Modern Teaching Strategies for (Introductory) Physics

• The Problem
• A Solution
• The Details
  
  “Lecture” Time
  • Peer Instruction
  • Just-in-Time Teaching
  • Interactive lecture Demos

  “Lab” Time
  • Cooperative Learning Groups
  • SCALE-UP

Full report of the Reform 1K committee: http://www.physics.smu.edu/sdalley/Reform1K/
The Problem

• Students come into the introductory physics course at the high school or college level with definite views (often wrong) about physics concepts based on their experiences.

• Physics education research shows that the vast majority of students will leave a traditional introductory physics course with the same (incorrect) views, and little understanding of physics concepts.

• Research done in many forms (student interviews, open-ended questions, short-answer questions, well-designed multiple choice questions) reaches the same conclusion.

• Result appears to be consistent for traditional methods of instruction, regardless of the skill of the instructor.
The Teaching Process
The Clear Explanation Misconception

Common Source of Frustration of Faculty, TAs, Students, & Administrators

Instructor pours knowledge into students by explaining things clearly.

Little knowledge is retained. **Student’s Fault**

Impedance mismatch between student and instructor. **Instructor’s Fault**

Learning is much more complicated

Leonard et. al. (1999). Concept-Based Problem Solving.
A Solution

WHY NOT TRY

A SCIENTIFIC APPROACH TO SCIENCE EDUCATION?
## Learning Environments

<table>
<thead>
<tr>
<th>Passively Individual</th>
<th>Actively Social</th>
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<tr>
<td>Instructor’s role is authority.</td>
<td>The physical world is the authority. Instructor’s role is guide.</td>
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<tr>
<td>Students' naïve beliefs not challenged.</td>
<td>Learning cycle: prediction/observation/comparison. Challenges students' beliefs.</td>
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<tr>
<td>Collaboration with peers often discouraged.</td>
<td>Collaboration and shared learning with peers is encouraged.</td>
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<tr>
<td>Experimental results are often presented as facts in lecture.</td>
<td>Results from real experiments are observed in understandable ways—often in real time with computer-based tools.</td>
</tr>
<tr>
<td>Laboratory work, if any, is used to confirm theories &quot;learned&quot; in lecture.</td>
<td>Laboratory work is used to learn basic concepts.</td>
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Examples of **proven** active learning methods

**Instruction style**

1. Peer instruction
2. Interactive Learning Demos
3. Cooperative learning groups

**Course structure**

4. Just-in-Time Teaching and flipped instruction

**Deep reform**

5. SCALE-UP
6. New curriculum based on physics education research

Easier to implement; used to a various degree by many instructors in our department and SMU

Will require major reorganization of our current system
Will produce top-notch learning outcomes
Normalized gain $G$

A commonly used figure of merit to characterize “the teaching efficiency” is the normalized gain,

$$ g = \frac{P_{post} - P_{pre}}{100\% - P_{pre}} $$

$P_{pre}$ ($P_{post}$) is the average class score before (after) the instruction, as a percentage of the maximal score

$$ 0 < g < 1 $$

Better instructional methods presumably have $g$ values with (a) a higher average and (b) smaller variance due to circumstantial factors like initial preparation of students, instructor’s personality, etc.
Many SMU instructors are here in 2016

Traditional lectures are here

SCALE-UP at MIT, etc. in 2016

**Figure 5.3** A plot of the fractional FCI gain achieved in three types of classes: traditional, moderate active engagement (tutorial/group problem solving), and strong active engagement (early adopters of workshop physics). Histograms are constructed for each group and fit with a Gaussian, which is then normalized [Saul 1997].
Figure 5.3  A plot of the fractional FCI gain achieved in three types of classes: traditional, moderate active engagement (tutorial/group problem solving), and strong active engagement (early adopters of workshop physics). Histograms are constructed for each group and fit with a Gaussian, which is then normalized [Saul 1997].
Peer Instruction

Mazur

Think → Pair → Share
Effectiveness of peer instruction is demonstrated by many studies


http://www.physics.indiana.edu/~sdi/ajpv3i.pdf
Effectiveness of peer instruction is demonstrated by many studies.

