Interactive Learning: Using Research to Promote Student Understanding in the Science Classroom

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La recherche peut être effectuée sur l'efficacité de notre enseignement?

Can research be done on the effectiveness of our instruction?
La réponse

Oui. Les résultats montrent que le discours seul n'est pas le moyen le plus efficace d'enseigner aux étudiants les concepts de base en sciences.

Yes, and the results show that lecture alone is not the most effective way to teach students basic concepts in science.
Quelques citations pour encadrer la discussion

Some Quotes to Frame Our Discussion
Car l'esprit n'est pas comme un vase qu'il ne faille que remplir. À la façon du bois, il a plutôt besoin d'un aliment qui l'échauffe, qui fait naître en lui une impulsion inventive et l'entraîne avidement en direction de la vérité.

A mind is a fire to be kindled, not a vessel to be filled

Plutarch
Ce n'est pas que le professeur fait qui a d'importance ; plutôt, c'est que les étudiants font

It's not what the teacher does that matters; rather, it is what the students do
L'erreur pédagogique fatale est de donner des réponses aux étudiants qui n'ont pas des questions

The fatal pedagogical error is to give answers to students who do not yet have questions
What are clickers?

- Classroom response systems ("clickers") are remote controls which can submit answers to the instructor’s computer via an RF receiver.
- The instructor can see the results of the student responses in real time.
- These results can also be displayed graphically.
- Clickers are used to provide the instructor (and students) with real-time feedback about student understanding of a topic or concept.
Let’s try them out

Which of the following best describes you?

A) Scientific researcher
B) Instructor at a Université
C) Instructor at a Lycée
D) Instructor at a Collège
E) More than one of these apply to me
La présentation

• Why do research into student learning?
• What does the research show?
  – The Force Concept Inventory
  – Research in Astronomy
• What is Interactive Learning?
  – Think-pair-share (TPS) questions
  – Lecture Tutorials and Ranking Tasks
• Final thoughts
Nous avons fait des cours de la même façon depuis longtemps...

We’ve been teaching the same way for a long time...

2000 years ago

Comment efficace est-on ?
How effective are we?

Today
Un peu d’histoire

- Eric Mazur is a laser physicist at Harvard University
- In 1990, he began to take an interest in the learning in his introductory physics classes
- Why?
Trouver le pouvoir livré à chaque résistance
Find the power delivered to each resistor
Le circuit en dessous consiste en deux ampoules identiques qui brillent de façon égale et une pile de 12 V. Quand le commutateur est fermé, l'éclat d'ampoule A augmente.

The circuit below consists of two identical light bulbs burning with equal brightness and a single 12 V battery. When the switch is closed, the brightness of bulb A increases.

(a) augmente (increases)

(b) reste le même (remains unchanged)

(c) diminue (decreases)
Development of the FCI

• To measure achievement in the classroom, it is necessary to do a pre-instruction and post-instruction assessment
• In Physics, the most common topic studied is mechanics
• In 1992, Hestenes et al. developed the *Force Concept Inventory*, a 30-question multiple-choice survey on the basic concepts of Newton’s Laws
• This assessment tool is written in plain language to avoid biasing the results due to jargon
• The FCI is now widely used as the standard measure of students’ learning in introductory Physics classes

Example questions from the FCI

A steel ball is attached to a string and is swung in a circular path in a horizontal plane as illustrated in the accompanying figure.

At the point P indicated in the figure, the string suddenly breaks near the ball.

If these events are observed from directly above as in the figure, which path would the ball most closely follow after the string breaks?
A bowling ball accidentally falls out of the cargo bay of an airliner as it flies along in a horizontal direction.

As observed by a person standing on the ground and viewing the plane as in the figure at right, which path would the bowling ball most closely follow after leaving the airplane?
Example questions from the FCI

The figure below shows a boy swinging on a rope, starting at a point higher than A. Consider the following distinct forces:

1. A downward force of gravity.
2. A force exerted by the rope pointing from A to O.
3. A force in the direction of the boy’s motion.
4. A force pointing from O to A.

