The Journey from Traditional Instruction to Active Learning

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I’m not a physics education researcher, but I play one on TV
Beginning

...and beginning to excel
Ordinary path to professorship

“Played school” as a child

Typical lecture-based undergrad education

One year as TA in grad school (almost no training)
After postdoc, arrived at UNC as Assistant Professor in 1984, began to establish research program

Given instruction in how to teach:

You are teaching Modern Physics. Here is the textbook. The class meets in 247 Phillips Hall.
Became a “successful” teacher

Formal award:
Bowman and Gordon Gray Term Professorship
1996-99
“for excellence in inspirational teaching of undergraduate students”
College of Arts & Sciences

Informal award:
Crystalline Quartz Award
“for her outstanding clarity lecturing and amusingly neat presentations”
Senior physics majors, class of 1990
Awakening

...and awakening to responsibility
1999: National Task Force on Undergraduate Physics (NTFUP)

“Revitalization” of undergraduate physics programs

The SPIN-UP report

http://www.aapt.org/Programs/projects/ntfup/index.cfm
NTFUP brought close contact with PER specialists and their research.

To continue to teach without using methods proven to be effective would constitute academic malpractice.
Learning

...and learning about learning
The big picture

Active learning (of any kind) is more effective than traditional lecturing, regardless of class size, institution type, incoming SAT scores, etc. (45,000 students in 600 classes)

Von Korff et al., Am. J. Phys. 84 (2016)
1. Teaching by telling doesn’t work.
2. Algorithmic facility does not imply conceptual understanding.
3. Novice learners have preconceptions which must be specifically addressed in order to change them.
4. Scientific reasoning is not inborn.
5. The map is not the territory, and map-reading is not inborn either.
6. Understanding requires organizing knowledge in a way that facilitates application; this must be explicitly taught.

Available for free at https://www.nap.edu

With abundant thanks to Lillian McDermott, see Am. J. Phys. 61, 295 (1993)
Teaching by telling doesn’t work

But I learned that way!
• No, you engaged with the material--doing homework problems, working through lecture notes, discussing with peers, questioning your comprehension, confronting difficulties and resolving them
• Even if you had learned that way, your students are not you. Only 5% of physics majors become physics professors, and the fraction of “younger you” in an intro physics class is even smaller.

But I tell my students the correct physics, and they succeed in the course!
• Have you asked them to explain what they understand, or is the exam your only measure?
• Are they able to apply ideas in a variety of contexts? How do you know?
Algorithms ≠ understanding

Students can learn to solve standard quantitative problems without understanding the concepts behind them.

Calculate the current in the 2-Ω resistor and the potential difference between points $P$ and $Q$.

If the lightbulbs are identical, do the following increase, decrease, or stay the same when the switch is closed?

- Intensity of bulbs A and B
- Intensity of bulb C
- Current in circuit
- Voltage drop across each bulb

39% of students in a Harvard physics class did substantially worse on this question!

From Eric Mazur, see Peer Instruction: A User’s Manual
Students are not blank slates

Students have mental models about how the world works; these must be specifically addressed in order to change them.

A large truck collides head-on with a small compact car. During the collision

A. the truck exerts a greater amount of force on the car than the car exerts on the truck.
B. the car exerts a greater amount of force on the truck than the truck exerts on the car.
C. neither exerts a force on the other, the car gets smashed simply because it gets in the way of the truck.
D. the truck exerts a force on the car but the car does not exert a force on the truck.
E. the truck exerts the same amount of force on the car as the car exerts on the truck.

From the FCI: Hestenes, Wells & Swackhamer, Phys. Teacher 30 (1992)
Students are not blank slates

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A. the truck exerts a greater amount of force on the car than the car exerts on the truck.

Before instruction 75-80% of students choose A.

After traditional instruction ~65% of students still choose A!

From the FCI: Hestenes, Wells & Swackhamer, Phys. Teacher 30 (1992)
Scientific reasoning is not inborn.

Though children are “born scientists,” scientific reasoning at the level we aspire to for our students involves multiple higher-order thinking skills.

- Systematic hypothesis-testing
- Drawing conclusions based on valid evidence
- Thinking in terms of abstractions or symbols
- Thinking in terms of proportions and probabilities
- Applying quantitative analysis
- Thinking about multiple variables or dimensions at once

This does not come automatically!
The map is not the territory

The map is not the territory, the word is not the thing it describes.

