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

ICER 2011
Rhode Island College
Providence, RI, 9 August 2011
Education
Education

lectures focus on delivery of information
not transfer but assimilation of information is key
let’s not abandon the scientific method when teaching
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 postest scores

average score (%)

0 20 40 60 80 100

women  men
Gender issues

Force Concept Inventory postest scores

Gender gap

average score (%)
Gender issues

Force Concept Inventory postest scores

![Graph showing gender gap in score between men and women at UMN. Men have a higher average score than women, with a gender gap of 20%.]

- Gender gap: 20%
- Average score:
  - Men: 80%
  - Women: 60%

Gender gap:
- 20% average score
Gender issues

Force Concept Inventory postest scores

<table>
<thead>
<tr>
<th>Gender Gap (%)</th>
<th>UMN</th>
<th>Harvard</th>
<th>WPI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender Gap (%)</td>
<td>20</td>
<td>15</td>
<td>10</td>
</tr>
</tbody>
</table>

- UMN: 0
- Harvard: 15
- WPI: 10

Average scores (%):
- Men: 80
- Women: 60
Gender issues

what causes this gap?
Gender issues

is it cultural?

![Gender Gap Chart](chart.png)

**FCI posttest**

- **US**: 10% gender gap (%)
Gender issues

![Gender Gap Chart](image)

- US: FCI posttest
- Belgium: FCI posttest

Gender gap (%)

- US: 10%
- Belgium: 20%
Gender issues

strong dependence on culture!

![Bar chart showing gender gap (%)](chart.png)

- US
- Belgium
- Taiwan

FCI posttest
Gender issues

effect of precollege education

![Bar chart showing average scores for women and FCI pretest with different levels of education (none, HS, AP)].
Gender issues

everyone gains...

![Bar chart showing average scores in FCI pretest and men categories for none, HS, and AP levels.](chart.png)
Gender issues

...but gap persists...
Gender issues

...and women underrepresented

![Bar chart showing average scores for none, HS, and AP levels with gender comparison.](chart.png)
Gender issues

what can we do?
Gender issues increase collaboration and interactivity
Gender issues

Compare three pedagogies:

T: traditional lectures

I: interactive lectures

I*: interactive assignments, lectures, and tutorials
Gender issues

does pedagogy help?

![Bar chart showing average scores for women and FCI pretest](chart.png)

- T
- IE
- IE+

Average score (%)
Gender issues

does pedagogy help?

<table>
<thead>
<tr>
<th></th>
<th>T</th>
<th>IE</th>
<th>IE+</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>women</strong></td>
<td>70%</td>
<td>60%</td>
<td>60%</td>
</tr>
<tr>
<td><strong>men</strong></td>
<td>60%</td>
<td>60%</td>
<td>60%</td>
</tr>
</tbody>
</table>

average score (%)
Gender issues

does pedagogy help?

![Bar chart showing FCI posttest average scores for T, IE, and IE+ groups. The average scores are approximately 70%, 85%, and 90% respectively.](chart.png)
Gender issues

yes, pedagogy can eliminate gap!

Gender issues

who are the low-gain students?

pretest: □ 70% □
posttest: □ 90%

20% gain

pretest score (%)
gain (%)
Gender issues

traditional class

![Graph showing the relationship between gain and pretest score for women in a traditional class. The graph illustrates a negative correlation between the two variables.]
Gender issues

traditional class

![Graph showing gender issues in a traditional class](image)

- **Gain (%)** against **Pretest Score (%)**
  - Data points for **women** and **men**
  - Line indicating a trend in performance based on pretest scores
Gender issues

traditional class: gender imbalance

![Graph showing gender imbalance in traditional classes. The graph plots pretest score (%) against gain (%). The data points for women are represented by circles, and the data points for men are represented by triangles. The graph illustrates a trend of lower gains for men compared to women at higher pretest scores.](image-url)
Gender issues

interactive class

![Graph showing the relationship between pretest score (%) and gain (%). The graph compares men (red triangles) and women (purple circles). The line of best fit suggests a negative correlation between pretest score and gain.](image-url)
Gender issues

interactive class: gender balance

![Graph showing the relationship between pretest score and gain. The graph compares men and women, with women generally showing a higher gain for lower pretest scores.](image)
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

24% of students

20 0

15 5

correct (mentions torque)
Lecture demonstrations

answers given

24% of students

Correct (mentions torque)