Which of the above forces is (are) acting on the boy when he is at position A?

(A) 1 only.
(B) 1 and 2.
(C) 1 and 3.
(D) 1, 2, and 3.
(E) 1, 3, and 4.
Example questions from the FCI

The positions of two blocks at successive 0.20-second time intervals are represented by the numbered squares in the figure below. The blocks are moving toward the right.

Do the blocks ever have the same speed?

(A) No.
(B) Yes, at instant 2.
(C) Yes, at instant 5.
(D) Yes, at instants 2 and 5.
(E) Yes, at some time during the interval 3 to 4.
Normalized gain, $g$

- Normalized gain, $g$, is a measure of student learning.
- It is the fraction of knowledge the student did not yet have that he or she learned in the class.
- For example, if pre = 40% and post = 70% then $g = (70-40/100-40) = 30/60 = 0.5$.

$$g = \frac{\text{post}\% - \text{pre}\%}{100\% - \text{pre}\%}$$
What did Mazur find?

Force Concept Inventory
Normalized Gain = (post - pre) / (100 - pre)

Students learned only 25% of the material they didn’t already know!

What did Mazur find?

The following year, the students did twice as well on the FCI. Why?

He introduced interactive learning into his classroom!

Continued use led to higher gains

Force Concept Inventory

Normalized Gain = (post - pre) / (100 - pre)

A U.S. Study by Hake

- Similar findings were found in a large meta-study by Hake*
- Hake’s study:
  - Focused on introductory Physics classes (primarily college level)
  - Included over 6000 students
  - Was national in scope
  - Used the FCI pre- and post-instruction to gauge the level of student learning
  - Compared traditional lecture-based courses to those incorporating interactive learning strategies (self-reported)

\( g > 0.7 \) "High"

\( g = \frac{\text{post}\% - \text{pre}\%}{100\% - \text{pre}\%} \)

0.3 < \( g \) < 0.7 "Medium"

\( g < 0.3 \) "Low"

red = traditional, green = interactive engagement

We have done a similar study in Astronomy classes in the U.S.

- Topic was Light and Spectroscopy (LSCI)
- Almost 4000 students
- 31 institutions
- 36 instructors
- 69 different sections
  - Section sizes vary from <10 to 180


Demographic Survey

- The Light and Spectroscopy Concept Inventory (LSCI) was accompanied by 15 additional demographic questions to allow us to determine how such factors as
  - Gender
  - English as a native language
  - Socioeconomic background (parental income, education, etc.)
  - Overall GPA
  - Academic major
  - Number of prior science or astronomy courses
  - Level of mathematical preparation

interact with instructional style to influence student conceptual learning
We conducted a full multivariate model of our data, with 13 independent variables (12 demographic variables and interactivity) to explain one dependent variable: learning gain.

We found that, not surprisingly, a number of student characteristics (more years in college, more math and science background) led to higher gains.

Most importantly, we confirm that level of interactivity is the single most important variable in explaining the variation in gain, even after controlling for all other variables.
So what is Interactive Learning?
Interactive Learning is a tool that can change the way students learn!
A Commonly Held Inaccurate Model of Teaching and Learning
“Students enter your lecture hall with *preconceptions* about how the world works.

If their initial understanding is not engaged, they may fail to grasp the new concepts and information that are taught, or they may learn them for the purposes of a test but *revert to their preconceptions* outside the classroom”

*HOW PEOPLE LEARN*, National Research Council
A cautionary tale...

...about a violin

From Carl Weiman’s*
“Physics of Everyday Life”
class, Univ. of Colo.

