Taking a scientific approach to Science education*

and most other subjects

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“the expertise centered classroom”

*based on the research of many people, some from my science ed research group
17 yrs of success in classes. Come into lab clueless about physics?

2-4 years later ⇒ expert physicists!

?????? ~ 25 years ago

Research on how people learn, particularly physics

• explained puzzle
• different way to think about learning and teaching
• got me started doing physics/sci ed research--controlled experiments & data!
Major advances past 1-2 decades ⇒ Bringing together research fields

University science & eng. classroom studies → cognitive psychology → brain research

Strong arguments for why apply to most fields
Science education goal—
*Not all become scientists/engineers, ...*
All learn to make **better decisions/choices**. Not just memorize facts, procedures, and vocabulary. 
*“Thinking like a scientist/expert”*

I. What is “*thinking like a scientist?*”

II. How is it learned?

III. Examples from applying learning principles in university science classrooms and measuring results.

* a bit on institutional change, if time & interest
Expert thinking/competence =
• factual knowledge
• **Mental organizational framework** ⇒ retrieval and application

I. Research on expert thinking*
historians, scientists, chess players, doctors,...

- New ways of thinking—everyone requires MANY hours of intense practice to develop.
- Brain changed—*rewired, not filled!*

*Cambridge Handbook on Expertise and Expert Performance*
II. Learning expertise*--

Challenging but doable tasks/questions
• Practicing specific thinking skills
• Feedback on how to improve

Sci. & Eng. thinking to practice & learn
• concepts and mental models + selection criteria
• does answer/conclusion make sense- ways to test
• moving between specialized representations (graphs, equations, physical motions, etc.)

Knowledge/topics important but only as integrated part with how and when to use.

* “Deliberate Practice”, A. Ericsson research accurate, readable summary in “Talent is over-rated”, by Colvin
Effective teacher—
• Designing suitable practice tasks
• Providing timely guiding feedback
• Motivating
(“cognitive coach”)
“Practice-with-feedback/Research-based/Active learning”

What it is **not:**
“experiential”
“flipped classroom”
“student centered”

These **may** contain the necessary mental practice activities and structure, but frequently do not.

**Also, centered on thinking to be learned.**
Lots of “instructor”—Design of task, feedback and elaboration to “prepared” students.
(“A time for telling”)
Teaching about electric current & voltage

1. Preclass assignment--Read pages on electric current. Learn basic facts and terminology without wasting class time. Short online quiz to check/reward.

2. Class starts with question:

Example-- large intro physics class (similar chem, bio, comp sci, ...)

III. How to apply in classroom? practicing thinking with feedback
When switch is closed, bulb 2 will
a. stay same brightness,
b. get brighter
c. get dimmer,
d. go out.

3. Individual answer with clicker
(accountability=intense thought, primed for learning)

3. Individual answer with clicker
(accountability=intense thought, primed for learning)

Jane Smith chose a.

4. Discuss with “consensus group”, revote.
Instructor listening in! What aspects of student thinking like physicist, what not?
5. Demonstrate/show result

6. Instructor follow up summary—feedback on which models & which reasoning was correct, & **which incorrect and why**. Many student questions.

**Students practicing thinking like physicists**—(applying, testing conceptual models, critiquing reasoning...)

**Feedback that improves thinking**—other students, informed instructor, demo
3. Evidence from the Classroom

~ 1000 research studies from undergrad science and engineering comparing traditional lecture with “scientific teaching”. Many from MSU

• consistently show greater learning
• lower failure rates
• benefit all, but usually at-risk more

A few examples— various class sizes and subjects

Massive meta-analysis all sciences & eng. similar. PNAS Freeman, et. al. 2014
Apply concepts of force & motion like physicist to make predictions in real-world context?

average trad. Cal Poly instruction

1st year mechanics

Cal Poly, Hoellwarth and Moelter, Am. J. Physics May '11

9 instructors, 8 terms, 40 students/section. Same instructors, better methods = more learning!
U. Cal. San Diego, Computer Science
Failure & drop rates— Beth Simon et al., 2012

Standard Instruction  Peer Instruction

<table>
<thead>
<tr>
<th>Course</th>
<th>Fail Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>CS1*</td>
<td>24%</td>
</tr>
<tr>
<td>CS1.5</td>
<td>14%</td>
</tr>
<tr>
<td>Theory*</td>
<td>25%</td>
</tr>
<tr>
<td>Arch*</td>
<td>16%</td>
</tr>
<tr>
<td>Average*</td>
<td>20%</td>
</tr>
</tbody>
</table>

same 4 instructors, better methods = 1/3 fail rate
Learning **in the in classroom**

Comparing the learning in two ~identical sections
UBC 1st year college physics.
270 students each.

