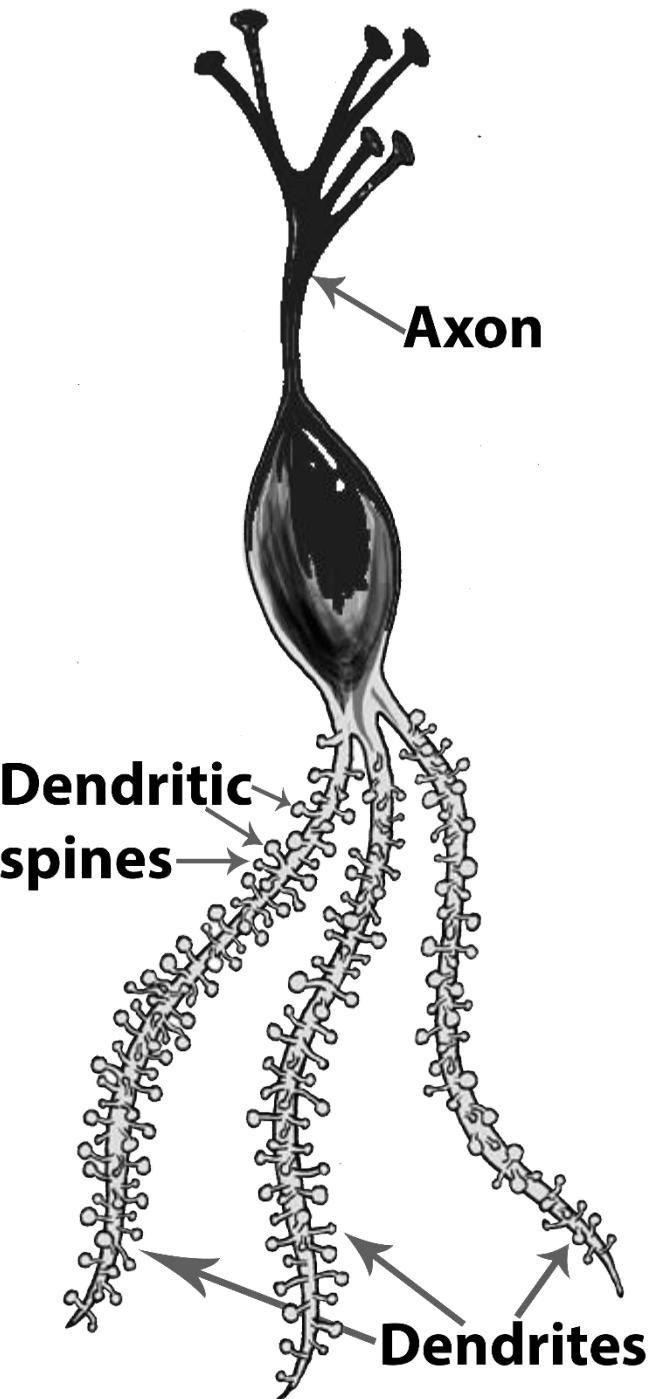


The Neuroscience of Learning— and How It Can Inform Educational Policy

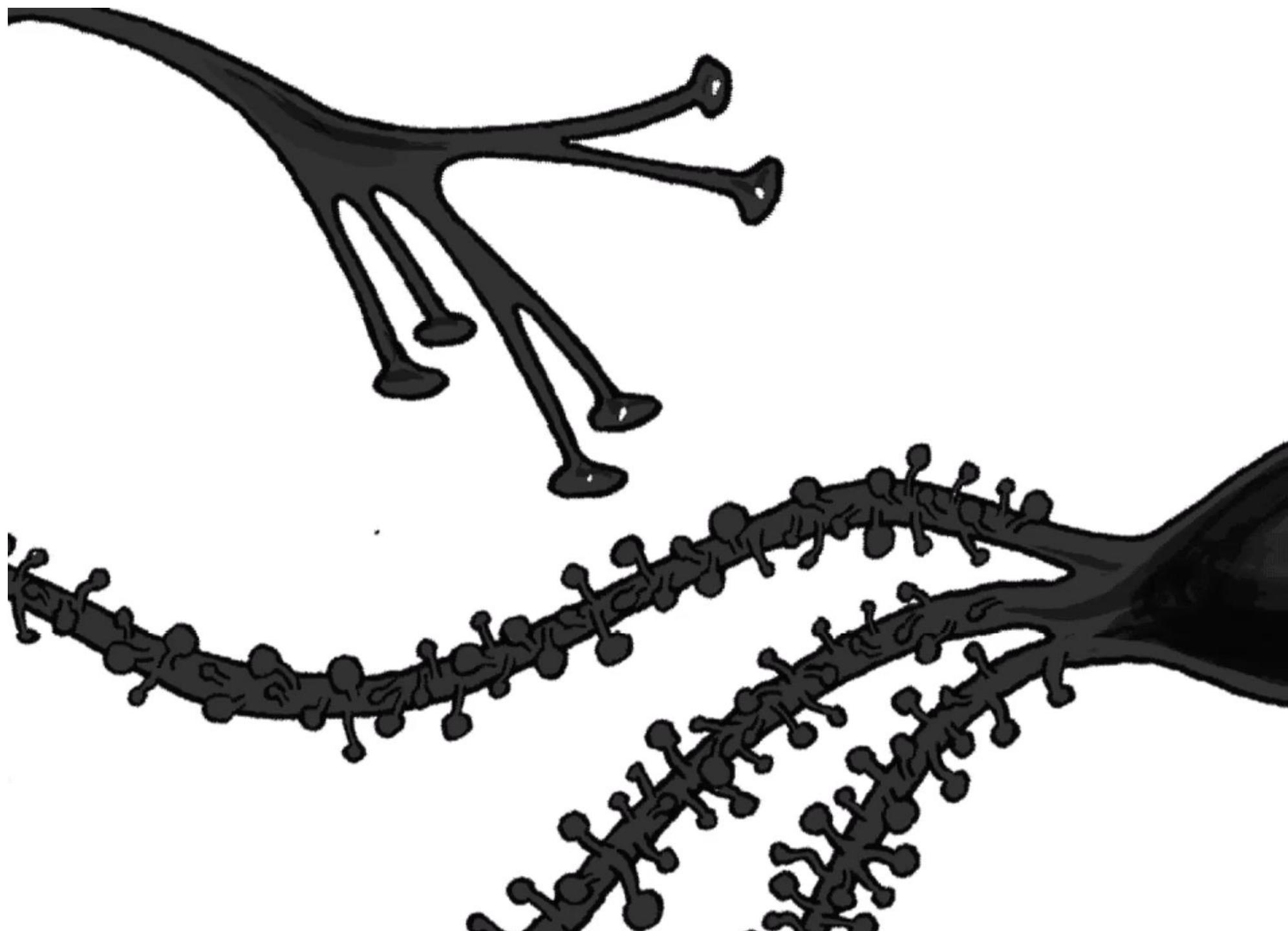
Barbara Oakley, PhD, FIEEE, FAIMBE
Distinguished Professor of Engineering
Oakland University



