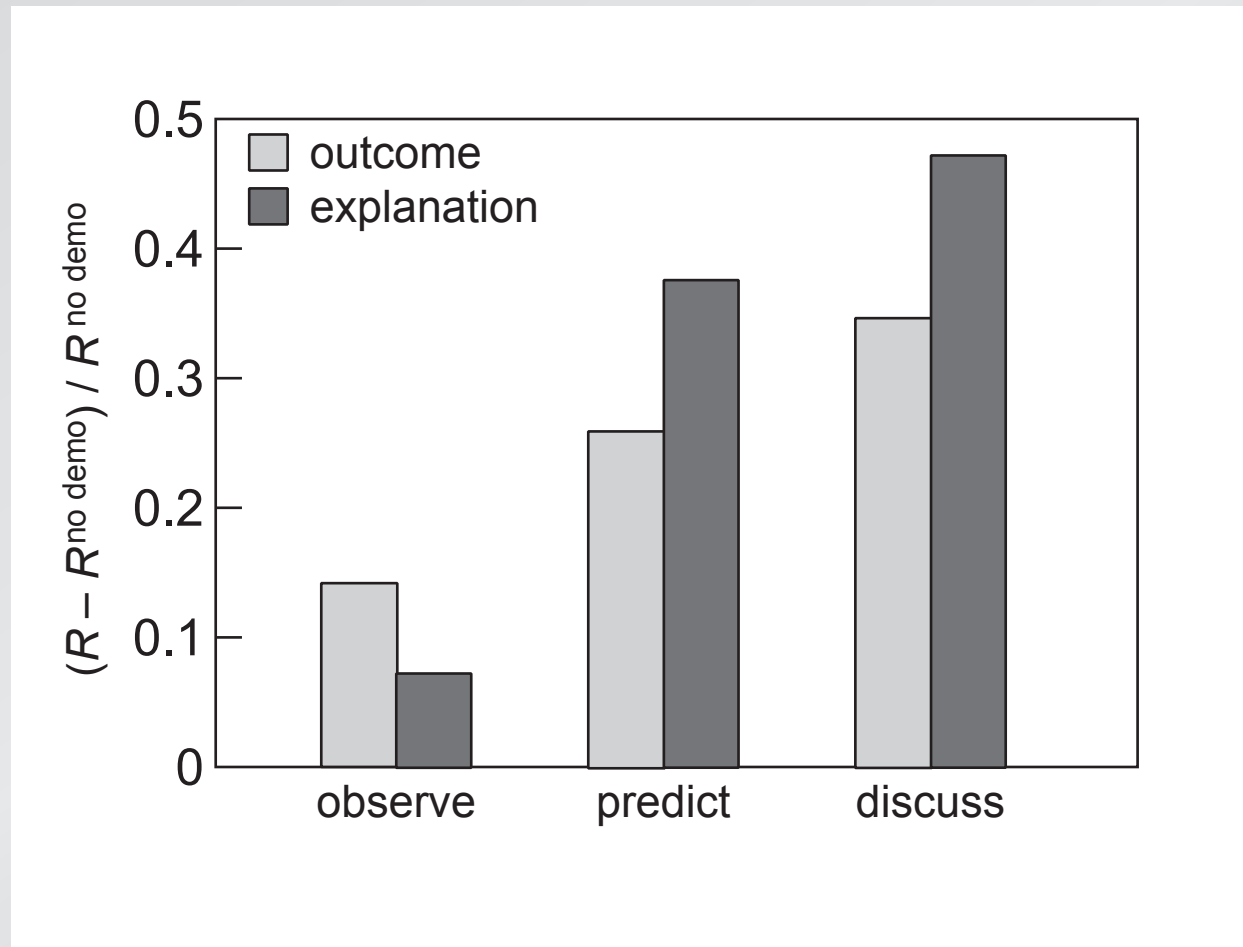
# Lecture demonstrations

improvement correlates with engagement



# Lecture demonstrations

improvement correlates with engagement