**Control**--standard lecture class– highly experienced Prof with good student ratings.

**Experiment**-- new physics Ph. D. trained in principles & methods of research-based teaching.

They agreed on:

• Same learning objectives
• Same class time (3 hours, 1 week)
• Same exam (jointly prepared)- start of next class

mix of conceptual and quantitative problems

*Deslauriers, Schelew, Wieman, Sci. Mag.  May 13, ‘11*
Experimental class design

1. Targeted pre-class readings

2. Questions to solve, respond with clickers or on worksheets, discuss with neighbors. Instructor circulates, listens.

3. Discussion by instructor follows, not precedes. (but still talking ~50% of time)
Clear improvement for entire student population. Engagement 85% vs 45%.
“A time for telling” Schwartz and Bransford, Cognition and Instruction (1998)

People learn from telling, **but only** if well-prepared to learn. Activities that develop knowledge organization structure.

Students analyzed contrasting cases ⇒ recognize key features

<table>
<thead>
<tr>
<th>Condition</th>
<th>Noted in Study Work</th>
<th>Missed in Study Work</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analyze + lecture</td>
<td>.60</td>
<td>.26</td>
</tr>
<tr>
<td>Analyze + analyze</td>
<td>.18</td>
<td>.15</td>
</tr>
<tr>
<td>Summarize + lecture</td>
<td>.23</td>
<td>.06</td>
</tr>
</tbody>
</table>
Final Exam Scores

nearly identical ("isomorphic") problems
(highly quantitative and involving transfer)

1 standard deviation improvement

practice & feedback, 1st instructor

practice & feedback 2nd instructor

taught by lecture, 1st instructor, 3rd time teaching course

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Stanford Outcomes

7 physics courses 2\textsuperscript{nd}-4\textsuperscript{th} year, seven faculty, ‘15-‘16

- Attendance up from 50-60\% to \sim 95\% for all.
- Covered as much or more content
- Student anonymous comments:
  90\% positive (mostly VERY positive, \textit{“All physics courses should be taught this way!”})
  only 4\% negative

- All the faculty greatly preferred to lecturing.
  Typical response across \sim 250 faculty at UBC & U. Col. New way of teaching much more rewarding, would never go back.
Better for students & faculty prefer *(when try)*

*Why not being used universally?*
What universities and departments can do. Experiment demonstrating transformation process.

Many issues—top 2
1. Teaching not recognized as expertise.
2. University incentive system—

transformed the teaching of ~ 200 science faculty and ~ 150,000 credit hours/year at UBC.
Necessary 1st step—better evaluation of teaching quality

“A better way to evaluate undergraduate science teaching”
Change Magazine, Jan-Feb. 2015, Carl Wieman

Requirements:
1) measures what leads to most learning
2) equally valid/fair for use in all courses
3) actionable—how to improve, & measures when do
4) is practical to use routinely
student course evaluations fail on all but #4

Better way—characterize the practices used in teaching a course, extent of use of research-based methods.
“Teaching Practices Inventory”
http://www.cwsei.ubc.ca/resources/TeachingPracticesInventory.htm

better proxy for what matters
Conclusion:

Meaningful science education—Learn to make decisions/choices, not memorize.

Research providing new insights & data on effective teaching and learning

A scientific approach to teaching greatly improves student learning & faculty enjoyment.

Good References:

S. Ambrose et. al. “How Learning works”
D. Schwartz et. al. “The ABCs of how we learn”
Colvin, “Talent is over-rated”
“Reaching Students” NAS Press (free pdf download)

cwsei.ubc.ca-- resources (implementing best teaching methods), references, effective clicker use booklet and videos
~ 30 extras  below
A better way to evaluate undergraduate science teaching
Change Magazine, Jan-Feb. 2015
Carl Wieman

“The Teaching Practices Inventory: A New Tool for Characterizing College and University Teaching in Mathematics and Science”
Carl Wieman* and Sarah Gilbert
(and now engineering & social sciences)

Try yourself. ~ 10 minutes to complete.
http://www.cwsei.ubc.ca/resources/TeachingPracticesInventory.htm

Provides detailed characterization of how course is taught
Research on Learning

Components of effective teaching/learning—expertise required.

