What every teacher should know about cognitive research

Or

How People Learn

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* = Science Education Initiative

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Major advances past 1-2 decades
Consistent picture ⇒ Achieving learning

classroom studies

brain research

cognitive psychology
Outline

1. What makes an expert?
2. Motivation is important
3. Actively engaging people is important (Learning as brain development)
4. What people know affects what they learn (context is important)
5. What we remember is affected by how our brain works (the limits of retention)
What are our goals in class?

**Novice**
- Formulas & “plug ‘n chug”
- Pieces
- By Authority
- Drudgery

**Expert**
- Concepts & Problem Solving
- Coherence
- Independent (experiment)
- Joy

**think** about science like a scientist

Adapted from: Hammer (1997) COGNITION AND INSTRUCTION (physics),
What makes an expert thinker?

Changing the brain

Expert-like ways of thinking-- not just more informed-- new way to think. Built into long term memory-- new “wiring”

Learning requires active construction of understanding.

Brain is changing--
• See in brain activation and imaging studies
• Understand in terms of chemical and biological basis of long-term memory
• See in development of expertise
Experts are organized

Expert competence =
• factual knowledge +
• Organizational structure  → effective retrieval and use of facts

or ?
Learning to perceive like experts

Pointing it out is not enough!

Exemplar

Contrasting Cases

Pick Same Breed
The value of experience

• One set of students read a chapter and then hear a lecture about it
• Another set of students analyze and graph data, deciding what they think is important to graph
• # A third set played around with graphing the data and then heard a lecture about it.
Invention Activities

creating a time for telling

• Instead of a lesson on density…
• Create a “crowded clown” index

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Motivation is important
If you see no reason to learn, you won’t bother!

- Learning takes effort
- No reason to expend energy if there’s no reason to = survival strategy
- Motivation is highly malleable… depends on perspective!
“This class is very hard and many of you will fail so you need to study really hard.”

How does this impact university student motivation to learn the material?

a. increases  b. decreases

Focus groups and interviews indicate is demotivating for university students. Psychology studies support.
What does motivate?

a. **Subject relevant** to lives, future plans, explains world they know, solves problems or answers questions they care about ("meaningful context")

b. **Instructor attitude**
   
   "Subject hard for everyone, but all can master with effort, and my goal for course is for all of you to succeed."
Attitudes and Beliefs*

Assessing the “hidden curriculum” - beliefs about physics and learning physics

Examples:
• “I study physics to learn knowledge that will be useful in life.”
• “To learn physics, I only need to memorize solutions to sample problems”

Can we affect students’ beliefs?

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(All ±2%)

The good news: yes…

Worse for females!

Students come out of introductory classes with more negative views of physics than they came in with!
why does this happen?
Trad’l Model of Education

Individual \( \xrightarrow{\text{transmission}} \) Content (e.g. circuits)

Students aren’t blank slates…. 
Built in to our classes?
Where does our model come from…

– Sumer, circa 3000 BCE
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actively engaging students is important

Learning is changing our brain “constructivism!”
A wake-up call

- Force Concept Inventory*
- Multiple choice survey, (pre/post)
- Instructors thought students would do well on this survey
  necessary (not sufficient) indicator of conceptual understanding.

* Hestenes, Wells, Swackhamer, Physics Teacher 20, (92) 141
Sample question

Looking down at a track (flat on table), a ball enters at point 1 and exits at point 2. Which path does it follow as it exits (neglect all friction)?
How much do students learn the traditional way? (The FCI)

Take home message:

Students learn less than 25% of the most basic concepts (that they don’t already know).

R. Hake, “…A six-thousand-student survey…” AJP 66, 64-74 (‘98).
But by actively engaging students based on what they know...
traditional lecture  interactive engagement

Fraction learned

Learned less  Fraction learned  Learned more

Clickers only (at CU)

Clickers and more (at CU)
Ways to actively engage...
How did you learn?
1. **Motivation major focus** ... pique curiosity...limited praise, never for person, all for process

2. **Understands what students do and do not know** ⇒ timely, specific, interactive feedback

3. **Almost never tell students anything**-- pose questions.

4. **Mostly students answering questions** & explaining.

5. **Asking right questions** so students challenged but can figure out. Systematic progression.

6. **Let students make mistakes**, then discover and fix.

7. **Require reflection:** how solved, explain, generalize,...