*Nobel prize winner AND good teacher
Teaching is not telling...
Learning is not listening

- Weiman reports the following example of trying to teach how a violin works—that the body of a violin is essential for amplifying the sound of the strings
- Most students have the preconception that the strings make all the sound
- Explaining about sound and how a violin works, he shows the class a violin and tells them that the strings cannot move enough air to produce much sound, so actually the sound comes from the wood in the back
- 15 minutes later in the lecture he asked students a question—the sound they hear from a violin is produced
  a. mostly by the strings, b. mostly by the wood in the violin back, c. both equally, d. none of the above
Teaching is not telling... Learning is not listening

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15 minutes later in the lecture he asked students a question—the sound they hear from a violin is produced:

a. mostly by the strings, b. mostly by the wood in the violin back, c. both equally, d. none of the above.
What fraction of the students got the right answer?

A) 0%
B) 10%
C) 30%
D) 70%
E) 90%
B) Only 10% of students gave the correct answer.

Fifteen minutes later in the same lecture!
Teaching by telling is surprisingly ineffective...

...if you want student to master concepts.

Minds must be *active* to learn
To fully develop competence, students must:

1. have a deep foundation of factual knowledge,

2. understand interrelationships among facts and concepts, and

3. organize knowledge in ways that facilitate retrieval and application

A “metacognitive” approach to instruction can help students learn to take control of their own learning and monitor progress.

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How People Learn

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A “metacognitive” approach to instruction can help students learn to take control of their own learning and monitor progress.

Fundamental reasoning elements

- When children touch something on the stove, they learn that temperature increases as distance decreases.
- When children hear a car’s horn, they learn that sound intensity increases as distance decreases.
- When children see a bright flashlight, they learn that brightness increases as distance decreases.

=> CLOSE MEANS MORE

Phenomenological primitive or $p$-prim
Examples of how “p-prims” influence teaching and learning in science, (e.g., Astronomy)

<table>
<thead>
<tr>
<th>P-Prim</th>
<th>Reasoning Difficulty in Astronomy</th>
</tr>
</thead>
<tbody>
<tr>
<td>CLOSE MEANS MORE</td>
<td>It’s hotter in the summer because we are closer to the Sun</td>
</tr>
<tr>
<td>INTERFERENCE</td>
<td>I can’t see all of the Moon because the Earth is in the way</td>
</tr>
<tr>
<td>BRIGHTER MEANS HOTTER</td>
<td>All bright stars must be very hot</td>
</tr>
</tbody>
</table>

CLOSE MEANS MORE: All objects closer to the Earth mean more. The Earth is closest to the Sun in January, so in January it’s hotter. The Earth is farthest from the Sun in July, so in July it’s cooler.

INTERFERENCE: All bright stars mean interference. Bright stars, like the Sun, must be very hot in order to be bright. However, we can’t see the Earth or the Moon because of interference from the Sun. This is why we can’t see the entire Moon.
Conceptual Change Theory:

**Elicit → Confront → Resolve**

- Students’ beliefs about the physical world are often based on common sense and experience more than scientific reasoning.
- Effective instruction must force students to consciously examine their current conception and find some dissatisfaction with it.
- As students realize their existing knowledge inadequately explains phenomena, they will gradually re-craft their naïve ideas into more sophisticated scientific reasoning.
- Most people require some social interactions in order to learn deeply and effectively.
What is Interactive Learning?

- Interactive Learning is a set of strategies to get students *actively involved* in their learning
  - Think-Pair-Share Questions
  - Lecture Tutorials and Ranking Tasks
  - Interactive Demonstrations
- Interactive Learning uses a *combination* of lecture, real-time assessment, and peer interaction and instruction
- Research (including our study) has shown that Interactive Learning strategies lead to significant improvement in conceptual understanding by students compared with lecture alone
Think-Pair-Share (TPS) Questions

- Short (10-20 minute) lecture on topic
- “Think-Pair-Share” Question posed
- Students given time to think
- Students record individual answers
- Students discuss with their neighbors
- Students record revised answers
- Instructor leads class discussion

Adapted from Eric Mazur, “Peer Instruction: A user’s manual”
Votre belle-sœur appelle pour dire qu'elle va avoir des jumeaux fraternelles (non identiques). Lequel des résultats suivants est le plus probable?