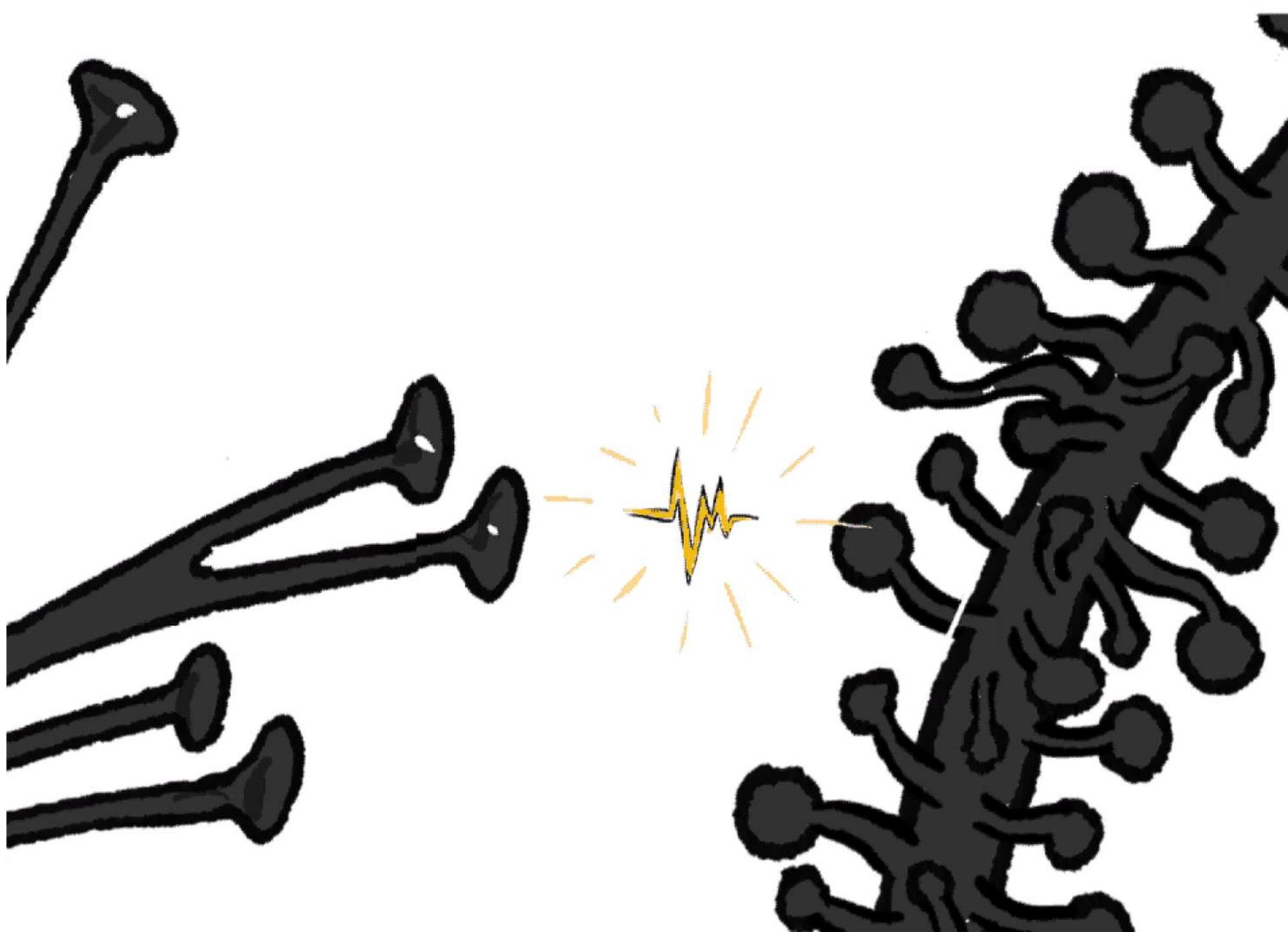


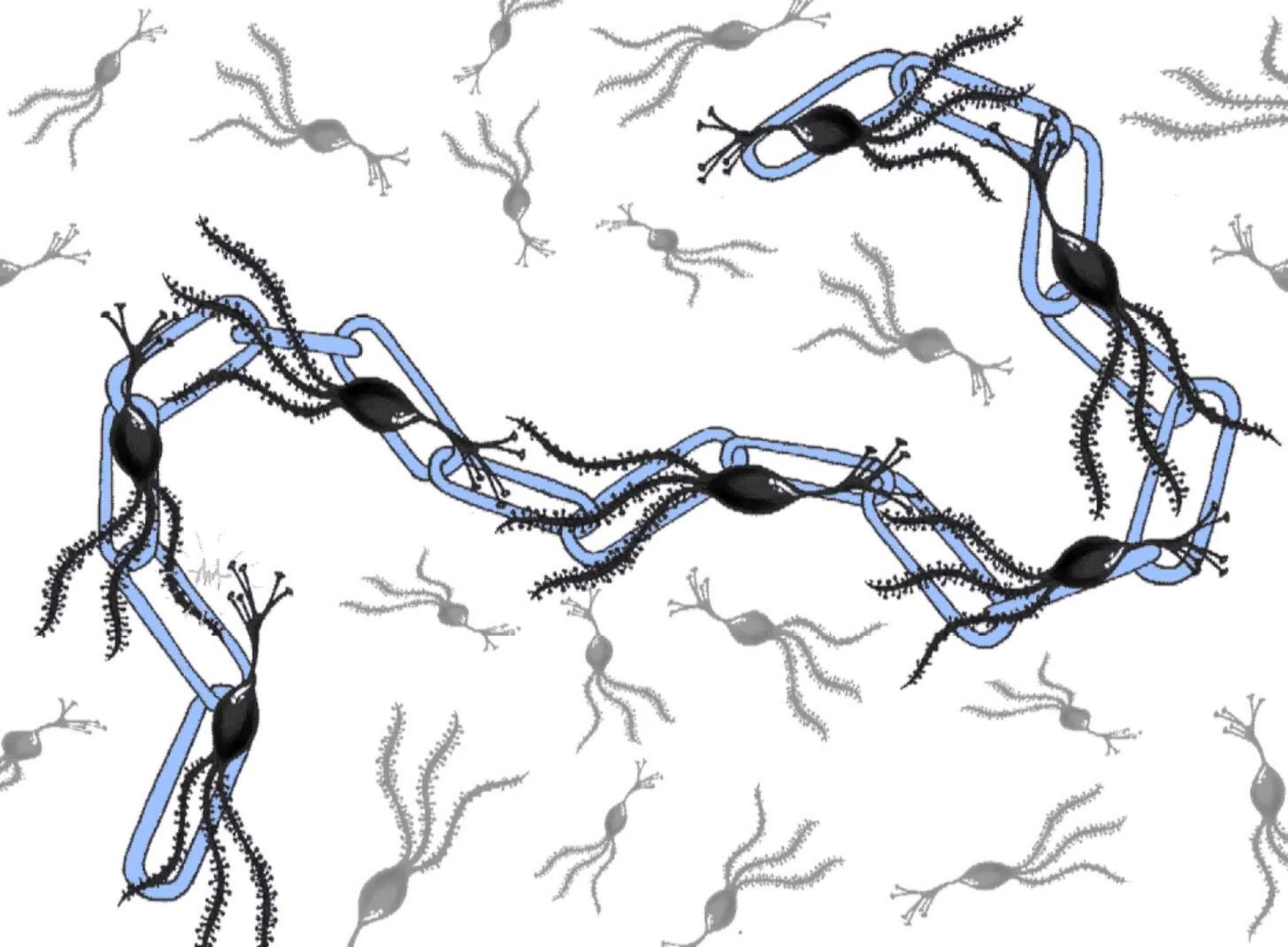


Neurons create
sets of links
when you learn
something.



Connections
strengthen
with practice

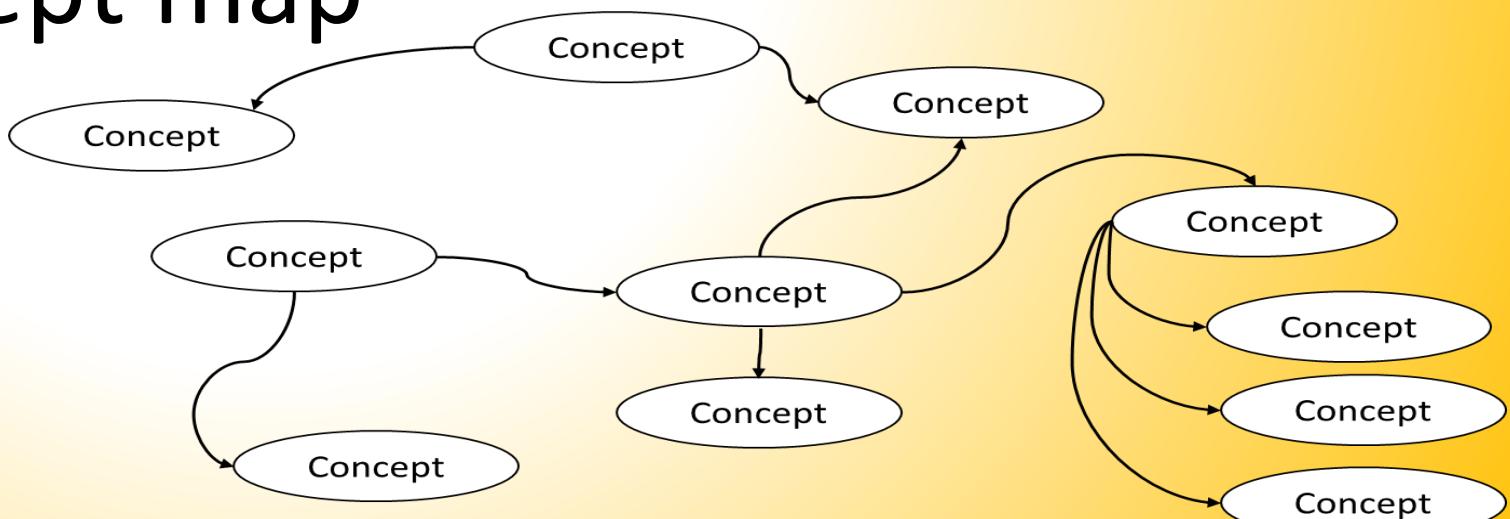




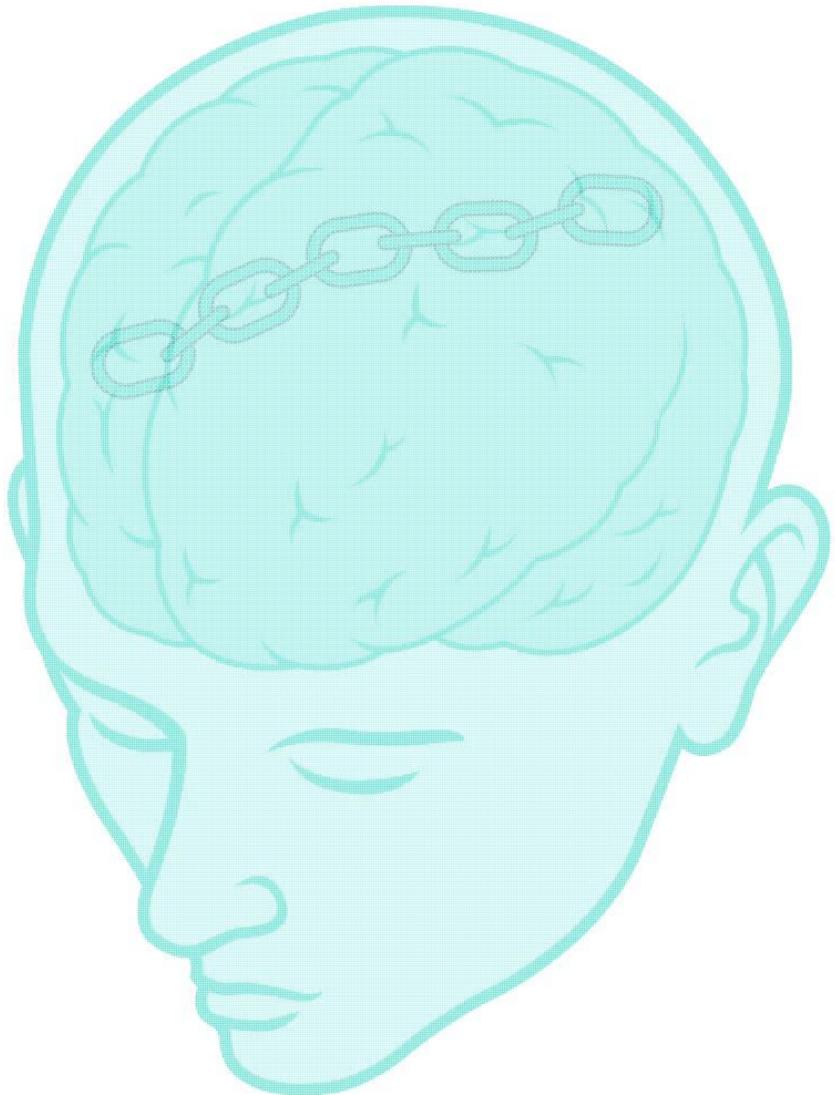
These are like
sets of links

What is the most powerful technique to help you learn most efficiently?

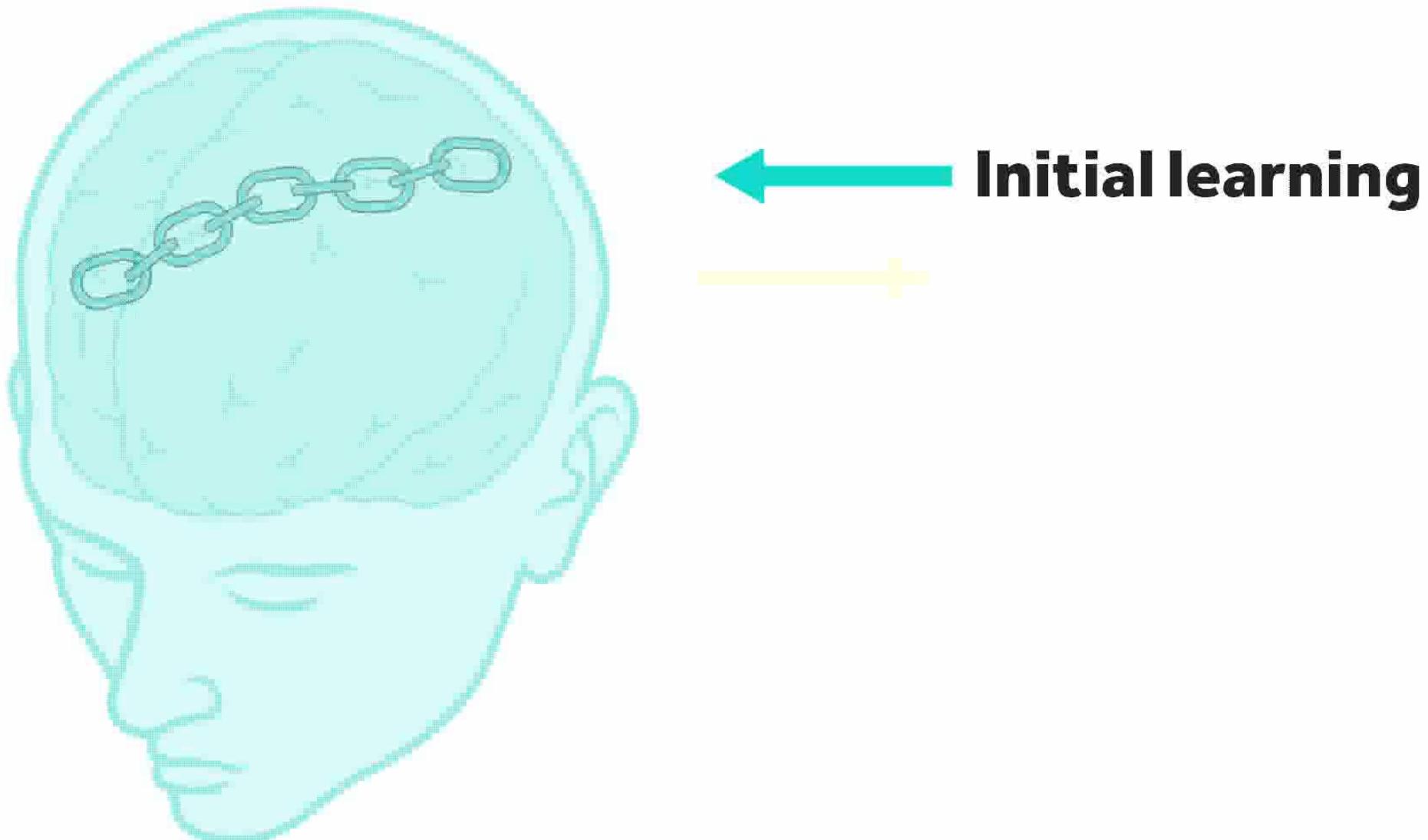
- Reread
- Highlight or underline
- Retrieval practice (“recall”)
- Create a concept map