Alfred Korzybski
The map is not the territory
The map is not the territory

Map-reading isn’t inborn either

\[
\vec{F} = -k \vec{x}
\]

\[
m \frac{d^2 \vec{x}}{dt^2} = -k \vec{x}
\]
Knowledge organization is not automatic

Facts (and equations) are not knowledge—understanding requires _organizing_ knowledge in a coherent way.

Gisela Kassoy
Knowledge organization is not automatic

Expert (but not novice) electronics technicians reproduced large portions of diagram after exposure of a few seconds.

Experts organized diagram into “chunks,” e.g. “amplifier,” “filter.”

Experts could not reproduce a random collection of elements.

Egan & Schwartz, Memory & Cognition 7 (1979)
What else PER gives us

Content knowledge is not enough—we also need **pedagogical content knowledge**

- Student difficulties
- Student mental models
- Effective instructional strategies for a particular concept
- Assessment methods

Excellent book from the Research Corp!
Doing

...and doing better
Evidence-based practices I have adopted (so far)

- **Peer instruction (TPS)**
  - Frequent application of concepts (retrieval practice)
  - Immediate feedback (do they get it?)
  - Resets attention span
- **JiTT**
  - Knowledge transfer before knowledge use
  - Advance warning of what students struggle with
  - Students feel their concerns are heard
- **Tutorials**
  - Scaffolding for guided reasoning
  - Address preconceptions explicitly
- **PhET**
  - Explore dependence on parameters
Evidence-based practices I have adopted (so far)

- Cooperative group problem-solving (Minnesota model)
  - Groups can solve more complex problems than individuals can
  - Context-rich: estimation, assumptions, sense-making
- Design from learning goals
  - What do I want the students to be able to do?
  - What class activities will lead to my desired outcomes?
  - How will I tell if I have succeeded?
- Studio physics
  - Most class time spent working in small groups to apply concepts
  - “All of us are smarter than any of us”
  - “Whenever we don’t understand, we explain to each other”
Backwards design

• Begin with learning goals
  • “After instruction, students should be able to...”
  • Active verbs: identify, construct, sketch, solve, distinguish, calculate, compare, determine, ...
  • “Understand”: how will you tell that they are not just performing an algorithm?
• Select class activities that will require students to apply knowledge step-by-step
• Assess specific goals
  • Formative: retrieval practice
  • Summative: have they achieved what you hoped, i.e. did the activity work?
Studio physics

• Lecturing reduced or eliminated
  • Reading assignment before class, with quiz (JiTT)
  • Instructor(s) is “guide on the side” rather than “sage on the stage”
  • All (or most) class time devoted to small group work
    • Experiments (often mini-)
    • Tutorials
    • Cooperative group problem solving
    • “Lightning round” for applications of math skills
    • Manipulate simulations
• Multiple types of activities within a single class period
• Activities provide “scaffolding” to guide concept development
• Specific learning goals addressed
Studio physics cont.

Facilitated by rooms designed for group work

Pittsburgh

Can be done in traditional lab spaces

FSU

MIT
Doing more

I'm not bossy, I just know what you should be doing.

...and doing more for more students
Stepping forward

So I have transformed my own teaching. Now what?

• Senior member of department (20+ years)
• Asked to take on leadership role (Department Chair)
• Opportunity to improve teaching across department
• Began with introductory courses (largest enrollment)
• NSF funding available
• Needed to persuade colleagues: opportunity for leadership development!
Getting my colleagues on board

Goals:
• All introductory physics courses to be taught using research-validated interactive engagement methods
• Common experience and expectations for all students in each course
• Teamwork to reduce duplication of effort
• Improved learning outcomes
What we have now: Lecture/Studio model

Weekly cycle:
• Reading assignment with quiz, including “what was confusing?” (JiTT)
• Class meetings (two sets each week)
  • Interactive lecture (all students) (Peer Instruction)
  • Studio session (multiple sections, 1 instructor per 30 students) (Tutorials, Cooperative Group Problem Solving, lab experiments)
• End-of-chapter HW (web-based, autograded)
Exams include conceptual and quantitative questions

Sequences for physical science majors (IPPS) and life science majors (IPLS) taught this way
What we have now: Lecture/Studio model

Learning gains on concept inventories are now significantly higher, with no loss of problem-solving ability!