A. Deux garçons
B. Un garçon et une fille
C. Deux filles
D. Ils ont tous la même probabilité
La Lune reste dans son orbite autour de la Terre au lieu de tomber sur la Terre parce que

A. la lune est en dehors de l'influence gravitationnelle de la Terre
B. la lune est en équilibre avec les forces gravitationnelles du Soleil et celles des autres planètes
C. la force nette sur la Lune est zéro
D. Aucune de ces réponses
E. Toutes les réponses sont justes
“Voici des fruits, des fleurs, des feuilles et des branches...”

Étant donné qu'un petit gland peut devenir un chêne puissant, lequel contribue la plupart de la masse à l'arbre ?

A. le sol (soil)
B. l’air (air)
C. l’eau (water)
D. la lumière du soleil (sunlight)
E. les minéraux dans le sol (minerals in the soil)
Peer Instruction Can Be Very Powerful

Before Peer Instruction
After Peer Instruction
Sometimes Further Teaching is Needed

Before Peer Instruction
After Peer Instruction
How do we know that peer instruction produces genuine learning, not just “copycat” behavior?

M. K. Smith et al. (U of Colorado, Science, Jan 2009)
Another form of Interactive Learning: *Lecture Tutorials*

Lecture Tutorials are Socratic-dialogue driven, highly structured collaborative activities designed to:

- Elicit misconceptions
- Confront naïve, incomplete or inaccurate ideas
- Questions go from straightforward to more conceptually difficult
- Common misconceptions are addressed directly and through “student debates”
- Require ~10-15 minutes and are easily implemented into traditional lecture courses

Cal Poly students enjoy working on a Lecture Tutorial
LECTURE-TUTORIALS FOR

introductory astronomy

Edward E. Prather, Timothy F. Slater, Jeffrey P. Adams, Gina Brissenden

AND THE CONCEPTUAL ASTRONOMY AND PHYSICS EDUCATION RESEARCH (CAPER) TEAM

SECOND EDITION
Lecture Tutorials Cover Topics Instructors Teach Most

- Position
- Motion
- Seasonal Stars
- Solar vs. Sidereal Day
- Ecliptic
- Kepler’s 2nd Law
- Kepler’s 3rd Law
- Newton’s Laws and Gravity
- Apparent and Absolute Magnitudes of Stars
- The Parsec
- Parallax and Distance
- Spectroscopic Parallax
- The Electromagnetic (EM) Spectrum of Light
- Telescopes and Earth’s Atmosphere
- Luminosity, Temperature and Size
- Blackbody Radiation
- Types of Spectra

- Light and Atoms
- Analyzing Spectra
- Doppler Shift
- The Cause of Moon Phases
- Predicting Moon Phases
- Path of Sun
- Seasons
- Observing Retrograde Motion
- Earth’s Changing Surface
- Temperature and Formation of Our Solar System
- H-R Diagram
- Star Formation and Lifetimes
- Binary Stars
- The Motion of Extrasolar Planets
- Stellar Evolution
- Milky Way Scales
- Galaxy Classification
- Looking at Distant Objects
- Expansion of the Universe
Idealized Classroom Implementation

- Professor lectures for approximately 20 minutes on core ideas of the topic to prepare students for working on the activity.
- Students are posed a conceptually challenging question on the presented lecture material to set the stage for the activity to come.
- Class is divided into pairs or small groups and instructed to work collaboratively and reach consensus on the questions presented in the lecture-tutorial activity.
- Students are often asked one or more TPS questions to help them assess where they are in understanding the topic.
- Professor may “debrief” the activity interactively highlighting the difficulties in reasoning and common problems.
- Professor returns to lecture mode on next course topic.
Research on a Lecture-Tutorial Approach to Teaching Introductory Astronomy for Non-Science Majors

- Pretest: 30%
- Post-Lecture: 52%
- Post-Lecture Tutorial: 72%

(N ~ 100)

Celestial Motion of Objects

You observe a star rising directly to the east. When this star reaches its highest position above the horizon, where will it be?