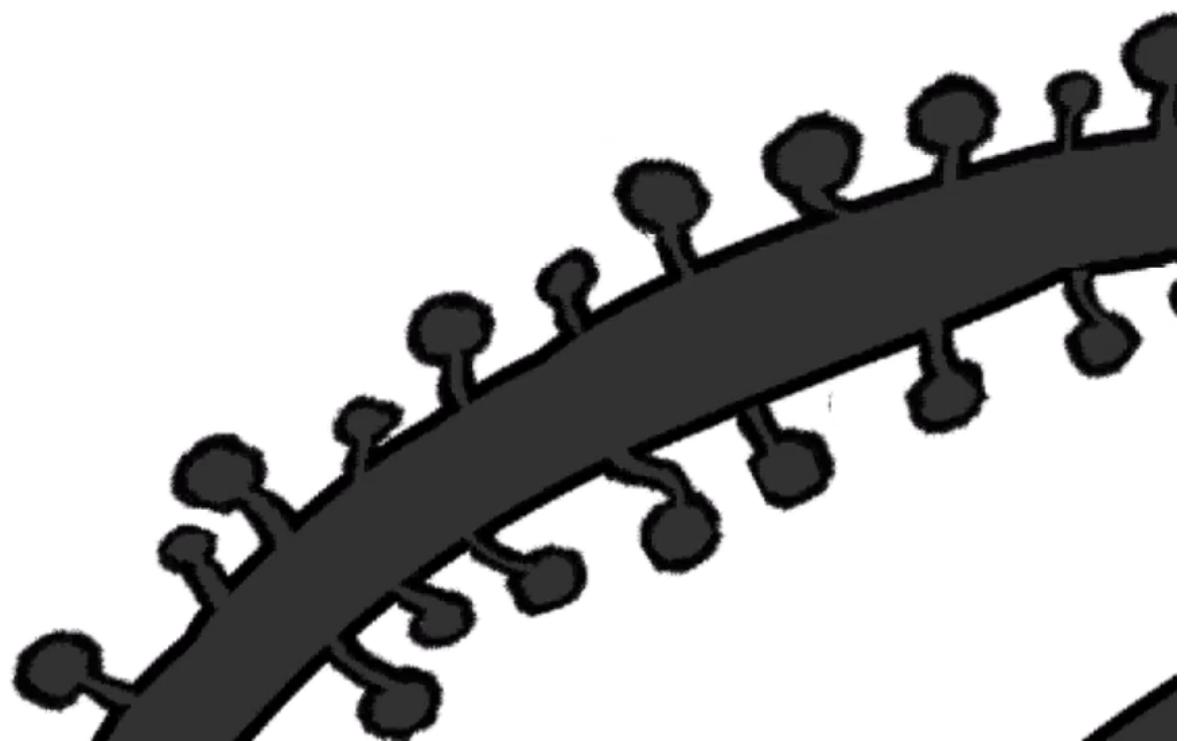


Retrieval Practice



Retrieval Practice





Before learning and before sleep



Images courtesy Guang Yang, NYU Langone

Before learning and before sleep

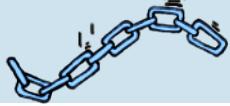


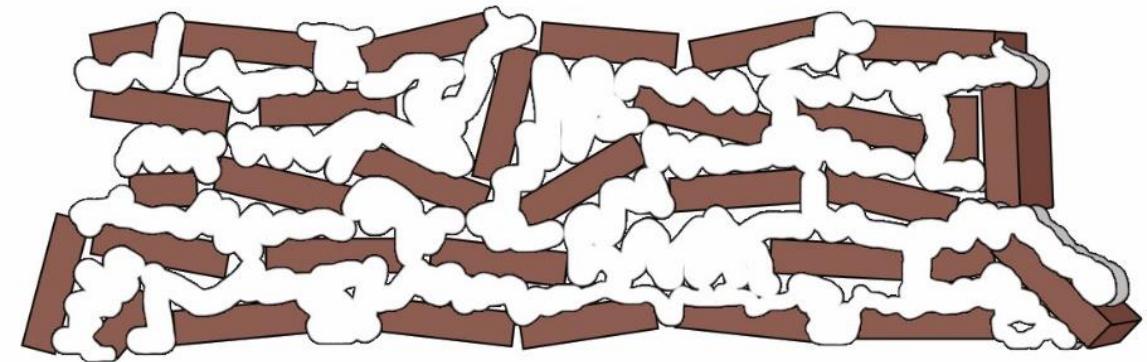
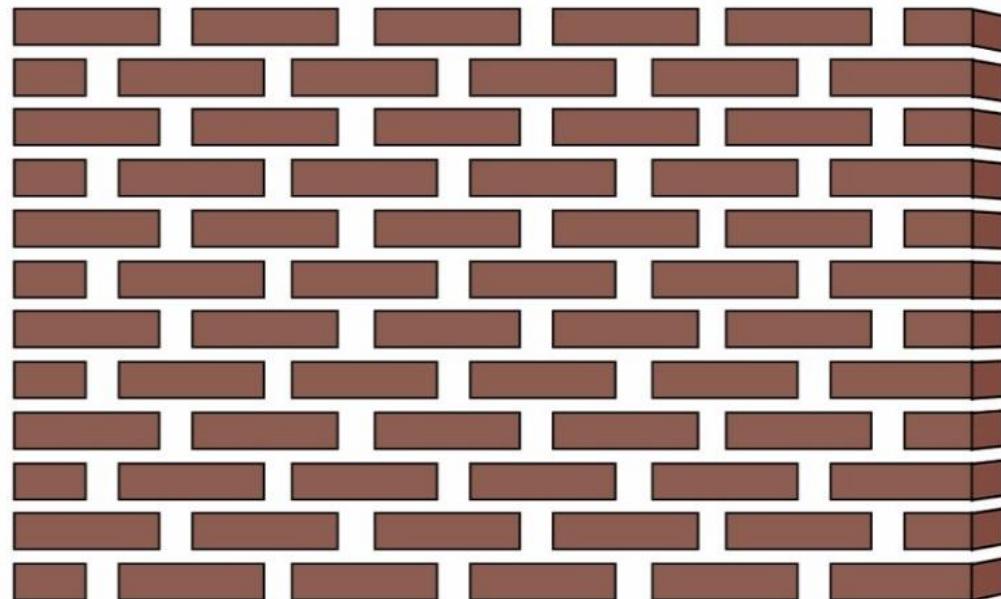
After learning and after sleep