# Lecture demonstrations

**Points to keep in mind:**

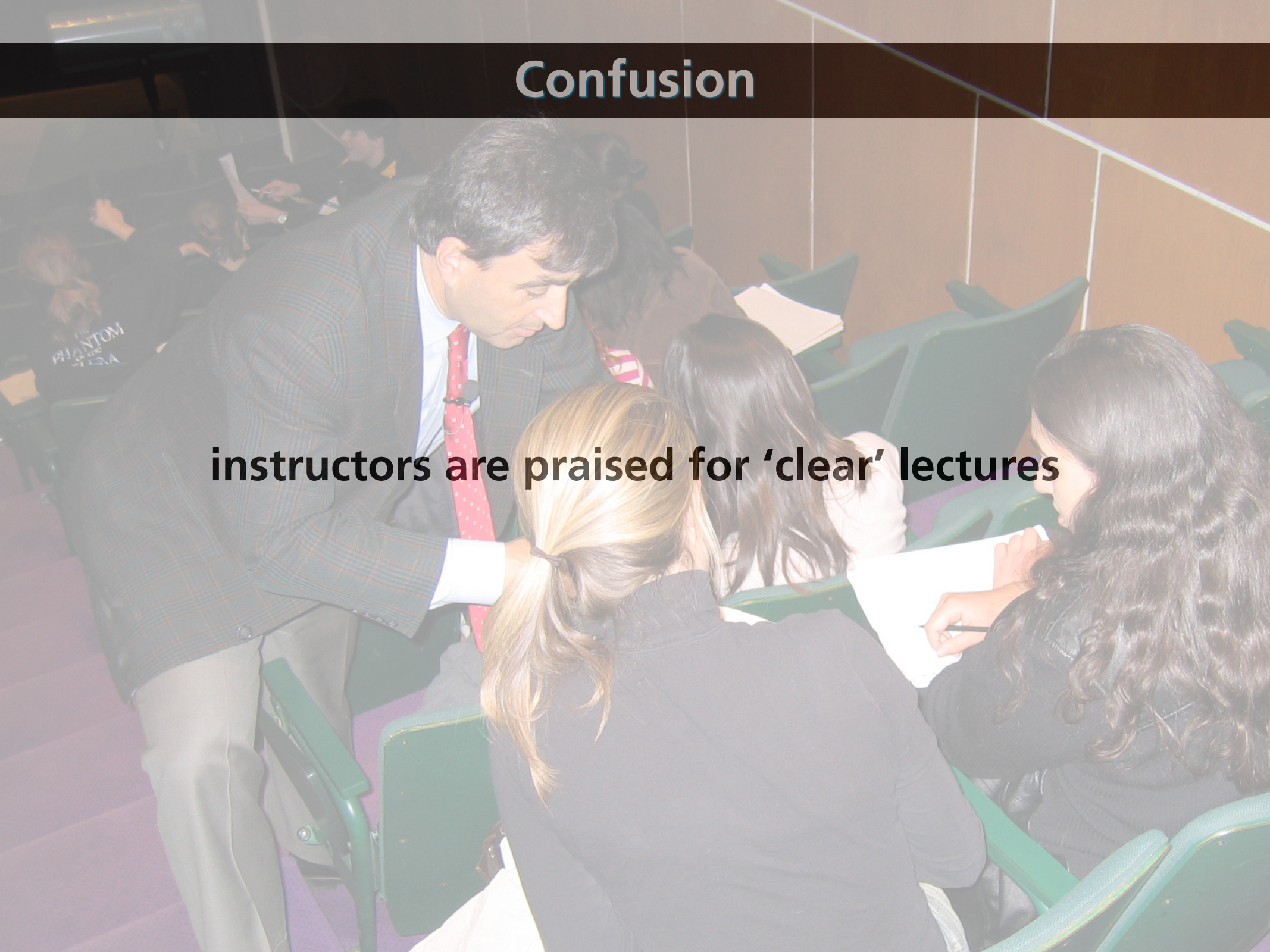
- **demonstrations without engagement not very helpful**
- **results can be improved by having students predict outcome**