1. Motivation
   - relevant/useful/interesting to learner
   - sense that can master subject

2. Connect with prior thinking

3. Apply what is known about memory
   - short term limitations
   - achieving long term retention

4. Explicit authentic practice of expert thinking

5. Timely & specific feedback on thinking
Biology  Jargon bogs down working memory, reduces learning?

Concepts first, jargon second improves understanding

L. Macdonnell, M. Baker, C. Wieman, Biochemistry and Molecular biology Education

Small change, big effect!
Emphasis on motivating students
Providing engaging activities and talking in class
Failing half as many
“Student-centered” instruction

Aren’t you just coddling the students?

Like coddling basketball players by having them run up and down court, instead of sitting listening?

Serious learning is inherently hard work
Solving hard problems, justifying answers—much harder, much more effort than just listening.

But also more rewarding (if understand value & what accomplished)—motivation
A few final thoughts—

1. Lots of data for college level, does it apply to K-12?

   There is some data and it matches. Harder to get good data, but cognitive psych says principles are the same.

2. Isn’t this just “hands-on”/experiential/inquiry learning?

   No. Is practicing thinking like scientist with feedback. Hands-on may involve those same cognitive processes, but often does not.
Use of Educational Technology

Danger!
Far too often used for its own sake! (electronic lecture)
Evidence shows little value.

Opportunity
Valuable tool if used to supporting principles of effective teaching and learning.

Extend instructor capabilities.
Examples shown.

- Assessment (pre-class reading, online HW, clickers)
- Feedback (more informed and useful using above, enhanced communication tools)
- Novel instructional capabilities (PHET simulations)
- Novel student activities (simulation based problems)
2 simple immediately applicable findings from research on learning. Apply in every course.

1. expertise and homework design

2. reducing demands on short term memory
Expertise practiced and assessed with typical HW & exam problems.

- Provide all information needed, and only that information, to solve the problem
- Say what to neglect
- Not ask for argument for why answer reasonable
- Only call for use of one representation
- *Possible* to solve quickly and easily by plugging into equation/procedure

- concepts and mental models + selection criteria
- recognizing relevant & irrelevant information
- what information is needed to solve
- How I know this conclusion correct (or not)
- **model** development, testing, and use
- moving between specialized representations (graphs, equations, physical motions, etc.)
2. Limits on short-term working memory -- best established, most ignored result from cog. science

Working memory capacity VERY LIMITED!
(remember & process 5-7 distinct new items)

MUCH less than in typical lecture

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

slides to be provided
A scientific approach to teaching

Improve student learning & faculty enjoyment of teaching

**My ongoing research:**

1. Bringing “invention activities” into courses—students try to solve problem first. **Cannot** but prepares them to learn.

2. Making intro physics labs more effective. (our studies show they are not. Holmes & Wieman, Amer. J. Physics)

Lesson from these Stanford courses—

**Not hard for typical instructor to switch to active learning and get good results**

- read some references & background material (like research!)
- fine to do incrementally, start with pieces
No Prepared Lecture

### Actions

#### Preparation

- **Students**: Complete targeted reading
- **Instructors**: Formulate/review activities

#### Introduction (2-3 min)

- **Students**: Listen/ask questions on reading
- **Instructors**: Introduce goals of the day

#### Activity (10-15 min)

- **Students**: Group work on activities
- **Instructors**: Circulate in class, answer questions & assess students

#### Feedback (5-10 min)

- **Students**: Listen/ask questions, provide solutions & reasoning when called on
- **Instructors**: Facilitate class discussion, provide feedback to class
3) Consider this optical setup

Laser with tunable frequency \( U_{\text{laser}} \)

\[ \text{mirror with } r_1 \text{ field reflectivity} \]

\[ \text{& } t_1 \text{ field transmission} \]

\[ \text{mirror with } r_2 \text{ field reflectivity} \]

\[ U = U_0 + U_1 + U_2 + \ldots \]

where \( U_{n+1} = r e^{i2kd} U_n \)