2 μ m
Images courtesy Guang Yang, NYU Langone

Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
						

Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
						

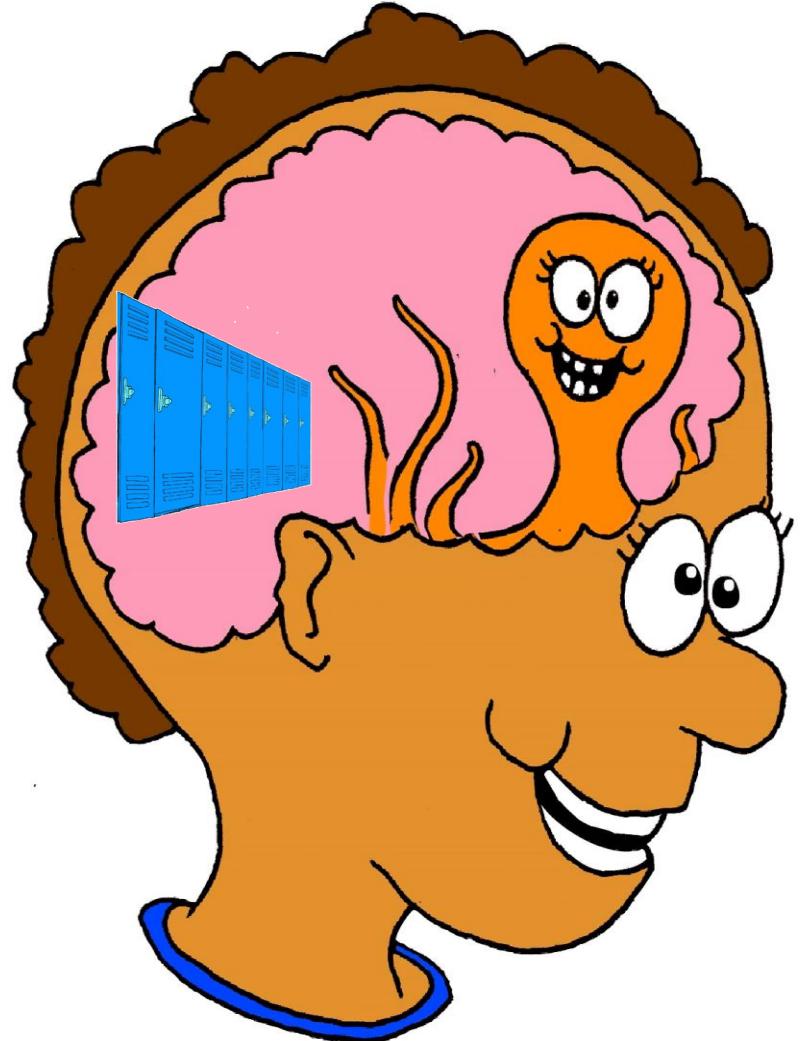


It takes time



Weight lifter Sultan Rakhmanov, RIA Novosti

Working memory



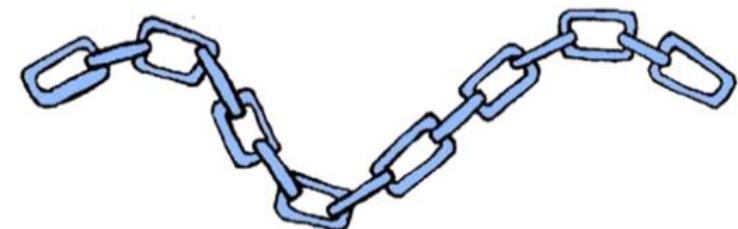
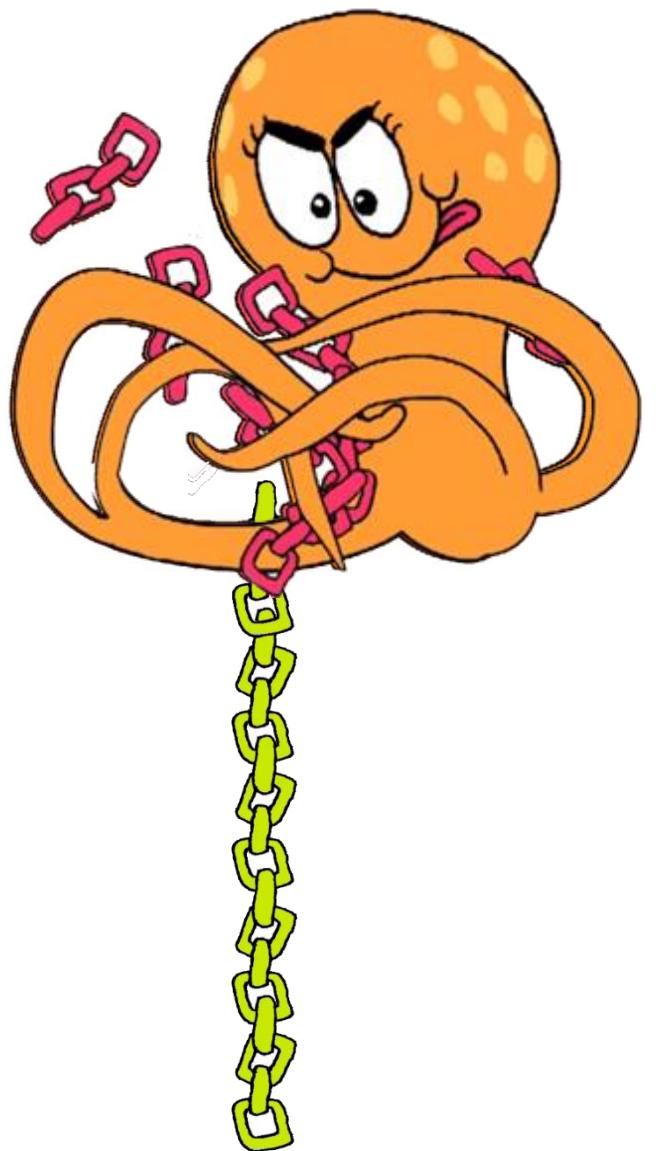
Long-term memory

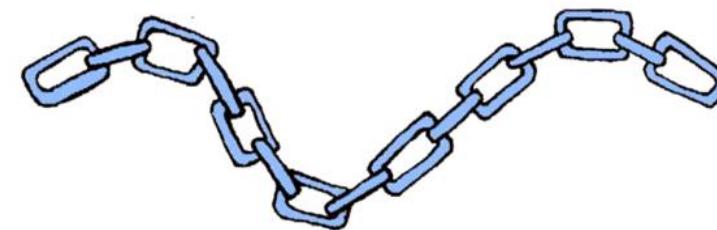
Working memory



Long-term memory







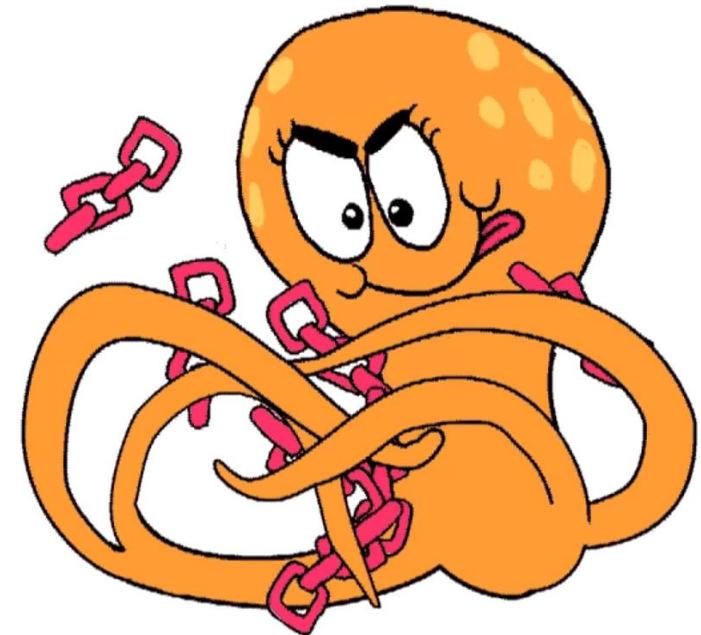


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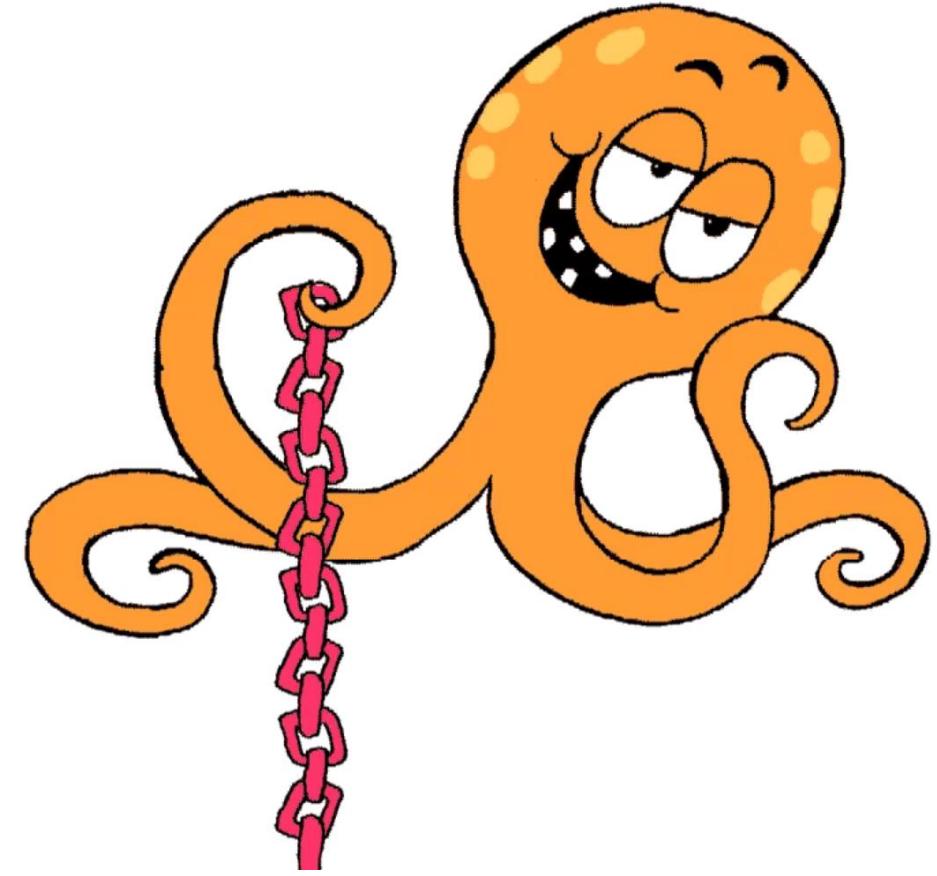


25 focused tangled octopus-20180922T134857Z-001.zip

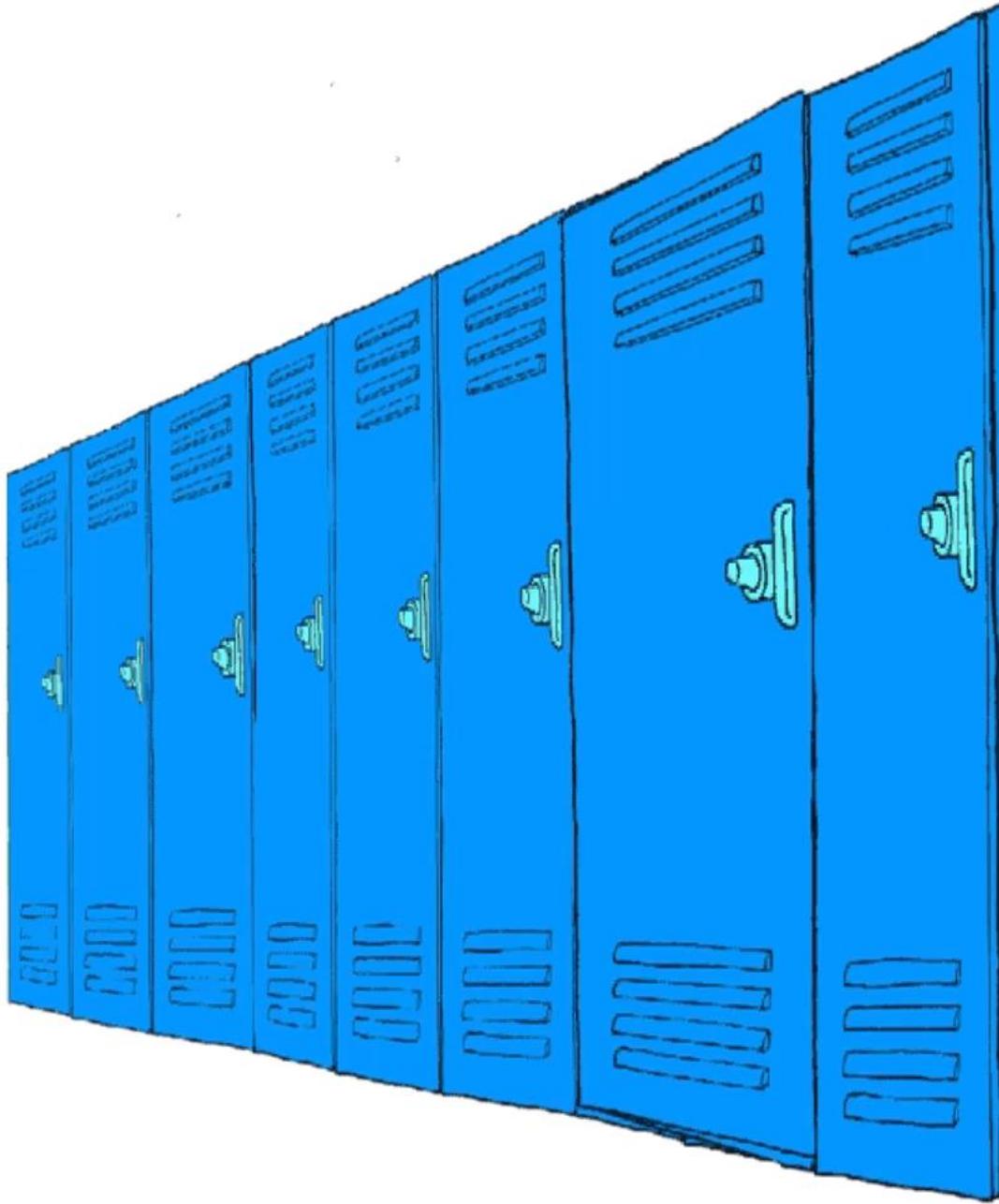
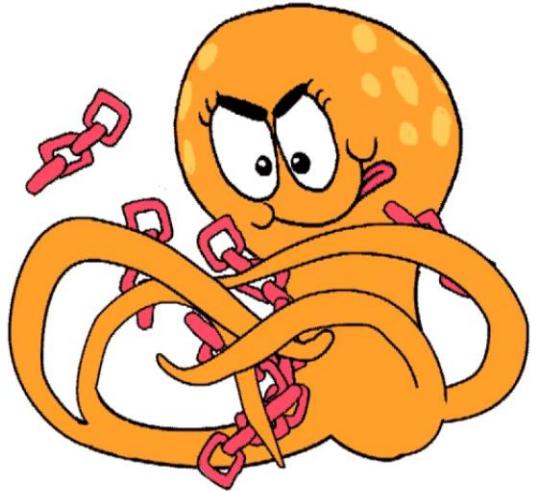