Fig. 2. Average Force Concept Inventory (Ref. 12) normalized gain ($g$) [Eq. (1)] for introductory calculus-based physics, Harvard University, Fall 1990–Fall 1997 (no data available for 1992), and for introductory algebra-based physics, Harvard University, Fall 1998–Fall 2000. Open bars indicate traditionally taught courses and filled bars indicate courses taught with PI. Dotted lines correspond to ($g$) = 0.23, the typical gain for a traditionally taught course, and ($g$) = 0.48, the typical gain for an interactive course (Hake–Ref. 1). The average pretest and posttest scores are provided in Table I.
Effectiveness of peer instruction is demonstrated by many studies.
Fig. 3. Mechanics Baseline Test (Ref. 13) scores for introductory calculus-based physics, Harvard University, Fall 1990–Fall 1997. Average score on entire test (circles) and on quantitative questions (Ref. 17) only (squares) vs year are shown. Open symbols indicate traditionally taught courses and filled symbols indicate courses taught with PI. The dotted line indicates performance on quantitative questions with traditional pedagogy (1990).
Scores on the standard BEMA test of E & M concepts, after early implementation of clicker-based peer instruction in 1304

Peer universities use peer instruction and either traditional or “Matter & interactions” curriculum
BEMA results in SMU PHYS 1304 and at Georgia Institute of Technology (1700+ students)

9 different instructors; instructors in Sections T3, T4, T8, and T9 have a reputation for excellent teaching
Flipped classroom and JiTT

• Flipping the traditional learning sequence facilitates active learning in class
  • Initial learning of new information takes place at home, before the lecture

• Just-in-Time Teaching (JiTT):
  • simplifies introduction of flipped instruction
  • combines well with peer instruction and other interactive techniques
A video with explanations of JiTT in PHYS 1304 and sample warm-up questions:  https://youtu.be/IfV9L0fdUiU
A weekly JiTT assignment in PHYS 1304

• By Tuesday, 7am:
  • read a new chapter in the textbook, watch a YouTube video with my explanations
  • complete a short “warm-up” assignment on SMU Canvas consisting of 1 multiple-choice, 1 qualitative, and 1 estimation questions

• Tuesday lecture: warm-up answers are reviewed in class; I show interesting answers

• By Saturday:
  • Revise the warm-up answers based on their discussion in the class

(Bi)weekly tests (25-50 minutes) + 1 comprehensive final exam
A possible warm-up question on statistics

If you choose an answer to this question at random, what is the chance you will be correct?

A) 25%  
B) 50%  
C) 60%  
D) 25%
A warm-up question for physics, engineering, and business majors

Communication lines for financial markets.

Your company builds a high-speed communication line between stock exchanges in Chicago, IL and New York, NY. The transmission of the information must be fast enough to match speed of the automated stock trading, which performs thousands of trade transactions per second. You have to decide between (a) building a chain of wireless relay stations sending a radio signal through the air; and (b) laying an optical cable in which light travels through a glass filament at a speed about 25% slower than in vacuum. Which transmission method is potentially faster? Why? How much more time delay would you expect from the slower line?
Warm-up is not a reading quiz

A well-designed warm-up...
...stimulates students to regularly **read** the textbook and **think** about the most difficult concepts
...turns this challenging weekly task into a fun activity
...does not have one straightforward answer
...brings up connections of the subject to students’ lives
Grading of the warm-ups

Warm-ups are supposed to be answered individually by each student. Many students will give misguided answers on the first try. Students can be given an opportunity to correct their answers after those are discussed in the class.

It is highly recommended to give most of the grade (>80%) for the warm-up based on the effort, relevance, and originality on the first try. A smaller credit (10-20%) can be added if their final answers are correct after in-class discussion and revisions.
Interactive lecture demos (ILDs)

Sokoloff & Thornton

Predict → Observe → Reflect
Interactive Lecture Demonstrations (ILDs)

1. Describe the demonstration and do it for the class without results displayed.
2. Ask students to record individual predictions on the Prediction Sheet.
3. Have the class engage in small group discussions.
4. Elicit common student predictions from the whole class.
5. Students record final prediction on the Prediction Sheet (which will be collected).
6. Carry out the demonstration and display the results.
7. Ask a few students to describe the results and discuss them in the context of the demonstration. Students may fill out the Results Sheet.
8. If appropriate, discuss analogous physical situations with different "surface" features.
ILD Example: The cart has equal and opposite forces acting on it. The frictional force is very small and can be ignored. The cart is given a quick push away from the motion detector and released. Sketch on the axes your predictions of the velocity and acceleration of the cart after it is released.
FMCE Results

- Pre-Instruction
- Post-Traditional Instruction: 8% Gain
- Compared to Pre-test: 74% Gain
- ILDs
Comparison of FMCE Gains