# Confusion



# Confusion

**instructors are praised for 'clear' lectures**



# Confusion

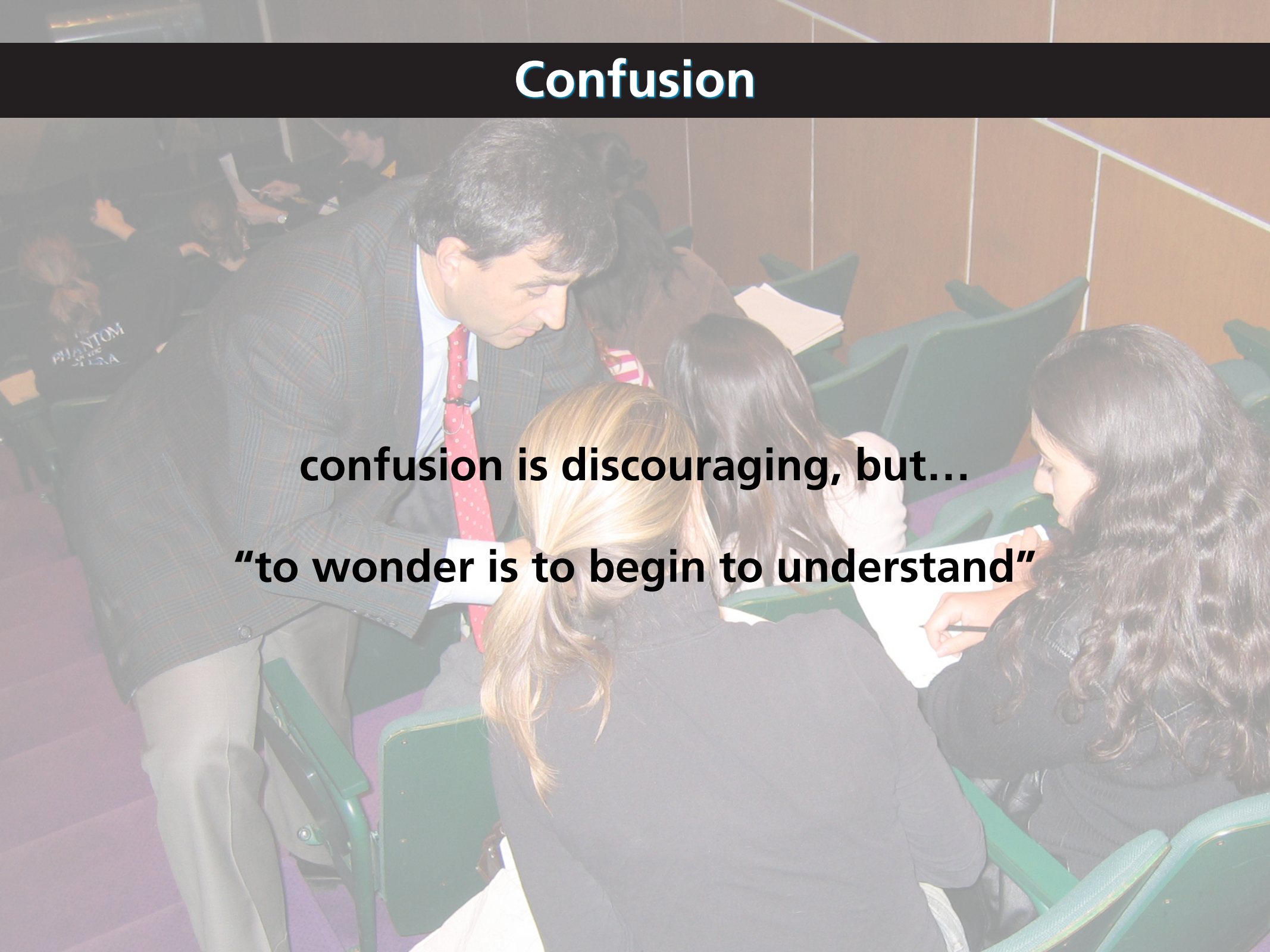
**confusion is discouraging, but...**

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 the wooden paneling of the room.