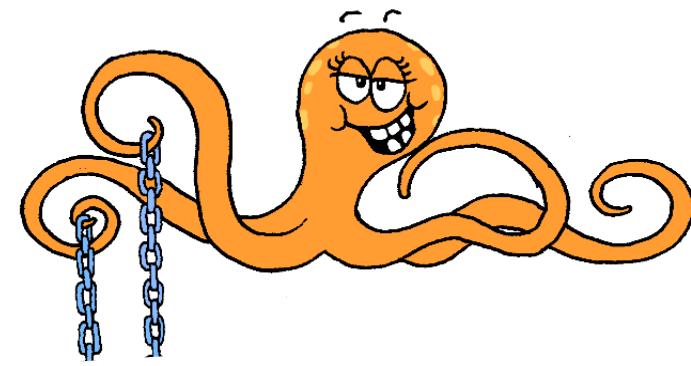


- Heavy cognitive load
- No working memory is available for anything else

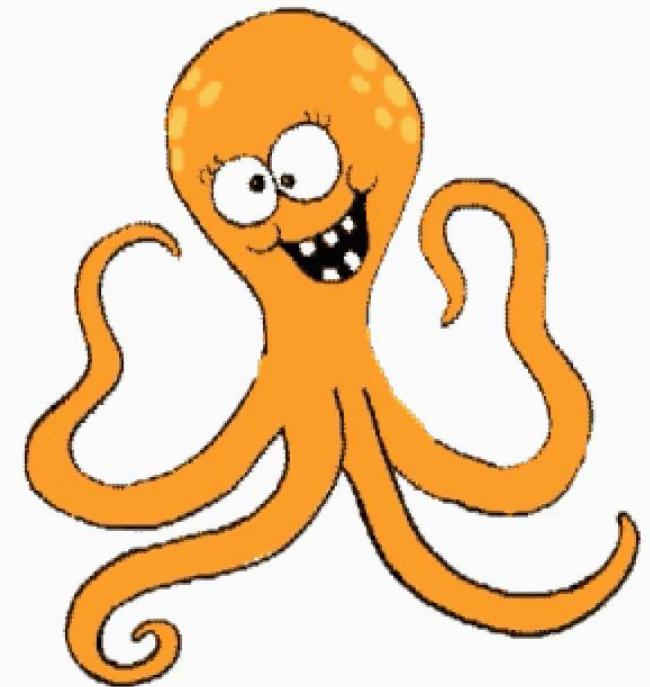


- Light cognitive load!
- Working memory is available for more complex thinking





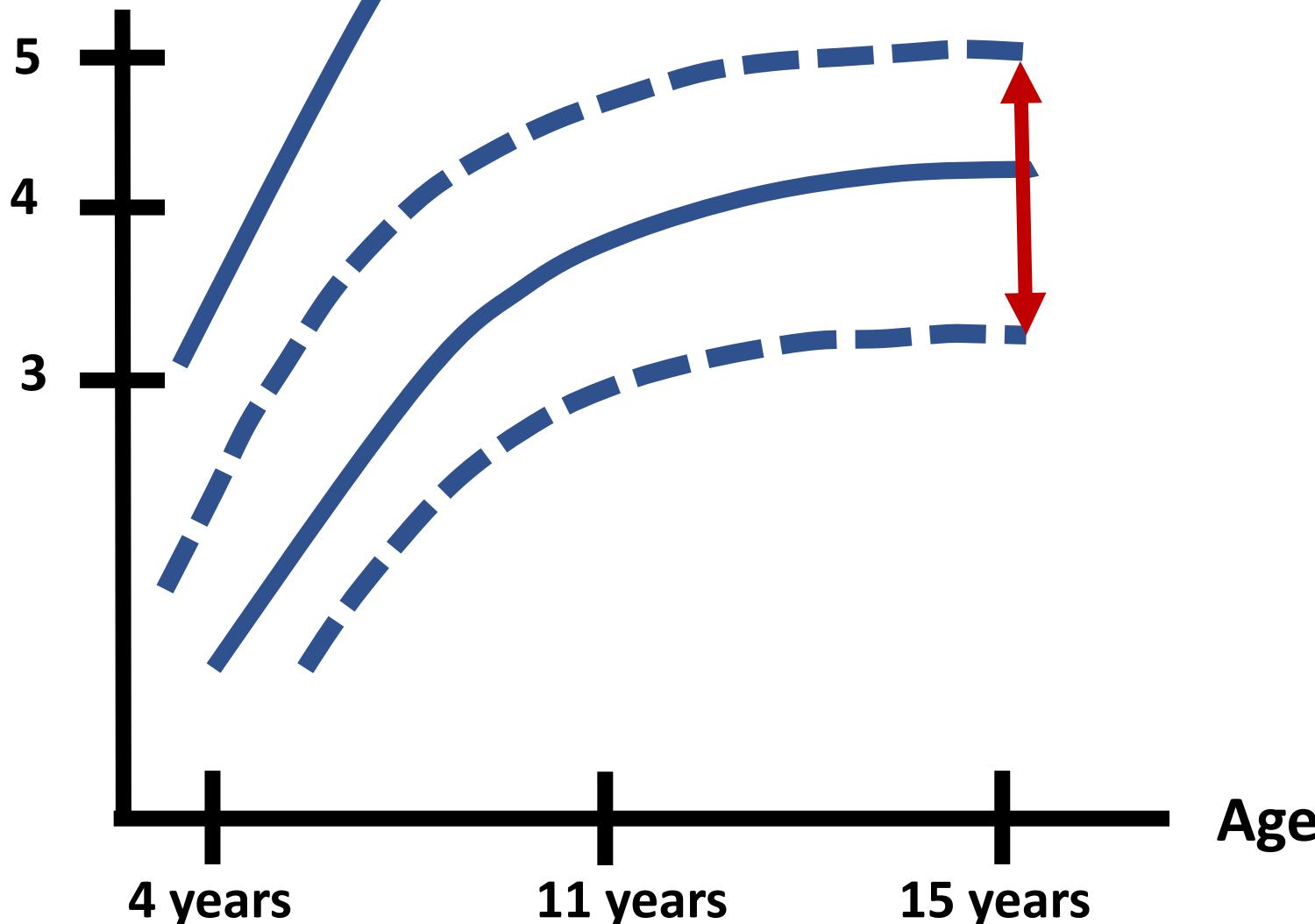
Working memory capacities vary



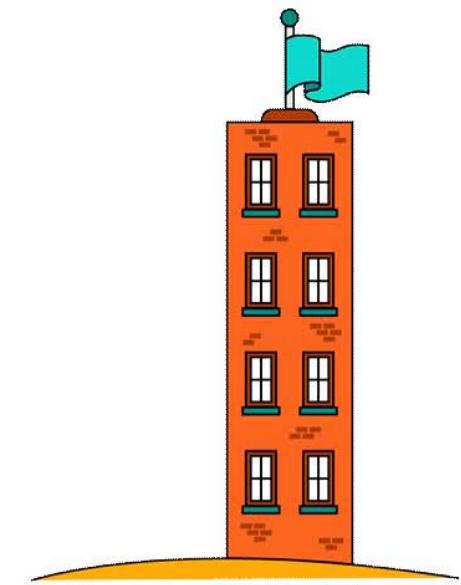
What about growth mindset?



Working memory capacity (pieces of information)



Differentiation



More practice

Changes in working memory capacity with age

Expertise reversal effect

The more knowledgeable a student is about a topic, the less guidance they need. Too much guidance in these situations can impede learning.

- Kalyuga, S., & Renkl, A. (2010). Expertise reversal effect and its instructional implications, *Instructional Science*, 38(3), 209-215. doi:10.1007/s11251-009-9102-0
- Chen, O., Kalyuga, S., & Sweller, J. (2017). The expertise reversal effect is a variant of the more general element interactivity effect. *Educational Psychology Review*, 29(2), 393-405.

To find all references for this presentation:

[https://barbaraoakley.com/
presentation-and-
references/](https://barbaraoakley.com/presentation-and-references/)



References Barb Oakley Presentation

General information on forming memories

- For a complete history of Hebbian learning, see (Sejnowski, 1999).
- Although not a rigorous source, an overview of the most recent findings related to how dendrites emerge and meet axons can be found here:
[https://en.wikipedia.org/wiki/Dendritic filopodia](https://en.wikipedia.org/wiki/Dendritic_filopodia).
- Recent overview of memory and consolidation processes: (Runyan, Moore, & Dash, 2019).

Working memory, long-term memory, and retrieval practice

- Overviews of current conceptions of working memory: (Cowan, 2017).
- Retrieval practice is important for learning: (Jeffrey D Karpicke, 2012; Smith, Floerke, & Thomas, 2016).
- Students need to be taught the importance of retrieval practice: (Robert A. Bjork, 2018; Jeffrey D Karpicke & Grimaldi, 2012).
- The importance of working sample problems: (Chen, Kalyuga, & Sweller, 2015).
- Active retrieval promotes meaningful learning: (Jeffrey D Karpicke, 2012).
- Retrieval practice produces more learning than elaborative studying with concept mapping: (J. D. Karpicke & Blunt, 2011). On a side note, one recent study incorporated retrieval practice *with* concept mapping: (O'Day & Karpicke, 2020). Surprisingly, it didn't help.
- Review of neurocognitive architecture of working memory: (Eriksson, Vogel, Lansner, Bergström, & Nyberg, 2015). There are dozens of different definitions of working memory. See (Baddeley, 2003; Cowan, 2017; Turi, Alekseichuk, & Paulus, 2018).
- Increase in size in working memory with age, and the distribution of working memory sizes in



