"Good morning, and welcome to The Wonders of Physics."
Human behavior in all realms is beset by wishful thinking—the tendency of people to really believe that what they want to be true is true.

Edward F. Redish
Millikan Lecture, 1998

How can you distinguish science from junk?
Science posits hypothesis and tests them.
Pseudoscience assumes conclusions and finds evidence to back them up.

Wendy Kaminer
Sleeping with Extra-Terrestrials, 1999
The first principle is that you must not fool yourself – and you are the easiest person to fool.

Richard Feynman

It's not what you don't know that hurts you. It's what you know that ain't so.

Mark Twain
Don’t Believe Everything You Think

6 Basic Mistakes We Make in Thinking
(There are many more)

• We prefer stories to statistics (data).

• We seek to confirm, not to question, our ideas.

• We rarely appreciate the role of chance and coincidence in shaping events.

• We sometimes misperceive the world around us.

• We tend to oversimplify our thinking.

• We have faulty memories.
The Hidden Curriculum
(Perry-Belenky Scheme)

1. Binary / Received Knowledge Stage
   • Everything is true or false, good or evil, right or wrong, etc.
   • “Truth” is learned from authorities
   • Student wants to be told the “right” answer
   • Memorization
     o Long lists of uninterpreted facts
     o Algorithmic solutions to problems
       ▪ w/o thought
       ▪ w/o making sense
     o Efficient route to knowledge
       ▪ Declarative, Superficial
       ▪ Received from “authority”, without evidence or support
       ▪ Situation dependent
       ▪ Quickly forgotten

2. Subjective / Multiplist / Relativist Stage
   • Nothing is true or false, good or evil, right or wrong, etc.
   • Every view has equal value
   • Knowledge is a matter of opinion
3. Constructivist Stage

- Weigh evidence, evaluate the merit of various positions
- Recognize contextual nature of knowledge
- Recognize that perspective, assumptions, and method of inquiry colors what one knows or concludes.

4. Consciously Constructivist Stage

(Need to be here to be a creative scientist)
(Can **not** be achieved if the instructor does all or most of the talking)

- Accept personal role in deciding productive and useful views
- Nothing can be perfectly known
- Integrate knowledge with own experiences and perspective
- Takes charge of building own understanding
- Carries out own evaluation of
  - Approach
  - Result
- Understands conditions of validity
- Understands fundamental principles
- Consciously raises questions:
  - What do we know …?
  - How do we know …?
  - Why do we accept or believe …?
  - What is the evidence for …?
- Is clearly and explicitly aware of gaps in available information
Consciously Constructivist Stage (continued)

- Probes for assumptions behind a line of reasoning (particularly implicit, unarticulated assumptions)
- Recognizes that words are symbols for ideas, not the ideas themselves
  - Uses only words of prior definition, rooted in shared experience, in forming a new definition
  - Avoids being misled by technical jargon
- Discriminates between observation and inference, between established fact and subsequent conjecture
- Draws inferences from data, observations, or other evidence
  - Recognizes when firm inferences cannot be drawn
  - Recognizes when relevant variables have or have not been controlled
- Discriminates between inductive and deductive reasoning
  - Inductive: Argument made from the particular to the general
  - Deductive: Argument made from the general to the particular
- Performs hypothetico-deductive reasoning
  - Given a particular situation, applies relevant knowledge of principles and constraints to visualize in the abstract the plausible outcomes of changes imposed on the system
- Tests one’s own line of reasoning and conclusions for internal consistency
  - Develops intellectual self-reliance
- Develops self-consciousness concerning one’s own thinking and reasoning processes
  - Recognizes the reasoning process one is using
  - Invokes the most appropriate reasoning process for the circumstances
  - Transfers reasoning methods from familiar to unfamiliar contexts
What we say to dogs

Okay, Ginger! I've had it! You stay out of the garbage! Understand, Ginger? Stay out of the garbage, or else!

What they hear

blah blah GINGER blah blah blah blah blah blah GINGER blah blah blah blah, blah blah blah blah...
THE CROCS ARE GOING TO COLLEGE.

WHAT FOR?

TO GET SMARTER.

COLLEGE LECTURES DO NOT MAKE YOU SMARTER.

THEN WHAT'S THEIR EFFECT?

zzzzZzzzz
Learner Attentiveness
Lecture presented by a brilliant scholar with an outstanding topic to a highly competent audience.

<table>
<thead>
<tr>
<th>Elapsed time after start of lecture</th>
<th>Audience</th>
<th>Behavior</th>
</tr>
</thead>
<tbody>
<tr>
<td>15 min.</td>
<td>10%</td>
<td>inattentive</td>
</tr>
<tr>
<td>18 min.</td>
<td>33%</td>
<td>inattentive</td>
</tr>
<tr>
<td>35 min.</td>
<td>100%</td>
<td>inattentive</td>
</tr>
<tr>
<td>45 min.</td>
<td>20%</td>
<td>transitive</td>
</tr>
<tr>
<td>47 min.</td>
<td>18%</td>
<td>asleep</td>
</tr>
</tbody>
</table>

- 24 hrs. later: 50% could recall only insignificant details about the lecture and these were generally incorrect.