38% of students

Proportional reasoning
Lecture demonstrations

10% of students

20% of students

independent of position

qualitative reasoning

answers given
Lecture demonstrations

20% of students

10% of students

Independent of position

Qualitative reasoning

6%: forces not balanced; 2%: other incorrect
## Lecture demonstrations

<table>
<thead>
<tr>
<th>mode</th>
<th>correct</th>
<th>incorrect</th>
</tr>
</thead>
<tbody>
<tr>
<td>no demo</td>
<td>30%</td>
<td>70%</td>
</tr>
<tr>
<td>observe</td>
<td>18%</td>
<td>82%</td>
</tr>
<tr>
<td>predict</td>
<td>29%</td>
<td>71%</td>
</tr>
<tr>
<td>discuss</td>
<td>30%</td>
<td>70%</td>
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</tbody>
</table>
## Lecture demonstrations

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<tr>
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<td>30%</td>
<td>70%</td>
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just presenting harmful?
A uniform plank is supported by two ropes at points $P$ and $Q$. The tension in the rope at $P$ is 150 N.
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

13% of students

12% of students
Lecture demonstrations

incorrect answers

lever arm reduced by factor 2

lever arms 1:3

13% of students

12% of students

150 N

300 N

75 N

225 N
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

1% of students
Lecture demonstrations

incorrect answers

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

3/8 plank 5/8 plank

8% of students 1% of students

only 3/4 of plank supported

who would have thought??
## Lecture demonstrations

<table>
<thead>
<tr>
<th>mode</th>
<th>correct</th>
<th>balances torques</th>
<th>no clear reasoning</th>
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</thead>
<tbody>
<tr>
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<td>31%</td>
<td>53%</td>
<td>42%</td>
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<tr>
<td>observe</td>
<td>42%</td>
<td>55%</td>
<td>42%</td>
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<tr>
<td>predict</td>
<td>41%</td>
<td>65%</td>
<td>32%</td>
</tr>
<tr>
<td>discuss</td>
<td>46%</td>
<td>85%</td>
<td>15%</td>
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</table>
Lecture demonstrations

aggregate results for seven demonstrations

<table>
<thead>
<tr>
<th>mode</th>
<th>$N$</th>
<th>$R_{\text{outcome}}$</th>
<th>$R_{\text{explanation}}$</th>
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</thead>
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<tr>
<td>no demo</td>
<td>297</td>
<td>61%</td>
<td>22%</td>
</tr>
<tr>
<td>observe</td>
<td>220</td>
<td>70%</td>
<td>24%</td>
</tr>
<tr>
<td>predict</td>
<td>179</td>
<td>77%</td>
<td>30%</td>
</tr>
<tr>
<td>discuss</td>
<td>158</td>
<td>82%</td>
<td>32%</td>
</tr>
</tbody>
</table>
Lecture demonstrations

improvement correlates with engagement

Lecture demonstrations

improvement correlates with engagement

Points to keep in mind:

- demonstrations without engagement not very helpful
- results can be improved by having students predict outcome
Confusion
instructors are praised for ‘clear’ lectures
confusion is discouraging, but...
confusion is discouraging, but...

“to wonder is to begin to understand”
Confusion

does confusion indicate lack of understanding?
Confusion

or, alternatively:

does lack of confusion indicate understanding?
Web-based free-response reading assignment:

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

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).
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?
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?
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.
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.
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Sample answer

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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.
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
traditional textbook on Laplace’s law and capillarity

<table>
<thead>
<tr>
<th>capillarity</th>
<th>correct</th>
<th>incorrect</th>
</tr>
</thead>
<tbody>
<tr>
<td>confused</td>
<td>44%</td>
<td>56%</td>
</tr>
<tr>
<td>not confused</td>
<td>25%</td>
<td>75%</td>
</tr>
</tbody>
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Confusion

traditional textbook on Laplace’s law and capillarity

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</tbody>
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<table>
<thead>
<tr>
<th>Laplace</th>
<th>correct</th>
<th>incorrect</th>
</tr>
</thead>
<tbody>
<tr>
<td>confused</td>
<td>49%</td>
<td>51%</td>
</tr>
<tr>
<td>not confused</td>
<td>21%</td>
<td>79%</td>
</tr>
</tbody>
</table>
“Confused” students twice as likely correct!
<table>
<thead>
<tr>
<th>torque</th>
<th>correct</th>
<th>incorrect</th>
</tr>
</thead>
<tbody>
<tr>
<td>confused</td>
<td>45%</td>
<td>55%</td>
</tr>
<tr>
<td>not confused</td>
<td>43%</td>
<td>57%</td>
</tr>
</tbody>
</table>
Confusion

using research-based text

text compels students to think while reading

<table>
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</table>
More confusion among students who understand!
(especially when students are not pushed to think)
Confusion…

- doesn’t correlate with understanding
- is not (necessarily) the result of poor teaching
- is part of the learning process
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.harvard.edu

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