Photo by Erik van Leeuwen

Julius Yego



Active
Learning

Lecture

A

Lecture

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Learning

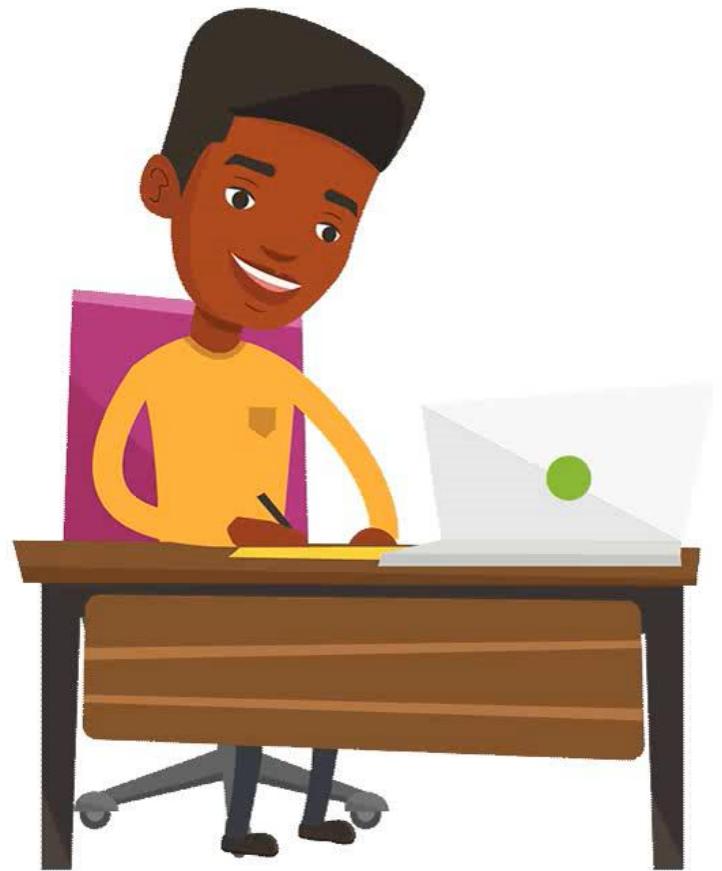
Lect-
ure

Active
Learning

Lecture



Direct instruction



Lecture

Active Learning

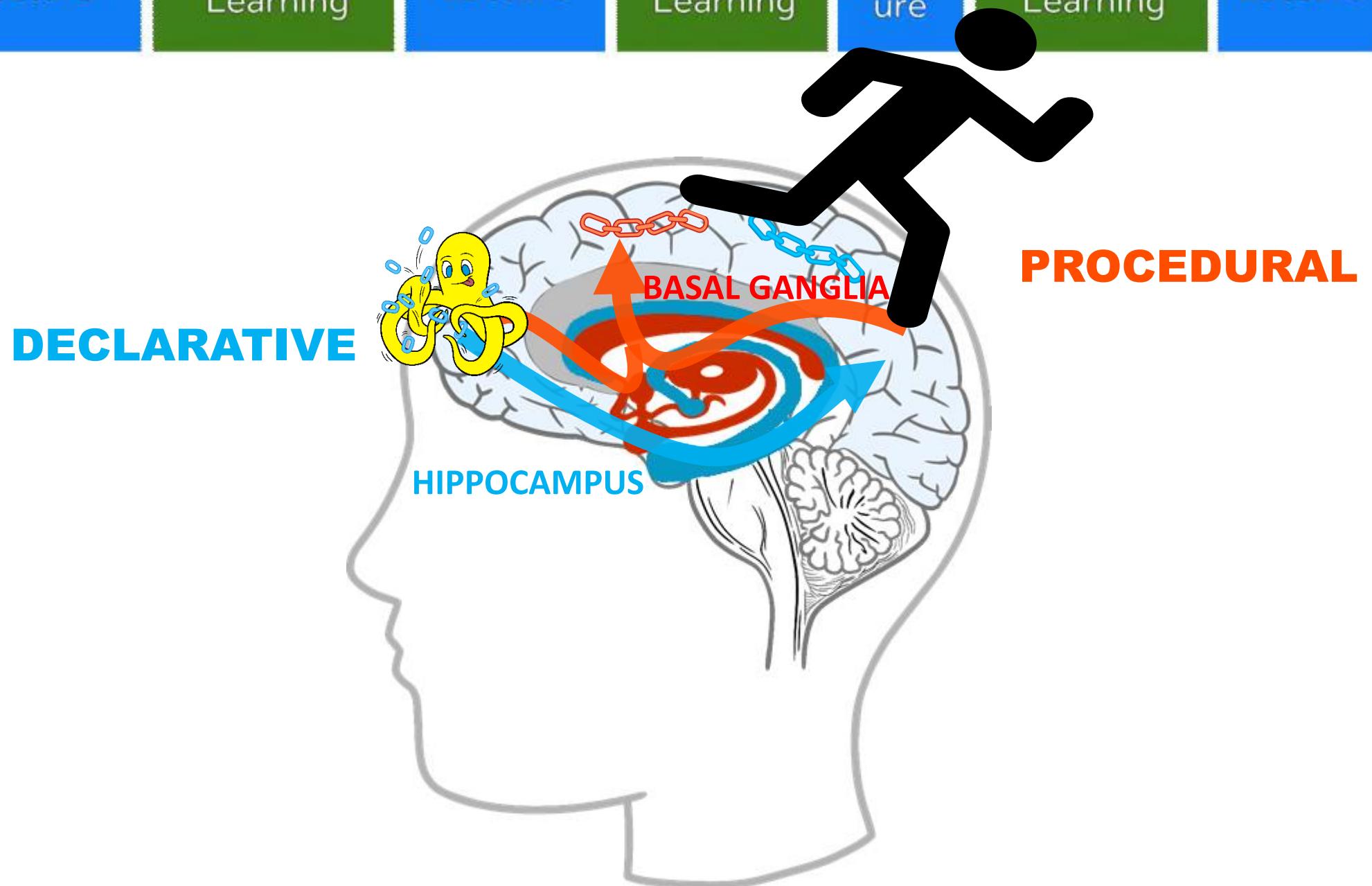
Lecture

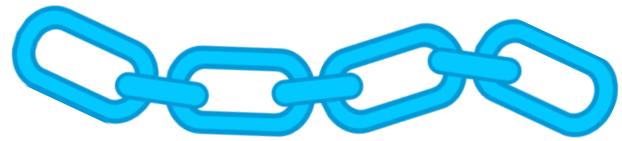
Active Learning

Lect-
ure

Active Learning

Lecture



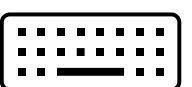


DECLARATIVE

- You're mostly conscious of it
- Develops through explicit instruction
- You can explain it.
- Involves sequential tasks.
- Fast to learn, slow to use.
- Flexible



PROCEDURAL

- You're not conscious of it
- Develops through *practice*
- You can't explain it (or not easily)
- Involves complex patterns
- Slow to learn, fast to use
- Inflexible 



DECLARATIVE



PROCEDURAL

RETRIEVAL PRACTICE

SPACED REPETITION

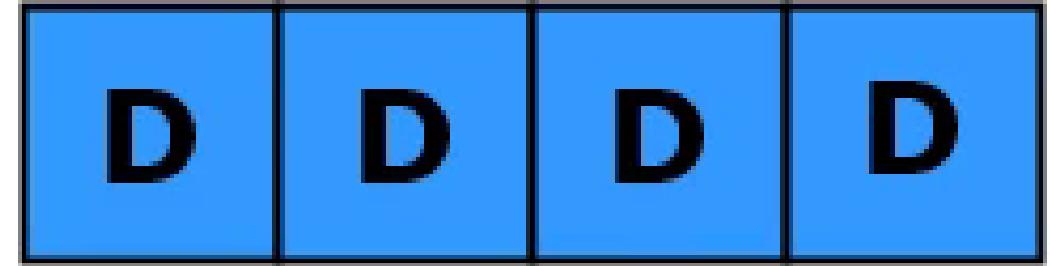
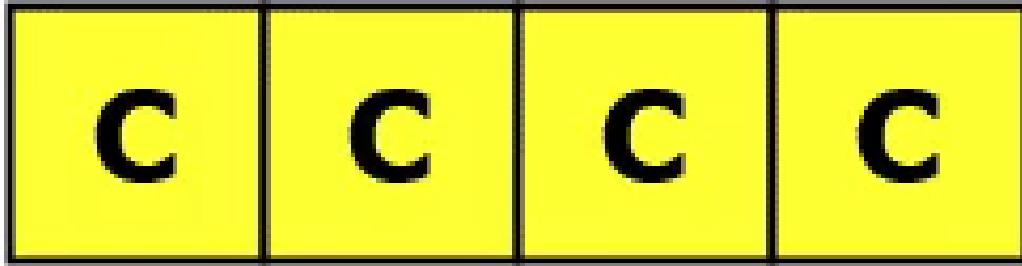
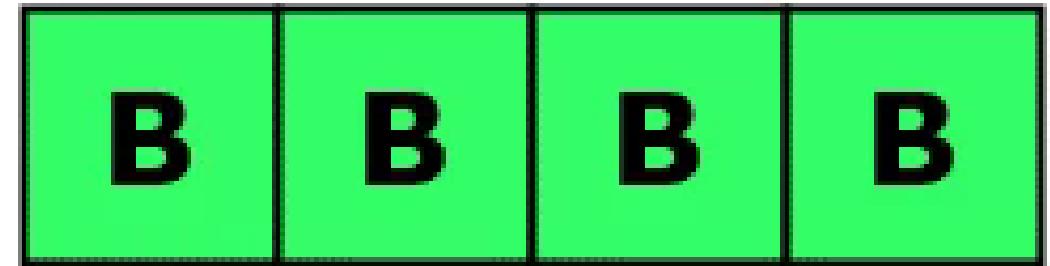
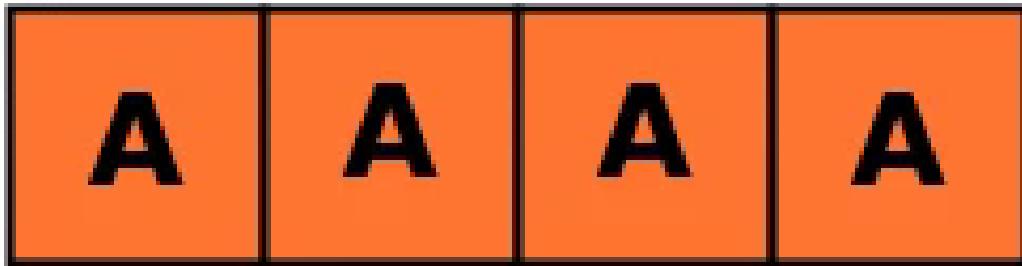


EXPLANATION

VARIED PRACTICE

INTERLEAVING

Blocking versus Interleaving



When you eliminate rote learning ("Drill and kill")

You eliminate the easiest, best way
the brain has to handle routine
learning tasks.

Drill to skill!