David Guynn M.S. thesis
Studio activities for IPLS

Absorption and Fluorescence

Introduction
The energy in a molecule is quantized, meaning it can only have certain discrete values and not any values in between. Thus a molecule can only absorb and emit energy in amounts equal to the differences in energy between two allowed states. Since the energy of a photon (in electron volts) is related to its wavelength (in nanometers) by $E = h\nu$ (where $h =$ Planck’s constant and $c =$ speed of light and $\lambda = 1200 \text{ nm}$), this means that a molecule will only be able to absorb specific wavelengths of light. The color we perceive in a material (biological or otherwise) is determined by the wavelengths of light that it absorbs and the wavelengths it does not absorb. Specific biomolecules absorb specific wavelengths of light, resulting in a variety of biological effects from photosynthesis to coloration.

Learning Goals
All the end of this activity, you should be able to:

- Relate the perceived color of an object to its absorption spectrum.
- Explain why the emission wavelength is larger than the absorption wavelength in a fluorescence process (Stokes shift).
- Using the transmission spectrum of the eye lens and the absorption spectra of the visual pigments, determine the range of wavelengths that an organism can perceive.
- Relate absorption and emission wavelengths to differences in energies of quantum states.

Newton’s Laws: Jumping Grasshoppers

Introduction
This activity is a follow-up to Grasshoppers 1, and expands upon that activity in two ways. First, while Grasshopper 1 explored the forces on a grasshopper during a single jump, today’s activity will compare key dynamical features such as mass, maximum force, and maximum jump distance across multiple jumps. Second, while in Grasshopper 1 we assumed that the grasshopper jumped straight upward, in today’s activity we will explore a grasshopper jump in two dimensions, allowing us to draw conclusions about jump distances.

Learning Goals
After completing this activity, you should be able to:

- Analyze the motion of connected objects.
- Apply Newton’s laws to reason about the changes in the maximum jump distance of a grasshopper.

A. Exploration 1: Deducing position from velocity, and taking a graphical perspective

First, some unfinished business from Grasshoppers 1, we will use numerical integration again, this time to find the position of the grasshopper from its velocity.

1. Complete the blanks in the following sentences:
   a. $v(t)$ is the __________ of $a(t)$, so to get $v(t)$ we need to look at the __________ of the $a(t)$ graph.
   b. $y(t)$ is the __________ of $v(t)$, so to get $y(t)$ we need to look at the __________ of the $v(t)$ graph.

Fluid Dynamics III: Reynolds Number

Introduction
The motion of an object in a fluid is controlled by its Reynolds number, a dimensionless quantity that is the ratio of inertial forces acting on the object to the drag forces it experiences. For a sphere of diameter $d$ moving at speed $v$ the Reynolds number can be expressed as:

$$Re = \frac{pdv}{\eta},$$

where $p$ is the density of the fluid and $\eta$ is its viscosity (sometimes called the dynamic viscosity).

Learning Goals
After completing this activity, you should be able to:

- Calculate the Reynolds number for a particular fluid and flow speed, using parameters provided.
- Use the Reynolds number in a particular situation of fluid and flow speed to determine whether inertial or drag forces dominate.
- Specify and calculate the forces on a sphere moving in a fluid, including the drag force.
- Use Newton’s laws and the drag force to determine the terminal speed of a sphere falling in a fluid.
- Apply dynamic scaling to determine appropriate values of size, speed, and viscosity for a scale model.
- Describe the motion of an organism in a fluid under conditions of very low Reynolds number.

Smith et al. AJP 86, 862 (2018)
Guidance for your journey

• Your students are like everybody else’s students
• Try one or two things at first
• Remember that effort can be painful (for you and your students)
• Persevere—it will be better the second time (and the third)
Guidance for your journey

• Don’t reinvent the wheel

...or the flat tire

James Steidl

Laura Tiger
Guidance for your journey

• Steal from the best
• Implement methods *in their totality*

• Novel isn’t always better
L’envoi

Teach like a scientist—you owe it to your students and to your own professionalism.

Do your “very goodest”—carry out your teaching duties as effectively as your circumstances allow—and they allow a lot more than you may think.

One must learn by doing the thing; though you think you know it, you have no certainty until you try.

Sophocles (Women of Trachis)