# Confusion

**confusion is discouraging, but...**

**“to wonder is to begin to understand”**



# Confusion

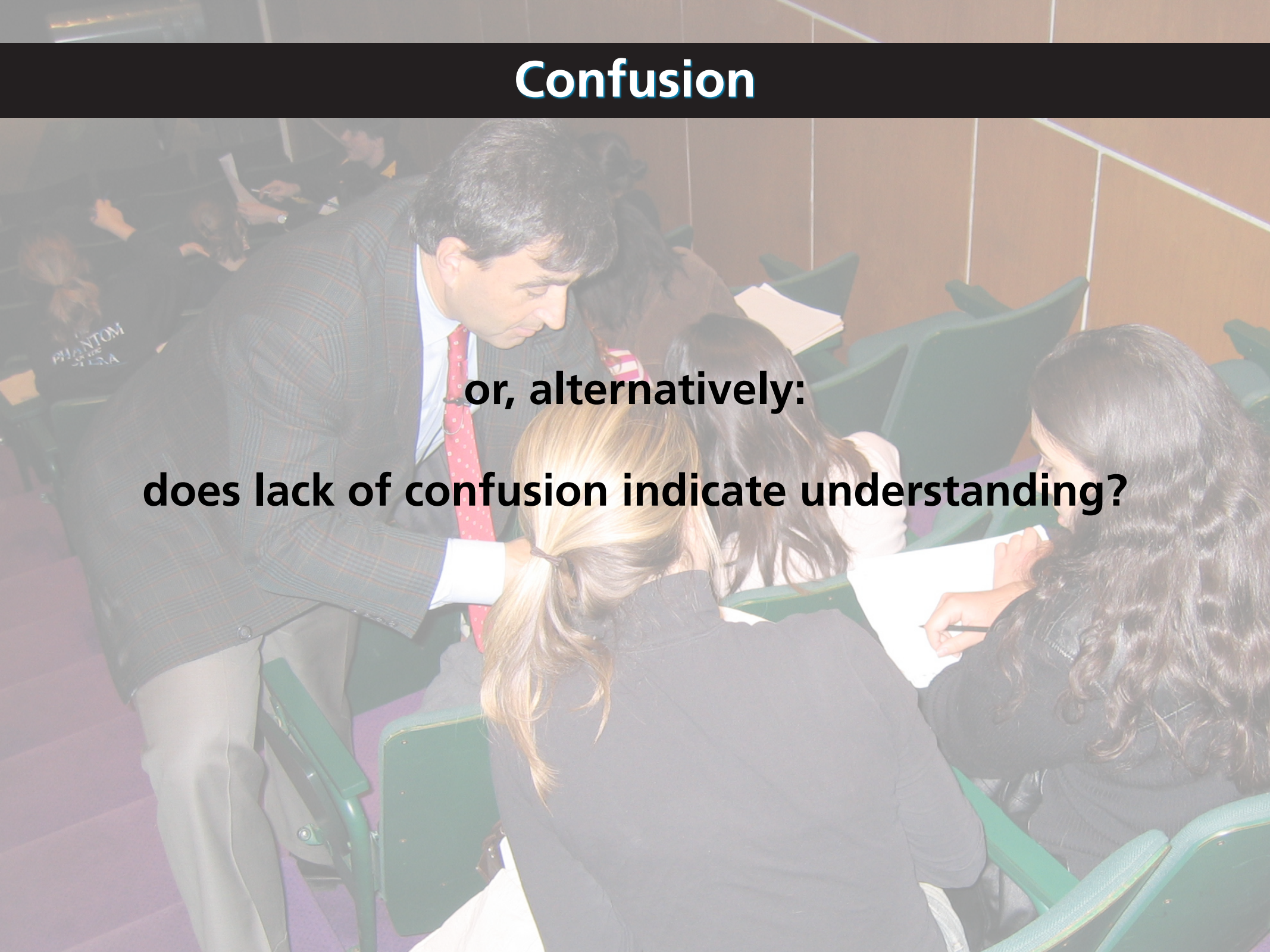
**does confusion indicate lack of understanding?**