3a) Explain what this second expression means:
3b) What is the meaning of the terms \( U_n \) and \( U_{n+1} \) ?
3c) What is \( U_0 \) in terms of \( r_1, r_2, t_1, \) and \( U_{\text{laser}} \) ?
3d) What is \( r \) in terms of \( r_1 \) and \( r_2 \) ?
3e) Suppose there was a loss inducing optical element inside the cavity with a field transmission coefficient of \( t_{\text{loss}} \). What would \( r \) be in terms of \( t_{\text{loss}}, r_1 \) and \( r_2 \) ? What if \( t_{\text{loss}} \) were complex?
3f) What is the effect of changing the index of refraction of the material between the mirrors? Is this equivalent to changing the distance between the mirrors? Why or why not?
3g) What is the effect of changing the wavelength of the input laser field? Is this equivalent to changing the distance between the mirrors? Why or why not?

Often added bonus activity to keep advanced students engaged
Pre-class Reading

Purpose: Prepare students for in-class activities; move learning of less complex material out of classroom
Spend class time on more challenging material, with Prof giving guidance & feedback

Can get >80% of students to do pre-reading if:
• Online or quick in-class quizzes for marks (tangible reward)
• Must be targeted and specific: students have limited time
• DO NOT repeat material in class!

Stanford Active Learning Physics courses (all new in 2015-16)

2nd-4th year physics courses, 6 Profs

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Instructor</th>
<th>Semester</th>
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<tbody>
<tr>
<td>PHYS 70</td>
<td>Modern Physics</td>
<td>Wieman</td>
<td>Aut 2015</td>
</tr>
<tr>
<td>PHYS 120</td>
<td>E&amp;M I</td>
<td>Church</td>
<td>Win 2016</td>
</tr>
<tr>
<td>PHYS 121</td>
<td>E&amp;M II</td>
<td>Hogan</td>
<td>Spr 2016</td>
</tr>
<tr>
<td>PHYS 130</td>
<td>Quantum I</td>
<td>Burchat</td>
<td>Win 2016</td>
</tr>
<tr>
<td>PHYS 131</td>
<td>Quantum II</td>
<td>Hartnoll</td>
<td>Spr 2016</td>
</tr>
<tr>
<td>PHYS 110</td>
<td>Adv Mechanics</td>
<td>Hartnoll</td>
<td>Aut 2015</td>
</tr>
<tr>
<td>PHYS 170</td>
<td>Stat Mech</td>
<td>Schleier-Smith</td>
<td>Aut 2015</td>
</tr>
</tbody>
</table>
Math classes– similar design

Other types of questions---

• What is next (or missing) step(s) in proof?
• What is justification for (or fallacy in) this step?
• Which type of proof is likely to be best, and why?
• Is there a shorter/simpler/better solution? Criteria?
Reducing demands on working memory in class

- Targeted pre-class reading with short online quiz
- Eliminate non-essential jargon and information
- Explicitly connect
- Make lecture organization explicit.
Perceptions about science

Novice

Content: isolated pieces of information to be memorized.

Handed down by an authority. Unrelated to world.

Problem solving: following memorized recipes.

Expert

Content: coherent structure of concepts.

Describes nature, established by experiment.


measure student perceptions, 7 min. survey. Pre-post intro physics course ⇒ more novice than before chem. & bio as bad

*adapted from D. Hammer
Perceptions survey results—
Highly relevant to scientific literacy/liberal ed. Correlate with everything important

Who will end up physics major 4 years later?

7 minute first day survey better predictor than first year physics course grades

recent research⇒ changes in instruction that achieve positive impacts on perceptions
How to make perceptions significantly more like physicist (very recent)—

• process of science much more explicit (model development, testing, revision)

• real world connections up front & explicit
Student Perceptions/Beliefs

Kathy Perkins, M. Gratny

Percent of Students

CLASS Overall Score

(0% to 100%)

- All Students (N=2800)
- Intended Majors (N=180)
- Survived (3-4 yrs) as Majors (N=52)

Novice

Expert

(measured at start of 1st term of college physics)
Student Beliefs

- Actual Majors who were originally intended phys majors
- Survived as Majors who were NOT originally intended phys majors

CLASS Overall Score (measured at start of 1st term of college physics)

Percent of Students
Perfection in class is not enough!