Shortcomings of Traditional Lecture-Based Instruction

1. Lectures are best for inspiration and an alternative to reading the textbook for the transmission of information, but are ineffective for teaching concepts.

2. Students lack sufficient concrete experience with physical phenomena to comprehend the theories and mathematical derivations presented in lectures.

3. Passive learning fails to confront and deal with students’ misconceptions about physical phenomena.

4. Cognitive overload that comes when too much material is covered leads to rote memorization.

5. Students are not engage in scientific reasoning, in particular in the process of abstraction and generalization.
1

Factual knowledge:
remember and recall factual information
1. **Factual knowledge:**
   remember and recall factual information

2. **Comprehension:**
   demonstrate understanding of ideas and concepts

- Define
- List
- State
- Name
- Site

- Restate
- Explain
- Summarize
- Interpret
- Describe
1. **Factual knowledge:**
   - Name
   - Site
   - State
   - List
   - Define

2. **Comprehension:**
   - Describe
   - Interpret
   - Summarize
   - Explain
   - Restate

3. **Application:**
   - Predict
   - Solve
   - Compute
   - Diagram
   - Use
   - Apply
1 Factual knowledge:
remember and recall factual information

2 Comprehension:
demonstrate understanding of ideas and concepts

3 Application:
apply comprehension to unfamiliar situations

4 Analysis:
break down concepts into parts

Define
List
State
Name
Site

Apply
Use
Diagram
Compute
Solve
Predict

Restate
Explain
Summarize
Interpret
Describe

Compare
Contrast
Distinguish
1. **Factual knowledge:**
   - Define
   - List
   - State
   - Name
   - Site
   - Remember and recall factual information

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   - Demonstrate understanding of ideas and concepts
   - Restate
   - Explain
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   - Interpret
   - Describe

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   - Apply comprehension to unfamiliar situations
   - Apply
   - Use
   - Diagram
   - Compute
   - Solve
   - Predict

4. **Analysis:**
   - Break down concepts into parts
   - Compare
   - Contrast
   - Distinguish

5. **Synthesis:**
   - Transform and combine ideas to create something new
   - Develop
   - Create
   - Propose
   - Design
   - Invent
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   - Solve
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   - Contrast
   - Distinguish

5. **Synthesis:**
   - Transform and combine ideas to create something new
   - Develop
   - Create
   - Propose
   - Design
   - Invent

6. **Evaluation:**
   - Think critically about and defend a position
   - Judge
   - Justify
   - Defend
   - Criticize
   - Evaluate
# Bloom’s Taxonomy

<table>
<thead>
<tr>
<th>Educational objective</th>
<th>Brief description of objective</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1. Knowledge</strong></td>
<td>Remembers facts, conventions, classifications, methods, and principles.</td>
</tr>
<tr>
<td><strong>2. Comprehension</strong></td>
<td>Understands and interprets phenomena when presented in verbal, pictorial, diagrammatic, graphical, or symbolic form.</td>
</tr>
<tr>
<td><strong>3. Application</strong></td>
<td>Applies knowledge productively to new problems without prompting concerning the principles to use. Uses productive problem solving strategies.</td>
</tr>
<tr>
<td><strong>4. Analysis</strong></td>
<td>Breaks material into its constituent parts. Detects relationships between these parts. Recognizes organizing principles and knowledge structures.</td>
</tr>
<tr>
<td><strong>5. Synthesis</strong></td>
<td>Combines previous conceptual and procedural knowledge with new to form a well integrated whole. Designs investigations and products — creative work.</td>
</tr>
<tr>
<td><strong>6. Evaluation</strong></td>
<td>Judges the value of work—its accuracy, effectiveness, and reasonableness. Are assumptions warranted? Are ideas supported by observations and consistent with each other?</td>
</tr>
</tbody>
</table>

*Taxonomy of Educational Objectives: The Classification of Educational Goals, Handbook I Cognitive Domain, B.S. Bloom*
# Cognitive Attitudes

(Dimensions of student "expectations")

<table>
<thead>
<tr>
<th></th>
<th>Favorable</th>
<th>Unfavorable</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Independence</strong></td>
<td>Learns independently, believes in their own need to evaluate and understand</td>
<td>Takes what is given by authorities (teacher, text) without evaluation</td>
</tr>
<tr>
<td><strong>Coherence</strong></td>
<td>Believes physics needs to be considered as a connected, consistent framework</td>
<td>Believes physics can be treated as separated facts or &quot;pieces&quot;</td>
</tr>
<tr>
<td><strong>Concept</strong></td>
<td>Stresses understanding of the underlying ideas and concepts</td>
<td>Focuses on memorizing and using formulas</td>
</tr>
<tr>
<td><strong>Reality link</strong></td>
<td>Believes ideas learned in physics are useful in a wide variety of real-world contexts</td>
<td>Believes ideas learned in physics are unrelated to experiences outside the classroom</td>
</tr>
<tr>
<td><strong>Math link</strong></td>
<td>Considers mathematics as a convenient way of representing physical phenomena</td>
<td>Views the physics and the math as independent with no strong relationship between them</td>
</tr>
<tr>
<td><strong>Effort</strong></td>
<td>Makes the effort to use information available to them to modify and correct their thinking</td>
<td>Does not use available information about their own thinking effectively</td>
</tr>
</tbody>
</table>

- Student attitudes can be at either extreme or somewhere in between.