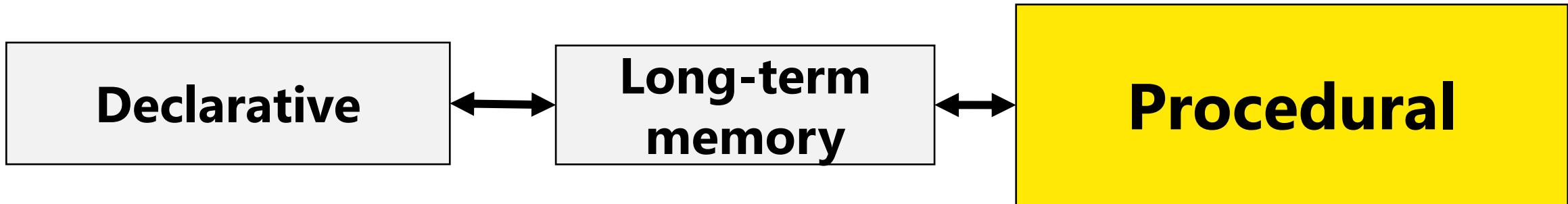


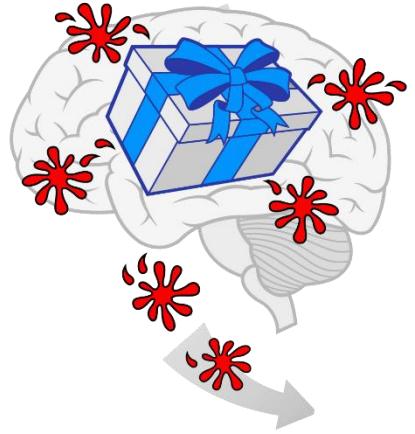
Declarative

**Long-term
memory**

Procedural







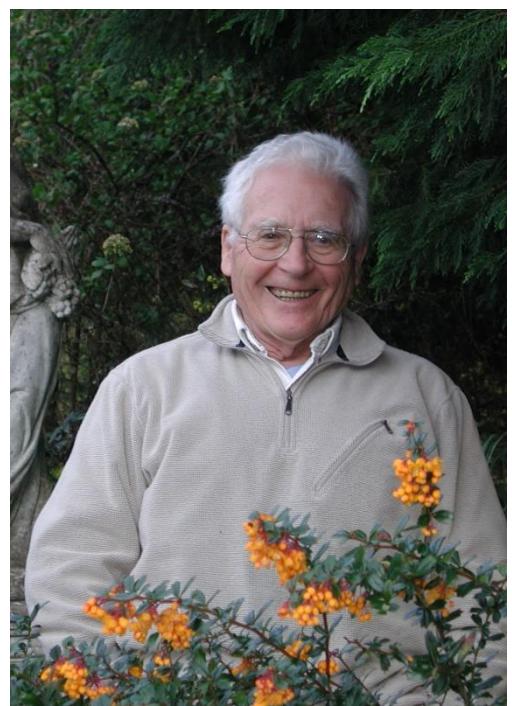
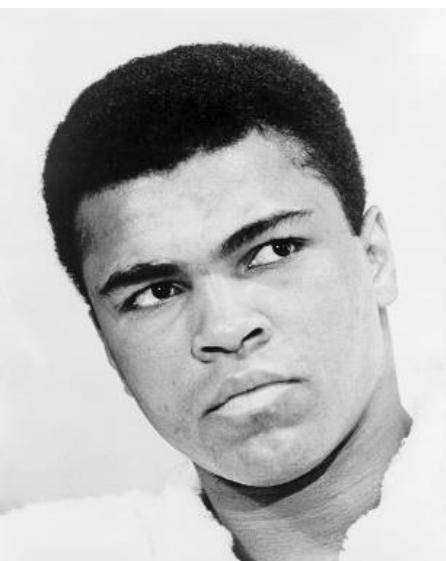
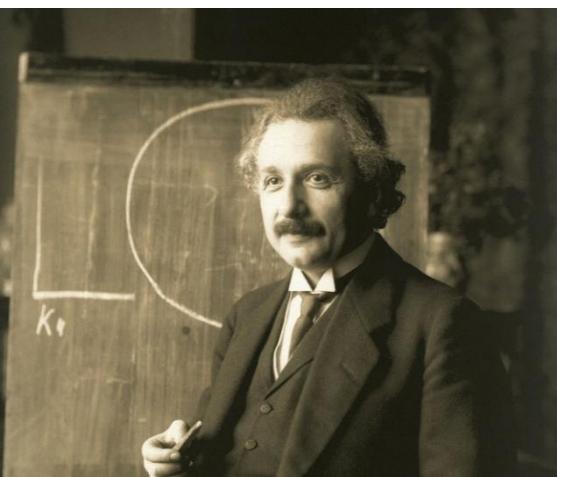
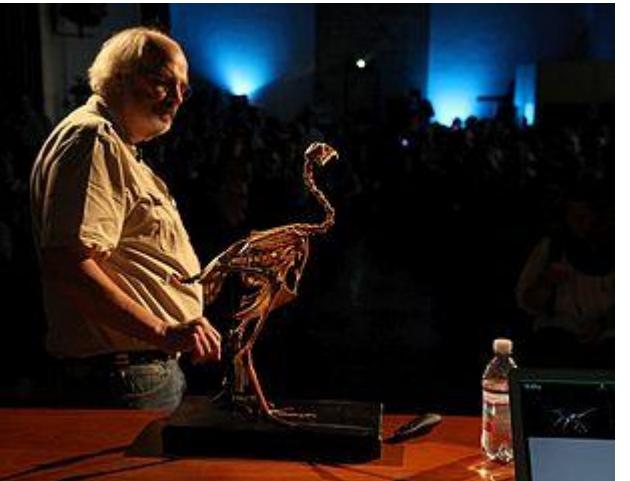
- Learning through one system can inhibit learning through the other
- Word-laden math impedes those with dyslexia

Dyslexia

Robinson and O'Connor (1988, unpublishted) reported significant improvements in subjects using a dual route in utilizing word-based, basic academic bigram reading comprehension, reading accuracy, and proportion of reading. Additionally, Wood (1987) evaluated the results of 17 students on 23 remedial high school students and a matched control group. Significant improvement for the experimental group was noted for time needed to locate words on a printed page, timed reading scores, length of time for sustained reading, and span of 18-21s, as well as other perceptual tasks. Additionally, seven of the 23 experimental found employment, but none of the control group was employed by the end of the semester.

In contrast, Winters (1987) was unable to find differences in his study. Winters gave 15 elementary school children four minutes to locate and circle 68 examples of the letter "b" on three pages, each page of which contained 600 random letters in 20 lines of

Nature loves heterogeneity —Terrence Sejnowski



The Challenges of Collaborative and Team Learning

OPINION

Why I'm Learning More With Distance Learning Than I Do in School

I'm 13 years old. I don't miss the other kids who talk out of turn, disrespect teachers and hit one another.

May 5, 2020

By Veronique Mintz

Ms. Mintz is an eighth-grade student.

"I go to a school that puts a big emphasis on collaborative learning; approximately 80 percent of our work is done in teacher-assigned groups of three to five students. This forces students who want to complete their assignments into the position of having to discipline peers who won't behave and coax reluctant group members into contributing." In essence, Veronique dreaded school because of teacher's inability to manage students, especially when it came to learning in groups.



Large teams develop and small teams disrupt science and technology

Lingfei Wu^{1,2}, Dashun Wang^{3,4,5} & James A. Evans^{1,2,6*}

One of the most universal trends in science and technology today is the growth of large teams in all areas, as solitary researchers and small teams diminish in prevalence^{1–3}. Increases in team size have been attributed to the specialization of scientific activities³, improvements in communication technology^{4,5}, or the complexity of modern problems that require interdisciplinary solutions^{6–8}. This shift in team size raises the question of whether and how the character of the science and technology produced by large teams differs from that of small teams. Here we analyse more than 65 million papers, patents and software products that span the period 1954–2014, and demonstrate that across this period smaller teams have tended to disrupt science and technology with new ideas and opportunities, whereas larger teams have tended to develop existing ones. Work from larger teams builds on more-

difference between two well-known articles: one about self-organized criticality¹⁷ (the BTW model, after the authors' initials) and another about Bose–Einstein condensation¹⁸ (for which Wolfgang Ketterle was awarded the 2001 Nobel Prize in Physics) (Fig. 1, Extended Data Fig. 1b). The two articles have received a similar number of citations, but most research subsequent to the BTW-model article has cited only the model itself without mentioning references from the article. By contrast, the Bose–Einstein condensation article is almost always co-cited with Bose¹⁹, Einstein²⁰ and other antecedents. The difference between the two papers is reflected not in citation counts but in whether they suggested or solved scientific problems—whether they disrupted or developed existing scientific ideas, respectively²¹. The BTW model launched new streams of research, whereas the experimental realization of Bose–Einstein condensation elaborated upon possibilities that

The Biggest Challenge of Teamwork

**There will always be some team members
who do not pull their weight**

A photograph showing the back of a man with short brown hair, wearing a light-colored suit jacket over a white shirt. He is seated on a light-colored couch, facing a woman with long blonde hair who is wearing a grey sweater. The woman has her hands clasped near her face, appearing distressed. They are in a room with a lamp and a painting on the wall.

THE CHRONICLE OF HIGHER EDUCATION

The Disparity Between Intellect and Character

By Robert Coles | SEPTEMBER 22, 1995

**Harvard's
“Michael”**



Using a Case Study to Help Students Learn How to Implement Boundaries

How to Manage Yourself in a Collaborative Team

You will usually find your teammates as interested in learning as you are. Occasionally, however, you may encounter a person who creates difficulties. This handout is meant to give you practical advice for this type of situation.

To begin with, let's imagine you have been assigned to a group this marking period with three others: Mary, Henrietta, and Jack. Mary is okay—she struggles with some of the more difficult material, but she tries hard, and she willingly does things like getting extra help from the teacher. Henrietta is irritating. She's nice, but she just doesn't put in the effort to do a good job. She'll sheepishly hand over partially worked homework problems and confess to spending the weekend watching TV. Jack, however, has been nothing but trouble. Here are a few of the things he has done:

- Jack infrequently turns in his part of an assignment. When he does, it's almost always wrong—he obviously spent just enough time to scribble something down that looks what it's supposed to be.
- He is off task or flees whenever the group works together, either in person or virtually. He always seems to be out of his seat for some reason—needing to go to the bathroom, getting a drink, covertly distracting other students in the class.
- When the group communicates outside of class, he ghosts them and later claims he never received any messages. If the group decides to meet before or after school, he has a litany of excuses as to why he can't meet.
- Jack's writing skills are okay, but he loses the drafts and doesn't reread his work. You've stopped assigning him work because you don't want to miss your teacher's strict deadlines.

Policies for Team Assignments[†]

Your team will have a number of responsibilities as it completes problem and project assignments.

- *Designate a coordinator, recorder and checker for each assignment. Add a monitor for 4-person teams.* Rotate these roles for every assignment.
- *Agree on a common meeting time and what each member should have done before the meeting* (readings,taking the first cut at some or all of the assigned work, etc.)
- *Do the required individual preparation.*
- *Coordinator checks with other team members before the meeting to remind them of when and where they will meet and what they are supposed to do.*
- *Meet and work.* **Coordinator** keeps everyone on task and makes sure everyone is involved, **recorder** prepares the final solution to be turned in, **monitor** checks to makes sure everyone understands both the solution and the strategy used to get it, and **checker** double-checks it before it is handed in. Agree on next meeting time and roles for next assignment. For teams of three, the same person should cover the monitor and checker roles.
- *Checker turns in the assignment, with the names on it of every team member who participated actively in completing it.* If the checker anticipates a problem getting to class on time on the due date of the assignment,it is his/her responsibility to make sure someone turns it in.
- *Review returned assignments.* Make sure everyone understands why points were lost and how to correct errors.
- *Consult with your instructor if a conflict arises that can't be worked through by the team.*

TEAM EXPECTATIONS AGREEMENT[†]

On a single sheet of paper, put your names and list the rules and expectations you agree as a team to adopt. You can describe any or all responsibilities—preparation for and attendance at group meetings, making sure everyone understands all the solutions, communicating frankly but with respect when conflicts arise, etc. Each team member should sign the sheet, indicating acceptance of these expectations and intention to fulfill them. Turn one copy in to your teacher, and keep a remaining copy or copies for yourselves.

These expectations are for your use and benefit—they won't be graded or commented on unless you specifically ask for comments. Note, however, that if you make the list fairly thorough without being unrealistic you'll be giving yourselves the best chance. For example, “We will each solve every problem in every assignment completely before we get together” or “We will get 100 on every assignment” or “We will never miss a meeting” are probably unrealistic, but “We will try to set up the problems individually before meeting” and “We will make sure that anyone who misses a meeting for good cause gets caught up on the work” are realistic.

[†]Adapted from Oakley, B, et al. "Turning student groups into effective teams." *Journal of Student Centered Learning* 2, no. 1 (2004): 9-34; in turn adapted from R. M. Felder & R. Brent, *Effective Teaching*, North Carolina State University, 2000.

