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

3rd Annual Conference of Educational Research Center
Brummana, Lebanon, 27 March 2011
Education
Introduction

If you were to give your students a reading assignment before your next class, what fraction of your students would complete it?
If you were to give your students a reading assignment before your next class, what fraction of your students would complete it?

1. (nearly) all of them
2. about three quarters
3. about half
4. about one quarter
5. not many
Introduction

WHY?
Education

why read if most lectures focus on information transfer?
education = information transfer?
Introduction

1. information transfer
1. information transfer
2. assimilation of information
Introduction

1. information transfer (easy)

2. assimilation of information (hard and left to student)
move information transfer out of classroom!
Introduction

move information transfer out of classroom!

(so we can help students assimilate the information in class)
Introduction

“Confessions of a converted lecturer”
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
• Gender issues

• Lecture demonstrations

• Confusion
Gender issues

Force Concept Inventory posttest scores

![Bar chart showing average scores for men and women](image)

- Men: 60% average score
- Women: 40% average score
Gender issues

Force Concept Inventory posttest scores

![Gender Gap Chart]

- **Average Score (%)**
  - Men: 80%
  - Women: 60%

Gender gap: 20%
Gender issues

Force Concept Inventory posttest scores

<table>
<thead>
<tr>
<th>Gender Gap (%)</th>
<th>UMN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Women</td>
<td></td>
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<tr>
<td>Men</td>
<td></td>
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</tbody>
</table>

Gender gap (%)

Average score (%)

<table>
<thead>
<tr>
<th>Gender</th>
<th>Average Score (%)</th>
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</thead>
<tbody>
<tr>
<td>Men</td>
<td></td>
</tr>
<tr>
<td>Women</td>
<td></td>
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</tbody>
</table>

Gender gap

Average score (%)
Gender issues

Force Concept Inventory postest scores

![Bar chart showing gender gap in postest scores between men and women across UMN, Harvard, and WPI. The gender gap is highest at UMN and lowest at Harvard.](image)
Gender issues

what causes this gap?
Gender issues

is it cultural?

FCI posttest

US

gender gap (%)
Gender issues

![Graph showing gender gap in US and Belgium](image)

- Gender gap (%)
- US
- Belgium
- FCI posttest
Gender issues

strong dependence on culture!
Gender issues

Effect of precollege education

![Bar chart showing average scores for women and FCI pretest.
Scores are as follows:
- FCI: none (around 20%), HS (around 50%), AP (around 70%).]
Gender issues

everyone gains...

![Bar chart showing average scores for FCI pretest and men, with categories none, HS, AP. Each category has two bars, one purple and one red, indicating varying scores.](chart.png)
Gender issues

...but gap persists...
Gender issues

...and women underrepresented

![Bar chart showing average scores for different groups.](image-url)
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?

average score (%)

women  FCI pretest

0 20 40 60 80 100

T  IE  IE+
Gender issues

does pedagogy help?

![Bar chart showing average scores (%)]

- **Women**
  - T: 80%
  - IE: 70%
  - IE+: 60%

- **Men**
  - T: 60%
  - IE: 70%
  - IE+: 60%
Gender issues

does pedagogy help?

![Bar chart showing FCI posttest scores for T, IE, and IE+ categories. The average score ranges from 0 to 100%.]
Gender issues

yes, pedagogy can eliminate gap!

Gender issues

who are the low-gain students?

![Graph showing pretest and posttest scores with a 20% gain.]
Gender issues

traditional class

![Scatter plot showing the relationship between pretest score (%) and gain (%). The data points represent women. The graph shows a downward trend as the pretest score increases.](image-url)
Gender issues

traditional class

![Graph showing gain vs pretest score for women and men in a traditional class setting. The graph illustrates a negative correlation between pretest score and gain.]
Gender issues

class: gender imbalance

![Graph showing gains against pretest scores for men and women. The graph illustrates a negative correlation between pretest score and gain, indicating that higher pretest scores are associated with lower gains. The data points for women are generally higher than those for men, indicating a gender imbalance in gains.](image)
Gender issues

interactive class

![Graph showing the relationship between pretest score and gain for men and women.](image)
Gender issues

interactive class: gender balance

![Graph showing gender balance](image-url)
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

Diagram: Balancing scales with weights and question marks.
Lecture demonstrations

answers given

24% of students

correct (mentions torque)
Lecture demonstrations

answers given

24% of students

\[ \begin{array}{c}
20 \\
(\text{correct (mentions torque)})
\end{array} \]

38% of students

\[ \begin{array}{c}
20 \\
(\text{proportional reasoning})
\end{array} \]

15

5
Lecture demonstrations

answers given

20% of students

10% of students

independent of position

qualitative reasoning
Lecture demonstrations

answers given

20% of students

20% \(\frac{10}{10}\) independent of position

10% of students

10% \(\frac{10}{10}\) qualitative reasoning

6%: forces not balanced; 2%: other incorrect
<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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<td>70%</td>
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</table>

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

<table>
<thead>
<tr>
<th>mode</th>
<th>correct</th>
<th>balances torques</th>
<th>no clear reasoning</th>
</tr>
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<tbody>
<tr>
<td>no demo</td>
<td>31%</td>
<td>53%</td>
<td>42%</td>
</tr>
<tr>
<td>observe</td>
<td>42%</td>
<td>55%</td>
<td>42%</td>
</tr>
<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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<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>
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<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>
improvement correlates with engagement

improvement correlates with engagement

![Graph showing improvement correlates with engagement](image-url)

\[ \frac{R - R_{\text{no demo}}}{R_{\text{no demo}}} \]

*Am. J. Phys. 72, 835 (2004)*
Points to keep in mind:

• demonstrations without engagement not very helpful

• results can be improved by having students predict outcome
instructors are praised for ‘clear’ lectures
confusion is discouraging, but...
Confusion

confusion is discouraging, but...

“to wonder is to begin to understand”
Confusion

does confusion indicate lack of understanding?
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

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.
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

<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>
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</table>
Confusion

traditional textbook on Laplace’s law and capillarity

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<table>
<thead>
<tr>
<th>Laplace</th>
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</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!
Confusion

using research-based text

<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>
<thead>
<tr>
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<td>43%</td>
<td>57%</td>
</tr>
</tbody>
</table>
Confusion

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
Conclusion

- active engagement essential for learning
- confusion likely to increase
Conclusion

• active engagement essential for learning
• confusion likely to increase

classroom data vital to improving education!
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