Not enough hours

• Activities that prepare them to learn from class (targeted pre-class readings and quizzes)

• Activities to learn much more after class
good homework—-
  o builds on class
  o explicit practice of all aspects of expertise
  o requires reasonable time
  o reasonable feedback
Motivation-- essential
(complex- depends on background)

Enhancing motivation to learn

a. Relevant/useful/interesting to learner
(meaningful context-- connect to what they know and value)
   requires expertise in subject

b. Sense that can master subject and how to master, recognize they are improving/accomplishing

c. Sense of personal control/choice
How it is possible to cover as much material? (if worrying about covering material not developing students expert thinking skills, focusing on wrong thing, but...)

• transfers information gathering outside of class,
• avoids wasting time covering material that students already know

Advanced courses-- often cover more

Intro courses, can cover the same amount. But typically cut back by ~20%, as faculty understand better what is reasonable to learn.
Benefits to interrupting lecture with challenging conceptual question with student-student discussion

Not that important whether or not they can answer it, just have to engage.

Reduces WM demands—consolidates and organizes. Simple immediate feedback ("what was mitosis?")

Practice expert thinking. Primes them to learn.

**Instructor listen in on discussion. Can understand and guide much better.**
On average learn <30% of concepts did not already know.

Lecturer quality, class size, institution,...doesn't matter!

R. Hake, “…A six-thousand-student survey…” AJP 66, 64-74 (‘98).

Measuring conceptual mastery

• Force Concept Inventory- basic concepts of force and motion
  Apply like physicist in simple real world applications?

Test at start and end of the semester--
What % learned? (100’s of courses/yr)

Fraction of unknown basic concepts learned

Average learned/course
16 traditional Lecture courses

improved methods

On average learn <30% of concepts did not already know.
Lecturer quality, class size, institution,...doesn't matter!
Highly Interactive educational simulations--
phet.colorado.edu >100 simulations
FREE, Run through regular browser. Download

Build-in & test that develop expert-like thinking and learning (& fun)

balloons and sweater

laser
clickers*--

Not automatically helpful--
give accountability, anonymity, fast response

Used/perceived as expensive attendance and testing device ⇒ little benefit, student resentment.

Used/perceived to enhance engagement, communication, and learning ⇒ transformative

• challenging questions -- concepts
• student-student discussion (“peer instruction”) & responses (learning and feedback)
• follow up instructor discussion - timely specific feedback
• minimal but nonzero grade impact

*An instructor's guide to the effective use of personal response systems ("clickers") in teaching-- www.cwsei.ubc.ca
Retention curves measured in Bus’s Sch’l course. UBC physics data on factual material, also rapid but pedagogy dependent. (in prog.)

Concept Survey Score (%)
Retention interval (Months after course over)

long term retention

transformed $\Delta = -3.4 \pm 2.2\%$

award-winning

traditional $\Delta = -2.3 \pm 2.7\%$
Comparison of teaching methods: identical sections (270 each), intro physics. (Deslauriers, Schewlew, submitted for pub)

I

Experienced highly rated instructor--trad. lecture

wk 1-11

very well measured--identical

II

Very experienced highly rated instructor--trad. lecture

wk 1-11

Wk 12--experiment
Two sections the same before experiment. (different personalities, same teaching method)

<table>
<thead>
<tr>
<th></th>
<th>Control Section</th>
<th>Experiment Section</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Students enrolled</td>
<td>267</td>
<td>271</td>
</tr>
<tr>
<td>Conceptual mastery (wk 10)</td>
<td>47 ± 1 %</td>
<td>47 ± 1%</td>
</tr>
<tr>
<td>Mean CLASS (start of term)</td>
<td>63 ± 1%</td>
<td>65 ± 1%</td>
</tr>
<tr>
<td>(Agreement with physicist)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean Midterm 1 score</td>
<td>59 ± 1 %</td>
<td>59 ± 1%</td>
</tr>
<tr>
<td>Mean Midterm 2 score</td>
<td>51 ± 1 %</td>
<td>53 ± 1%</td>
</tr>
<tr>
<td>Attendance before</td>
<td>55 ± 3%</td>
<td>57 ± 2%</td>
</tr>
<tr>
<td>Engagement before</td>
<td>45 ± 5%</td>
<td>45 ± 5%</td>
</tr>
</tbody>
</table>
Comparison of teaching methods: identical sections (270 each), intro physics. (Deslauriers, Schewlew, submitted for pub)

