The Cognitive Science of Teaching and Learning
(or, How People Learn)

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Disclaimer: None
Disclosure: None
Caveats:

Due to time limitations this presentation:
will simplify some concepts
will not discuss many topics
Outline:

**Knowledge acquisition**
People learn more by using retrieval, spaced learning, hand-written notes, interpolated tests, delayed summarization and metacognition.

**Understanding**
People understand more deeply from constructivism and collaborative discourse. This requires learners to justify their understandings and educators to listen for misunderstandings and then correct them.

**Severe limits exist within our cognitive systems**
People possess severe constraints in working memory capacity and they have profound difficulty with analogical transfer.

**Dealing with setbacks**
A ‘growth mindset’ helps learners and educators deal with setbacks or challenges in learning.
As a Program Director, I used to meet with residents twice a year. They **routinely** told me that they didn’t remember what they read.

They would say things like: “I know I read it because my highlighter marks are on the page but it just didn’t stick....I really thought I knew it when I read it....”

Is there anything that will help?
Knowledge Acquisition

Remembering more “stuff”:
1) Retrieval
2) Spacing
3) Hand-written notes

Finding out if you actually know something:
Delayed summarization
Retrieval:
Learning words in a new language

Learning phase

Restudy

Initial Learning 100%

Retrieve

Testing phase

1 week

Retrieval:
Learning words in a new language

Learning phase

Restudy
Initial Learning 100%
Retrieve

1 week

Testing phase

Percent Recalled

Restudy
Retrieve


\(d = 4; \text{metacog} = 0\)
Long term **retention** depends on the **processes** learners employ to “learn”

*repeated encoding/rereading*

→ low benefit

**Repeated Retrieval**

→ large benefits

*** Learners are **completely unaware** of this! ***
Spacing

Learning (1 afternoon)

<table>
<thead>
<tr>
<th>Study</th>
<th>Recall X1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Massed ØS</td>
<td>Short S</td>
</tr>
<tr>
<td>Medium S</td>
<td>Long S</td>
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</table>

Initial Learning, 96% Correct

Testing

3 Retrievals

1 week later

Test

Karpicke et al. J. Exp. Psych. 37, 1250 (2011) Undergrads, Swahili-English pairs
Spacing

Testing Phase, 1 week later

Percent Recalled after 1 week

0 10 20 30 40 50 60 70 80

Study
Retrieval X1
Massed Ret.

Spacing

Ø

Short
Medium
Long

3 Retrievals

Karpicke et al. J. Exp. Psych. 37, 1250 (2011) Undergrads, Swahili-English pairs, 1 week until test
Taking notes

Laptop & typing vs. Pencil & paper

Method of Note-taking

Laptop & typing
30% more words
2x more verbatim

Paper & pencil

Return to lab & Study Notes

1 week

Taking notes

Laptop & typing vs. Pencil & paper

Method of Note-taking

- Laptop & typing
  - 30% more words
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- Paper & pencil

Return to lab & Study Notes

1 week

Test

How do you get people to **take more notes, pay attention and learn more** when you speak?

\[ R_x = Q \text{ vs. } Q + A \text{ vs. Math} \]

5-6 minute, recorded lecture segments

- Lecture
- Q
- Lecture
- Q
- Lecture
- Q + A
- Lecture
- Q + A
- Lecture
- Math
- Lecture
- Math
- Lecture
- TEST
- Lecture
- TEST
- Lecture
- TEST
- Lecture
- TEST
- Lecture
- TEST

Interpolated tests result in:
More notes, More attention & More learning

Szpunar. P.N.A.S. 110 6313 (2013) – Harvard, statistics: all Q p < 0.03, d > 1.01, else ns
Metacognition

_Essential cognitive activity for learning_ (‘meta’ – beyond or more than)

“Thinking about your thinking”
“Knowing about your knowing”

Metacognition is occurring when you realize that you do (or don’t) know, or understand, something.

This information is used in the “discrepancy-reduction model” for self-regulated learning.
How accurate are people at predicting how much they learned after reading a paragraph?

Summarizing, *After a Delay*, improves **metacognitive** accuracy
(improved realization of what you do, and don’t, know)

Details *

- Read → estimate
- Read → Summarize → estimate
- Read → **DELAY** → Summarize → estimate

* Similar results obtain when learning concepts
Short term memory (STM) is *Fleeting* (minutes).