a) high in the northern sky
b) high in the eastern sky
c) **high in the southern sky**
d) high in the western sky
e) directly overhead

- Before Lecture (N=42): 2% correct
- After Lecture (N = 135): 19% correct
Celestial Motion of Objects

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b) high in the eastern sky
c) high in the southern sky
d) high in the western sky
e) directly overhead

• Before Lecture (N=42): 2% correct
• After Lecture (N = 135): 19% correct
• After Lecture Tutorial (N=134): 66% correct
The graph at right shows the blackbody spectra for three different stars. Which of the stars is at the highest temperature?

a) Star A
b) Star B
c) Star C

- Before Lecture (N=42): 12% correct
- After Lecture (N=120): 16% correct
The graph at right shows the blackbody spectra for three different stars. Which of the stars is at the highest temperature?

a) Star A  
b) Star B  
c) Star C

- Before Lecture (N=42): 12% correct  
- After Lecture (N=120): 16% correct  
- After Lecture Tutorial (N=80): 80% correct
What Causes Moon Phases

The diagram below shows Earth and the Sun as well as five different possible positions for the Moon. Which position of the Moon best corresponds with the phase of the Moon shown in the figure at the right?

- Before Lecture (N=42): 5% correct
- After Lecture (N=127): 53% correct
What Causes Moon Phases

The diagram below shows Earth and the Sun as well as five different possible positions for the Moon. Which position of the Moon best corresponds with the phase of the Moon shown in the figure at the right?

- Before Lecture (N=42): 5% correct
- After Lecture (N=127): 53% correct
- After Lecture Tutorial (N=104): 72% correct
Students are able to answer conceptually difficult questions after completing a Lecture Tutorial

Use the spectral curves for objects A-D shown below to answer the next three questions. The scale is the same for all four graphs.

24. Which, if any, of the other objects has the same temperature as object B?
   a. Object A.
   b. Object C.
   c. Object D.
   d. They are all the same temperature.
   e. There is insufficient information to answer this question.

25. Which, if any, of the objects could be approximately the same size as object D?
   a. Object A.
   b. Object B.
   c. Object C.
   d. They could all be the same size.
   e. None of the above.

26. Which of these objects is the smallest?
   a. Object A.
   b. Object B.
   c. Object C.
   d. Object D.
   e. More than one of these objects is the smallest.
Given the location marked with the dot on the star’s radial velocity curve, at which location would you expect to find the planet at this time?
Another form of interactive activity

For those of you who prefer to emphasize quantitative or mathematical reasoning:

**Ranking Tasks for Introductory Astronomy**
What is a Ranking Task?

- Ranking task exercises are based on a technique called rule assessment originated by Robert Siegler (1976).

- Typically, ranking tasks present learners with a series of four to eight pictures or diagrams that describe several slightly different variations of a basic physical situation.

- The student is then asked to make a comparative judgment and to identify the order or ranking of the various situations based on some physical outcome or result.

Consider the images of six different astronomical objects (A-F) below.

A. The Moon
B. The Sun
C. Spiral Galaxy
D. Neutron Star
E. Nebula
F. Solar System

Ranking Instructions: Rank the objects in terms of size from smallest to largest. Assume that objects are a “typical” size for that type of object.

A. Rank (from greatest to least) the strength of the gravitational force exerted on the asteroid located on the left side of each pair.

B. Using Newton’s Second Law, rank the acceleration (from greatest to least) that the asteroids located on the left side of each pair would experience due to the gravitational force exerted on it.
A. Rank (from greatest to least) the strength of the gravitational force at positions A - E exerted by the Moon on the spacecraft

B. Rank (from greatest to least) the strength of the net (or total) gravitational forces at positions A - E exerted by both the Earth and the Moon on the spacecraft

Rank the size of the objects A-E, from largest to smallest.

Des propos pour terminer

- Can the ideas of interactive learning be applied to the French educational system?
- Are there instructors interested in doing research into how much their students are really learning?
- Can such work be tied together with existing programs (EU-HOU, Sciences à l’École, others?)