- Oregon Traditional Algebra 1988-1989 (N=236)
- SUNY Albany Traditional Calculus F1998 (N=73)
- Sydney Traditional Calculus 1995 (N=472)
- RPI Studio Physics S1998 (N=145)
- Minnesota Calculus-based with CGPS 1996 (N=325)
- Sydney Calculus + ILDs 1999 (N=60)
- Mt. Ararat H.S. ILDs S1998 (N=33)
- RPI Studio Physics + ILDs S1999 (N=311)
- Muhlenberg Col. Calculus + ILDs F1997 (N=87)
- CU Calc +Peer & UW Tutorial S2004 (N=391)
- Joliet Junior College Calculus RTP labs1997-2003 (N=199)
- Dickinson Workshop Physics F1997-2000 (N=203)
- Oregon Algebra + ILDs F1991, Pre from 1989 (N=79)
- Oregon Algebra RTP labs F1991-94, Pre from 1989 (N=613)

<g> (% Normalized Gain)
Cooperative Learning Groups

*Heller*

Collaborate  Present

Compare
Problem Solving Is an Organized Framework for Making Decisions

Non-linear process, requires students to reflect on their work

Not natural for most students – must be explicitly taught
Student Difficulties Solving Problems

- **Lack of an Organizational Framework**
  - Random walk (knowledge fragments + math)
  - Situation specific (memorized pattern)

- **Physics Misknowledge**
  - Incomplete (lack of a concept)
  - Misunderstanding (weak misknowledge)
  - Misconceptions (strong misknowledge)

- **No Understanding of Range of Applicability – Mathematics & Physics**
  - Always true
  - True under a broad range of well-defined circumstances
  - True in very special cases
  - Never true

- **Lack of internal monitoring skills (reflection on what they did and why, asking skeptical questions about their actions)**

  Students must be taught a problem solving framework that addresses these *explicitly*
Examples of Scaffolding in teaching Introductory Physics using problem solving

- Problems that discourage novice problem solving
- An explicit problem solving framework
- Cooperative group structure that facilitates peer coaching
- A worksheet that structures the framework
- Limit use of formulas by giving an equation sheet
- Explicit grading rubric to encourage expert-like behavior
Cooperative Learning Groups: Provides peer coaching and facilitates expert coaching.
A typical 50-minute class engaged in Cooperative Problem Solving

• Students sit in structured groups of three, facing each other.
• Instructor begins class by talking for a few minutes to set the goal
• Groups will have 35 minutes to solve the problem.
• Instructor gives each group a formula sheet. (No textbooks or notes)
• Instructor circulates slowly through the room
• Instructor assigns one member from each group to draw a diagram and write the equations used on the boards on the walls
• Instructor leads a class discussion that clarifies which are solutions are correct and which are incorrect
• Instructor hands out a complete solution at the end
Appropriate Problems for Practicing Problem Solving

1. The problem must be complex enough so that the best student in the class is not certain how to solve it.

2. The problem must be simple enough so that the solution, once arrived at, can be understood and appreciated by everyone.

3. The problem cannot be resolved in one or two steps by copying a pattern.
Solving This

An infinitely long cylinder of radius R carries a uniform (volume) charge density \( \rho \). Use Gauss’ Law to calculate the field everywhere inside the cylinder.

is NOT Problem Solving
Example Problem

Your task is to design an artificial joint to replace arthritic elbow joints.

After healing, the patient should be able to hold at least a gallon of milk while the lower arm is horizontal. The biceps muscle is attached to the bone at the distance $1/6$ of the bone length from the elbow joint, and makes an angle of 80 degrees with the horizontal bone.

How strong should you design the artificial joint if you can assume the weight of the bone is negligible?
The result of students “natural” problem solving inclinations

Circled work by evaluators
Desired Student Solution

Plan the solution:

- **Variables:** d, v_{ix}, v_{iy}, \Phi, \Theta, \alpha, m, g, h, v_{i0}, v_{x0}, v_{y0}, m, h, \alpha

- **Step 1:**
  - **Objectives:** d, v_{ix}, v_{iy}, \Phi, \Theta
  - **Equations:**
    - \text{Qualitative relationship:}
      - \text{V}_{y0} = v_0 \cos(\Theta)
      - \text{V}_{x0} = v_0 \sin(\Theta)
  - **Solution:**
    - Calculate \text{V}_{y0} and \text{V}_{x0}

- **Step 2:**
  - **Objectives:** \text{V}_{x}, \text{V}_{y}, \text{d}
  - **Equations:**
    - \text{V}_{x} = \text{V}_{x0}
    - \text{V}_{y} = \text{V}_{y0} + g \cdot t
    - \text{d} = \text{V}_{x} \cdot t