The mechanism underlying the fleeting nature of STM is debated but *decay* and *replacement* by new information are leading contenders for the rapid failure of STM.

If you want to know if you *really learned something*, try *to recall what you learned* after a delay of at least 15 minutes.
For the person who reads but doesn’t remember:

1) Take a break after reading (at least 15’) and try to recall what was read. In the case of failure, review the material and repeat.

2) While reading, take handwritten notes (not verbatim). Review the notes after a break of at least 15’. Use the notes to help recall what was read. In the case of failure, review the material and repeat.

3) Repeat 1) or 2) the next day and on subsequent occasions until the material is retrieved more than once (10x rule).
A faculty member corners me and tells me that a person just “doesn’t seem to understand some key concepts”. The faculty member admits that the person knows basic medical facts but they are not putting it together.

Is there anything that will help?
Understanding concepts and ideas:

Constructivism
Collaborative Discourse
When people get “taught” a new idea, what happens inside their minds?
People come with preconceptions about how things work. If their prior understandings are not engaged, they may fail to incorporate new concepts into their thinking.

Fish is Fish. Leo Lionni (1970)
“Constructivism maintains that individuals incorporate new information into their previous conception.... and that they only change ideas when they realize that the new information conflicts with their previous understanding, creating cognitive dissonance.

Constructivism defines the types of practice....exercises that challenge previous conceptions and require students to explain their thinking.”

“Explaining” Creates Elaborated Knowledge

Haak et al. Science 332, 1215 (2011)
Words/phrases that foster constructivism:

Why? Why not?

Explain that...

What other options exist?

What if ... [change the scenario]

What evidence supports your point?
What evidence does not support your point?
Tips for helping the person who is not using medical knowledge in a sound or cogent manner:

1) When a learner makes a decision, ask them to explain how they made that decision even if *is a sound or good decision*. This will reveal their understanding which can serve as a starting point for further discussion.

2) Ask the learner to explain a concept to someone else and listen for appropriate understanding while they explain the concept. *Discuss any misunderstandings.*
Vignette

A faculty member corners me, again, and tells me that a junior resident just “doesn’t seem to follow their instruction”. The faculty member admits that the resident is smart and is trying hard but,

...they just can’t seem to follow the faculty member’s explicit instructions during a procedure.

Is there anything that can help?
Limits of our cognitive systems

• Working memory capacity & cognitive load theory
• Analogical Transfer
Mayer’s Cognitive Theory Model

WMC is the Bottleneck

Attention & Choice

Prior Knowledge

Mayer, Med Ed 44 543 (2010)
Principles of learning from a cognitive science perspective

**Limited capacity principle:** learners can only process a few elements at any one time (*WMC is limited = Bottleneck*).

**Active learning principle:** meaningful learning occurs when learners engage in appropriate cognitive processing during learning, including mentally organizing information into coherent cognitive representations and integrating it with prior knowledge activated from long-term memory.
Paying attention to complete a newly learned task (suturing) *can severely* reduce performance on an otherwise easy task (seeing ‘+’ signs).

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How vulnerable is the learning process?

Do you think walking could interfere with learning?

Lindenberger et al. Psych Aging 15 417 (2000) – Table 6
The Disruptive Potential of Concurrent Feedback

Learners use their entire WMC when learning new procedures and when trying to understand new ideas. This leaves no cognitive capacity for any other activities.

During task completion, feedback competes for working memory resources, forcing out information necessary for operator compilation.

(think of the slide on suturing and spotting the + signs)

Tips for the person who is not able to attend to direct instruction during learning

1) **Disengage the person** from the task that they are attempting. Once they are ‘unlocked’ from the task and are focused on you, provide instruction or feedback.

2) Ask the person to **mentally rehearse** the procedure on their own time so that the basic elements become a bit more automated and don’t require as much active cognitive control (i.e. WMC).

*Over time, people subordinate much (but not all) of what they do to automatic processes. They also develop ‘scripts’ to know what to do. These processes reduce cognitive load and free up WMC to attend to other things.*
Analogical Transfer

The process of taking a principle and using it to solve a new but related problem (an analogous problem). This is what we typically mean by ‘applying knowledge’ or ‘problem solving’.