I
Experienced highly rated instructor-- trad. lecture

wk 1-11

identical on everything
diagnostics, midterms,
attendance, engagement

Wk 12-- competition

elect-mag waves
inexperienced instructor
research based teaching

II
Very experienced highly rated instructor-- trad. lecture

wk 1-11

elect-mag waves
regular instructor
intently prepared lecture

wk 13 common exam on EM waves
<table>
<thead>
<tr>
<th></th>
<th>control (%)</th>
<th>experiment (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. Attendance</td>
<td>53(3)</td>
<td>75(5)</td>
</tr>
<tr>
<td>3. Engagement</td>
<td>45(5)</td>
<td>85(5)</td>
</tr>
</tbody>
</table>
Design principles for classroom instruction
1. Move simple information transfer out of class. Save class time for active thinking and feedback.

2. “Cognitive task analysis”-- how does expert think about problems?
3. Class time filled with problems and questions that call for explicit expert thinking, address novice difficulties, challenging but doable, and are motivating.
4. Frequent specific feedback to guide thinking.
What about learning to think more innovatively?
Learning to solve challenging novel problems

Jared Taylor and George Spiegelman

“Invention activities”—practice coming up with mechanisms to solve a complex novel problem. Analogous to mechanism in cell.

2008-9-- randomly chosen groups of 30, 8 hours of invention activities.
This year, run in lecture with 300 students. 8 times per term. (video clip)
Reducing unnecessary demands on working memory improves learning.

* jargon, use figures, analogies, pre-class reading
Changing educational culture in major research university science departments necessary first step for science education overall

• Departmental level
  ⇒ scientific approach to teaching, all undergrad courses = learning goals, measures, tested best practices
  Dissemination and duplication.

All materials, assessment tools, etc to be available on web
Institutionalizing improved research-based teaching practices. *(From bloodletting to antibiotics)*

Goal of Univ. of Brit. Col. CW Science Education Initiative *(CWSEI.ubc.ca)* & Univ. of Col. Sci. Ed. Init.

- Departmental level, widespread sustained change at major research universities
  ⇒ scientific approach to teaching, all undergrad courses
- Departments selected competitively
- Substantial one-time $$$ and guidance

Extensive development of educational materials, assessment tools, data, etc. Available on web.
Visitors program
Fixing the system

but...need higher content mastery, new model for science & teaching

Higher ed  →  K-12 teachers  →  everyone

STEM teaching & teacher preparation

STEM higher Ed
Largely ignored, first step
Lose half intended STEM majors
Prof Societies have important role.
Many new efforts to improve undergrad stem education (partial list)

1. College and Univ association initiatives (AAU, APLU) + many individual universities
2. Science professional societies
3. Philanthropic Foundations
4. New reports — PCAST, NRC (~april)
6. Government— NSF, Ed $$, and more
7. ...
Deliberate Practice of desired expert thinking

**Learning goals**
- including metacognition
- knowledge organization

**Practice Tasks**
- expert decision making
- problem solving processes and procedures,
- knowledge organization,
- planning and checking

**Guiding Feedback**
- Important features: timely, specific, why incorrect, wrong, ...
- Formative assessment

**Brain science**
- working memory
  - cognitive load
  - optimizing use
- long term memory
  - connecting with
  - spaced, interleaved, repeated practice

**Motivation**
- Self efficacy
  - belief can learn subject
  - know how to learn it
  - see are learning interest & value
  - sense of belonging & supportive ed environ

**Prior Knowledge and Experiences**
- expert-novice differences
- difficult ideas

**Enablers of D. P.**
- Time (on task)
- Metacognition
- Group work/ collab learning

**Brain science**
- working memory
  - cognitive load
  - optimizing use
- long term memory
  - connecting with
  - spaced, interleaved, repeated practice

**Guiding Feedback**
- Important features: timely, specific, why incorrect, wrong, ...
- Formative assessment