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:**

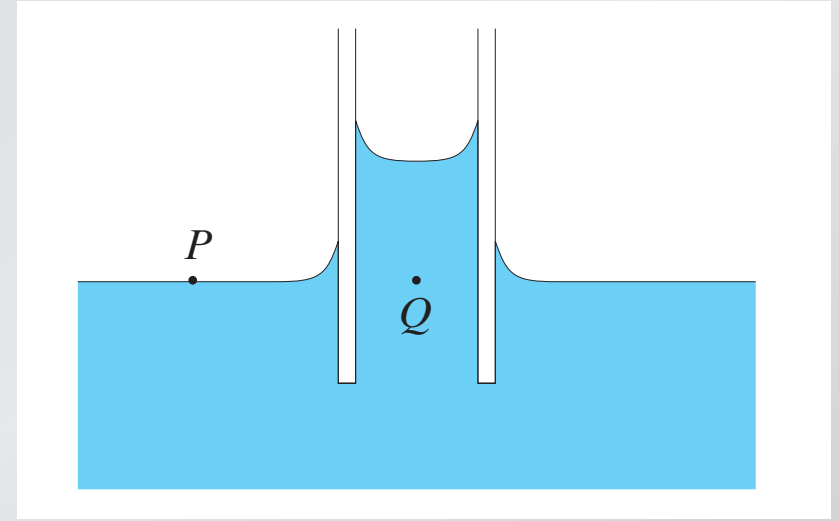
- **two questions on content (difficult!)**
- **one feedback question**

**analyze understanding and confusion**

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

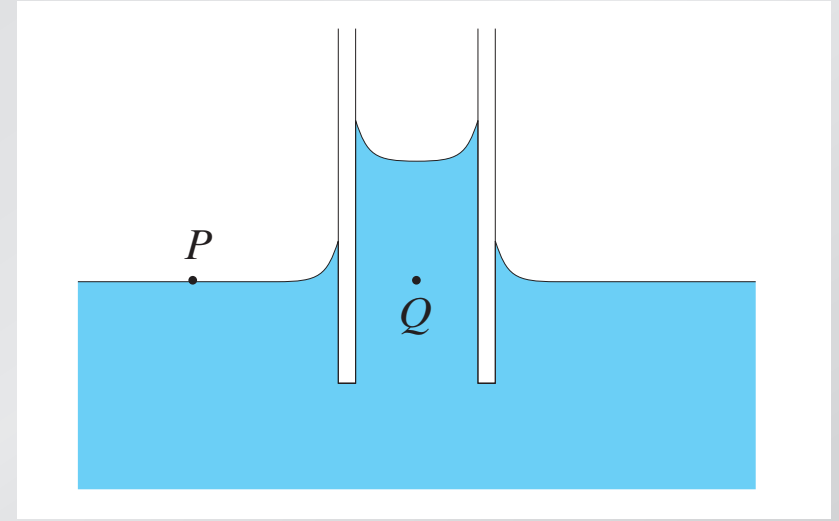
# Confusion

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?

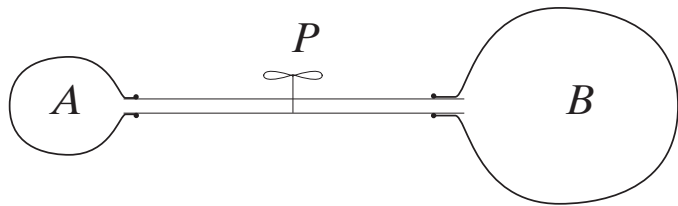


# Confusion

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

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

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

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

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.

# 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.

# 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.

# 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.

# 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

---

<b>torque</b>	<b>correct</b>	<b>incorrect</b>
<b>confused</b>	<b>45%</b>	<b>55%</b>
<b>not confused</b>	<b>43%</b>	<b>57%</b>

---

# Confusion

using research-based text

---

<b>torque</b>	<b>correct</b>	<b>incorrect</b>
<b>confused</b>	<b>45%</b>	<b>55%</b>
<b>not confused</b>	<b>43%</b>	<b>57%</b>

---

**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!**

## **Acknowledgments:**

**Catherine Crouch**

**Mercedes Lorenzo**

**Paul Callan**

**Adam Fagen**

**Jessica Watkins**

**Emily Fair Oster**

**Pat and Ken Heller (UMN)**

**Laura McCullough (UMN)**

**Steve Pierson (WPI)**

**Tom Keil (WPI)**

**Funding:**

**National Science Foundation**

**for a copy of this presentation:**

**<http://mazur-www.harvard.edu>**

**[http://twitter.com/eric\\_mazur](http://twitter.com/eric_mazur)**