- **Step 3:**
  - **Objectives:** m, \text{g}, h, \alpha
  - **Equations:**
    - \text{m} = \text{m}_{x0} \cdot \text{m}_{y0}
    - h = \text{V}_{y0} \cdot t + \frac{1}{2} \text{g} \cdot t^2

- **Step 4:**
  - **Objectives:** m, \text{g}, h, \alpha
  - **Equations:**
    - \text{m} = \text{m}_{x0} \cdot \text{m}_{y0}
    - h = \text{V}_{y0} \cdot t + \frac{1}{2} \text{g} \cdot t^2

- **Step 5:**
  - **Objectives:** m, \text{g}, h, \alpha
  - **Equations:**
    - \text{m} = \text{m}_{x0} \cdot \text{m}_{y0}
    - h = \text{V}_{y0} \cdot t + \frac{1}{2} \text{g} \cdot t^2

- **Step 6:**
  - **Objectives:** m, \text{g}, h, \alpha
  - **Equations:**
    - \text{m} = \text{m}_{x0} \cdot \text{m}_{y0}
    - h = \text{V}_{y0} \cdot t + \frac{1}{2} \text{g} \cdot t^2

- **Step 7:**
  - **Objectives:** m, \text{g}, h, \alpha
  - **Equations:**
    - \text{m} = \text{m}_{x0} \cdot \text{m}_{y0}
    - h = \text{V}_{y0} \cdot t + \frac{1}{2} \text{g} \cdot t^2

**Is the answer complete?**
- *Yes, the distance was found in terms of the requested variables.*

**Is the answer reasonable?**
- *Yes, the units check out, and d will be smaller than h due to some kind of reason.*

**Is the answer correctly stated?**
- *Yes, it is in units of distance, meters.*
Gain on FCI (Hake plot)
Each letter represents a different professor (39 different ones)

- Incoming student scores are slowly rising (better high school preparation)
- Our standard course (CGPS) achieves average FCI ~70%
- Our “best practices” course achieves average FCI ~80%
- Not executing any cooperative group procedures achieves average FCI ~50%
SCALE-UP
(Student-Centered Active Learning Environment with Upsidedown Pedagogies)

Beichner

Highly collaborative, hands-on, computer-rich, interactive learning environment for large-enrollment courses.

Problem Solving

Hands-on = Detailed hypothesis-driven labs*
Short (15 min) activities or simulations*

*Lab content redesign – Tom Coan’s committee
Modern Teaching Strategies for (Introductory) Physics

-- Lab Time --

• SMU Physics Faculty are already using some of these strategies in their introductory classes.

• With minimal disruption and small changes, Cooperative Learning Groups can be incorporated in lab time
Prerequisite: Introductory course content must be consistent with course catalog.

Three requirements need to be met

1. All lecture instructors must teach subject matter in same chronological sequence and timing (i.e., cover same topics each week).

2. Lab schedule must be synchronized with the corresponding lecture courses. Topic of lab should be presented in same or prior week in lecture.

3. Labs must be shortened to 2 hours without loss of value and content. The first hour will employ Cooperative Learning Groups solving a problem designed and provided by the lecture Professors.
Consistency with Course Catalog & Lab Synchronization

Over the summer, Matt Stein reviewed course syllabi comparing them to the course catalog.

Overall we are in good compliance but some small changes are needed.

Matt’s findings are summarized in a spreadsheet available from the committee.
Lab Shortening

- Identify target labs for easy changes:
  1. Reduce number of measurements.
  2. Reduce number of trials.

- Strategic use of lab report templates to reduce student time spent organizing and designing lab reports.

- Equipment upgrades to make data collection quick and simple.

- Use Motion Analysis software like Capstone by PASCO.

- ...
Committee Recommendations

Lectures

• Move to a common lecture style, combining traditional, peer instruction, ILDs.

• Construct a common pool of resources at SMU (YouTube videos, peer questions, demos, flipped pre-class study materials, help with SRS, etc.). Appointment of a manager from SMU Physics faculty for the shared resource pool.

• Physics Education Research expert at SMU (Visiting Prof?) to train faculty.
Committee Recommendations

Labs

• 1 hour Cooperative Problem Solving session at the beginning of every 3 hour lab, involving faculty.

• Correlate that week’s lecture topics with lab (and Coop. Prob. Sol.)

• Redesign lab space to promote social learning

• Redesign lab content (Coan); upgrade lab equipment, use online simulations (PhET), tutorials, etc.

• Consider introduction of an undergraduate learning assistant ULA system, similar to Univ. of Colorado system