*Lepper and Woolverton pg 135 in Improving Academic Achievement*
Feedback is important

If we’re to change how we think, we need feedback on our thinking

➤ What does that mean?
➤ What kind of feedback is most helpful?
➤ How can students get it?
1. What makes an expert?
2. Motivation is important
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4. **What people know affects what they learn** (context is important)
5. What we remember is affected by how our brain works (the limits of retention)
what people know affects what they learn

Context matters!
Theorem: If a moving particle, carried uniformly at constant speed traverses two distances, then the time intervals required are to each other in the ratio of their distances.

\[ \frac{d_1}{d_2} = \frac{r \times t_1}{r \times t_2} \]

\[ \frac{t_1}{t_2} = \frac{d_1}{d_2} \]

From diSessa (2000) Changing Minds
The card game

Rule: *If there is a vowel on one side, there is an even number on the other*

Verify the rule for:

A 2 L 5
The bartender game

You are a bartender and need to verify that the following drink orders/ages don’t break the law: *if you drink alcohol you must be 21 or older*

Gin/Tonic
Age: 16

Coke
Age: 52

Adapted from Johnson-Laird ‘83
Stroop test

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Stroop ///

rot, grün, blau, gelb, rosafarben, orange, blau, grün, blau, weiß, grün, gelb, orange, blau, weiß, braun, rot, blau, gelb, grün, rosafarben, gelb, grün, blau, rot
Strong indication: *Prior knowledge* matters
Where does prior knowledge come into play in class?

- Harmful?
- Helpful?
- Does “scaffolding” have anything to do with any of this?
The importance of context

The procedure is quite simple. First arrange items into different groups. Of course one pile may be sufficient depending on how much there is to do. If you have to go somewhere else due to lack of facilities that is the next step; otherwise, you are pretty well set. It is important not to overdo things. That is, it is better to do too few things at once than too many. In the short run this may not seem important but complications can easily arise. A mistake can be expensive as well. At first, the whole procedure will seem complicated. Soon, however, it will become just another facet of life. It is difficult to foresee any end to necessity for this task in the immediate future, but then, one can never tell. After the procedure is completed one arranges the material into different groups again. Then they can be put into their appropriate places. Eventually they will be used once more and the whole cycle will then have to be repeated. However, this is part of life.
Foreground / Background

From: R. McDermott ‘93
Strong indication: CONTEXT matters
Context in the classroom

• Where can/do we take into account students’ prior knowledge?
• Where does context come into our instruction?
PhET Computer Simulations
http://phet.colorado.edu

Free online simulations

• Engaging
• Visual
• Real-world
Interactive Physics Simulations

Fun, interactive, research-based simulations of physical phenomena from the Physics Education Technology project at the University of Colorado.

Play with sims... >
Visual Models
Make the man start at -5 meter mark, move with constant speed to the 2 meter mark and then accelerate to the 8 meter mark.

A. Sketch the position, velocity and acceleration graphs that you see.
B. How do the three graphs relate?

Sketch what you think the graphs will look like for this story that Jill told:

“Bobby was talking to me on his cell phone standing by his car. The phone signal was poor, so he walked toward his house trying to get a better signal and then stood still so we could talk.”

A. Explain why each part of your graph makes sense.
B. Test your ideas using the simulation

Can create activities that:
- Connect to student experiences
- Connect to student knowledge (prediction)
- Ask students to reason and make sense
Circuit Construction Kit (CCK)
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What we remember is affected by how the brain works

Limits of retention
How much do you remember from this talk already?

Probably 10% of you remember any non-obvious fact from 15 minutes ago

Want to remember it?

– **Study it** over several days
– **Test yourself on it**
– **Explain it** to someone

H. Roediger, J. Karpicke
Psych. Sci. Vol.17 pg 249
“hooks” for memory

Hooks for retention-- mental connections

e.g. lesson on fasteners-- here are all the types and how they are used.

vs.

Here is an interesting job problem, here are possible types of fasteners for solving problem, and here is how a certain type of fastener solved it.
Working Memory Capacity

VERY LIMITED!
every added demand hurts learning ("cognitive load")

(remember/process max 4-7 unrelated items)

Without great care, exceeded in almost every lecture.

Mr. Anderson, May I be excused?
My brain is full.
Reduce cognitive load

• How do we do this?
1. **Motivation major focus** (context, pique curiosity,...) limited praise, never for person, all for process

2. **Understands what students do and do not know** ⇒ timely, specific, interactive feedback

3. **Almost never tell students anything**-- pose questions.

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*Lepper and Woolverton pg 135 in Improving Academic Achievement*
It’s not about our teaching, it’s about student learning
Conclusions

• Educational practice is a researchable endeavor
  – We can make systematic progress
  – Imperative to include physicists

• Possible to achieve dramatic repeated results

• CU model strongly couples:
  – Reform and research
  – Education and physics

• Sustaining & Scaling reforms is possible
  – Requires theoretical framing
  – Both CONTENT and CONTEXT matter