- Research at UMD (MPEX) and ASU (VASS) has shown that, on the average, the percentage of students with favorable attitudes tends to deteriorate as a result of traditional instruction.
# Traditional vs. Learning-to-Learn Strategies

<table>
<thead>
<tr>
<th>Conventional</th>
<th>Developing learning skills</th>
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<tbody>
<tr>
<td>Skills of learning are covert (hidden)</td>
<td>Skills of learning are made overt and discussed</td>
</tr>
<tr>
<td>The instructor explains concepts</td>
<td>Learners develop concepts</td>
</tr>
<tr>
<td>Learner is passive</td>
<td>Learner is active</td>
</tr>
<tr>
<td>Mistakes are mostly avoided</td>
<td>Mistakes are viewed as useful learning opportunities</td>
</tr>
<tr>
<td>Instructor poses questions and provides solutions</td>
<td>Instructors poses problems and discusses learner’s solutions</td>
</tr>
<tr>
<td>Assessment concerns primarily the product</td>
<td>Concerned with the product and the process—both are important</td>
</tr>
</tbody>
</table>

*Learning Management: Emerging Directions for Learning to Learn in the Workplace, S. S. Downs*

*Learning How to Learn, J. D. Novak and D. B. Gowin*
Table 2.1 of the AAAS’s Vision and change in undergraduate biology education (VCUBE).

<table>
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<tr>
<th>Core Competency</th>
<th>Instantiation of ability in disciplinary practice</th>
<th>Demonstration of competency in practice</th>
<th>Examples of core competencies applied to biology practice</th>
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<td>Ability to apply the process of science</td>
<td>Biology relies on applications of quantitative analysis and mathematical reasoning</td>
<td>Design scientific process to understand living systems</td>
<td>Observational strategies</td>
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<td>Ability to use quantitative reasoning</td>
<td>Biology focuses on the study of complex systems</td>
<td>Apply quantitative analysis to interpret biological data</td>
<td>Developing and interpreting graphs</td>
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<tr>
<td>Ability to use modeling and simulation</td>
<td>Biology is an interdisciplinary science</td>
<td>Use mathematical modeling and simulation tools to describe living systems</td>
<td>Computational modeling of dynamic systems</td>
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<tr>
<td>Ability to tap into the interdisciplinary nature of science</td>
<td>Biology is a collaborative scientific discipline</td>
<td>Apply concepts from other sciences to interpret biological phenomena</td>
<td>Applying physical laws to biological dynamics</td>
</tr>
<tr>
<td>Ability to communicate and collaborate with other disciplines</td>
<td>Biology is conducted in a societal context</td>
<td>Communicate biological concepts and interpretations to scientists in other disciplines</td>
<td>Scientific writing</td>
</tr>
<tr>
<td>Ability to understand the relationship between science and society</td>
<td></td>
<td>Identify social and historical dimensions of biology practice</td>
<td>Evaluating the relevance of social contexts to biological problems</td>
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Examples of core competencies applied to biology practice:

- **Observational strategies**
  - Developing and interpreting graphs
  - Applying statistical methods to diverse data
- **Hypothesis testing**
  - Applying informatics tools
- **Experimental design**
  - Mathematical modeling
  - Managing and analyzing large data sets
- **Evaluation of experimental evidence**
  - Managing and analyzing large data sets
- **Developing problem-solving strategies**
  - Incorporating stochasticity into biological models
  - Applying imaging technologies
  - Collaborating across disciplines
  - Evaluating ethical implications of biological research
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I hear, I forget.
I see, I remember.
I do, I understand

Anon
Workshop Physics Curriculum

Underlying Philosophies:

- Eliminate formal lectures.
- Reduce content and emphasize the process of scientific inquiry.
- Emphasize directly observable phenomena, to give necessary experience.
- Use the microcomputer as a flexible tool.
Workshop Physics Organization

Learning sequence mimics the scientific method:

- **Prediction**: examination of own preconceptions.
- **Observation**: make qualitative observations of phenomena.
- **Reflection**: individual/group reflection, discussion, and concept formation.
- **Theory**: group/class development of definitions, concepts, and mathematical models and theories.
- **Application**: quantitative experimentation centered on verification of mathematical models and theories.

Adapted from recommendations of cognitive psychologists (e.g. David Kolb) and physics educators (e.g. Robert Karplus, Roger Osborne)
Figure 1. Normalized gain vs. pre-test score on the Force Concept Inventory diagnostic for traditional courses surveyed by Hake.
Figure 2. Normalized gain vs. pre-test score on the Force Concept Inventory diagnostic for interactive-engagement courses surveyed by Hake.
Figure 3. Normalized gain vs. pre-test score on the Force Concept Inventory diagnostic for Physics 151, Westminster College.
Figure 4. Normalized gain vs. pre-test score on the Force Concept Inventory diagnostic for Physics 211, Westminster College.