Problems have:

- **Surface Structure:** details that don’t affect the solution
- **Deep Structure:** the core features of the problem

Example: [Google] → MIT grads light bulb

*Humans are STUNNINGLY POOR at AT!*

Casale et al: Mem Cogn 40 434 (2012)
Do you want learners to recognize something?  
If yes, teach CONCRETE examples.

If you want the learner to become familiar with something clinical, for example how a patient may present with a myocardial infarction, then use MANY specific examples. This will help build a schema of how myocardial infarction presents so that the next case is recognized (near transfer).

Do you want learners to apply their knowledge?  
If yes, teach principles or ABSTRACT concepts.

If you want the learner to have deeper understanding that they can apply to a novel problem (far transfer) then teach deep structure and principles (abstract concepts). Analogical transfer is remarkably difficult for most humans. Showing the problem solving process (scaffolding, tips) helps the learner “see” how the transfer was made.
Analogical Transfer?

Yes ... & no...

Cognitive limits exist in ALL of us.

There is no known simple way to make these limits go away.

I believe these limits require educators to have patience with learners and to show empathy towards them too.

Given these limits, it is most effective to approach the learner with a mindset of ‘growing the learner’ past the difficulty.

**Helping learners overcome** the challenge of learning with the goal of improving performance takes something called a **growth mindset**.
Adopting a ‘growth mindset’

The goal is to functionally respond to challenging learning situations
We ALL face Challenges

You...

- get a poor evaluation
- don’t understand something
- don’t know the answer
- get a low test score
- miss the diagnosis
- fail at a procedure
- get some negative feedback
- etc...
When *you* meet a challenge, what is *your goal*?

- **Mastery**
  - "Learning Goal"
  - "Growth Mindset"
  - "Learning Orientation"

- **Validate ability**
  - "Validation Orientation"
  - "Performance Orientation"
Definitions:

**Learning Goal Orientation**
*(Growth Mindset)*
The active striving toward development and growth in competence

**Validation Goal Orientation**
Seeking to validate one’s ability, gain favorable judgments of one’s attributes and avoid negative judgments of one’s self
Examples:

**Learning Oriented** individuals would say:

*I felt very satisfied when:*

... I learned something new  
... I saw improvement in my work  
... I was totally involved in something I was doing  
... I worked hard  
... I worked on a challenging task or assignment

**Validation Oriented** individuals would say:

*I felt very satisfied when:*

... I got a higher grade than the others  
... I received recognition or prestige  
... I was the only one in class who knew the answer  
... all the tasks and assignments were easy

“I am more convinced than ever that **mindsets** toward learning could **matter more than anything else** we teach.”

Sal Kahn, 2014
Do Goal Orientations Matter to Skill Acquisition?

Video:
Knot Tying (KT) & Camera Nav (CN)

Do Your Best (Control)
Performance Goals
Learning Goals

A Learning Orientation (LO) During Training Results in Better Skill Acquisition

Interactions between ‘Person’ and ‘Environment’ Favors a Learning Orientation Environment

<table>
<thead>
<tr>
<th>Person</th>
<th>Environment</th>
</tr>
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<tbody>
<tr>
<td>Performance O</td>
<td>DYB: -0.92</td>
</tr>
<tr>
<td>Learning O</td>
<td>Performance: ns</td>
</tr>
<tr>
<td></td>
<td>Learning: +0.85</td>
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</table>

Research findings on Learning Orientation (LO)

- Response to a setback is more functional with a **LO** (1-4)
- **LO** can be increased by primes and environment (5)
- Medical student **LO** decreases during 1st year (6)
- Teachers prefer students who have a **LO** (7)
- Residents with a **LO** accept negative feedback better (8)
- A **LO** increases information sharing with colleagues (9)
- **LO** scientists engage in more collaborative research (10)
- One’s **LO** is unrelated to one’s validation orientation (11)

5) Heslin et al., J App Psych 90 842 (2005)
8) Teunissen et al., Acad Med 84, 910 (2009)
9) Matzler et al., J Econ Psych 32 317 (2011)
10) Bateman et al., PNAS 112 3653 (2015)
Thanks for your attention and participation

Questions?

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