EVALUATION OF PROGRESS TOWARD EFFECTIVE TEAM FUNCTIONING[†]

Your Team Name: _____

Symptoms of Internal Meeting Problems	<u>Usually</u>	Sometimes	Hardly Ever
Team meetings generally begin 5-15 minutes late			
Members often arrive late, leave early, or never even show up for the meetings.			
No agenda exists—members simply have a vague notion of what they want to accomplish.			
One or two members monopolize discussion throughout the meeting.			
Members have not read the assignment, performed the necessary background research, or <u>done</u> what they were expected to do. Consequently, individuals are poorly prepared for the meeting.			
With words or by appearance, some members clearly			

Peer Rating of Team Members[†]

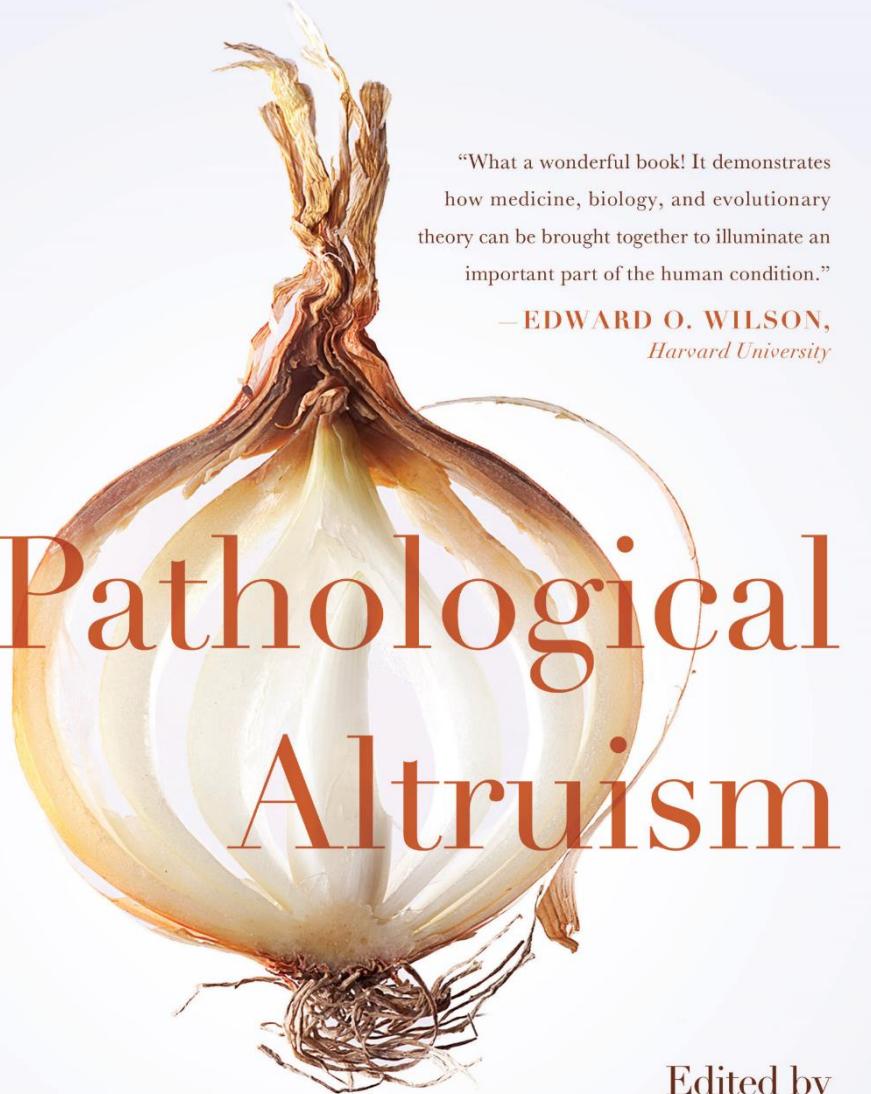
Your Name _____ Your Team _____

Please write the names of all of your team members, INCLUDING YOURSELF, and rate the degree to which each member fulfilled his/her responsibilities in completing the team assignments. *DO NOT LEAVE ANY COMMENTARY BLANK!* Place this form in a sealed envelope, with your team name/number on the outside, and give it to your instructor. The possible ratings are as follows:

- Excellent:** Consistently carried more than his/her fair share of the workload.
- Very good:** Consistently did what he/she was supposed to do, very well prepared and cooperative.
- Satisfactory:** Usually did what he/she was supposed to do, acceptably prepared and cooperative.
- Ordinary:** Often did what he/she was supposed to do, minimally prepared and cooperative.
- Marginal:** Sometimes failed to show up or complete assignments, rarely prepared.
- Deficient:** Often failed to show up or complete assignments, rarely prepared.
- Unsatisfactory:** Consistently failed to show up or complete assignments, unprepared.
- Superficial:** Practically no participation.
- No show:** No participation at all.

These ratings should reflect each individual's level of participation and effort and sense of responsibility, not his or her academic ability.

Name of team member	Rating	Commentary (DO NOT LEAVE BLANK!)
_____	_____	_____
_____	_____	_____
_____	_____	_____



Pathological Altruism

Edited by

Barbara Oakley, Ariel Knafo,
Guruprasad Madhavan, and David Sloan Wilson

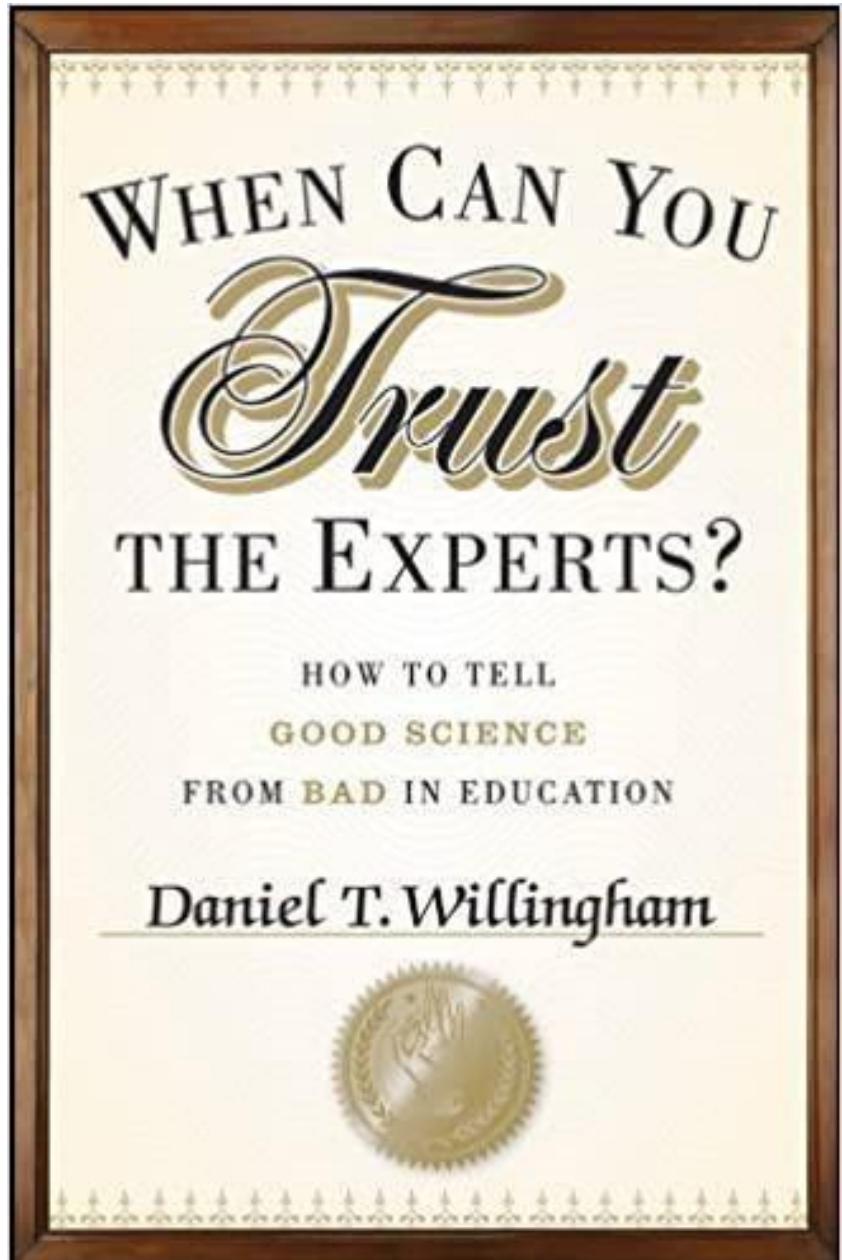
“What a wonderful book! It demonstrates how medicine, biology, and evolutionary theory can be brought together to illuminate an important part of the human condition.”
— EDWARD O. WILSON,
Harvard University

OXFORD

Early emphasis on empathy reaches the already-empathic

Can lead toward

- Being bullied
- Taken advantage of
- Codependency



Educators fall into two groups:

Understand the world through:

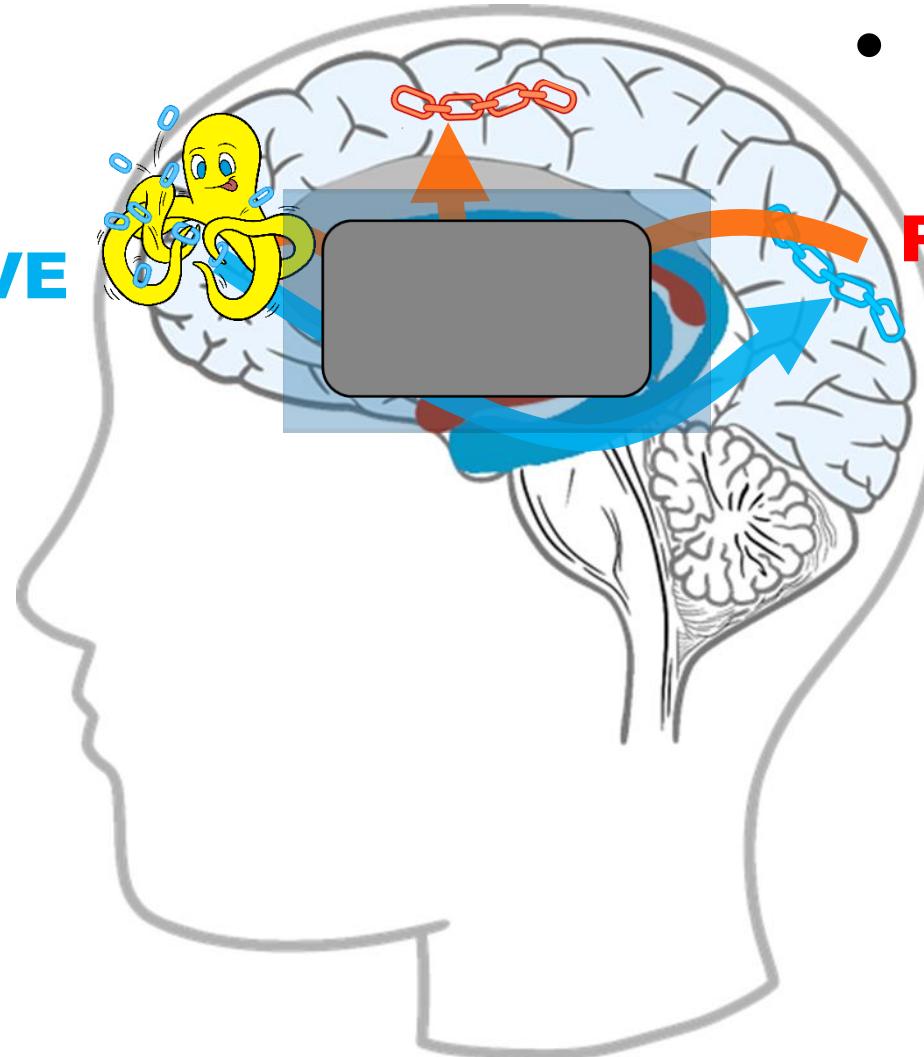
- **Reason**
- **Experience**

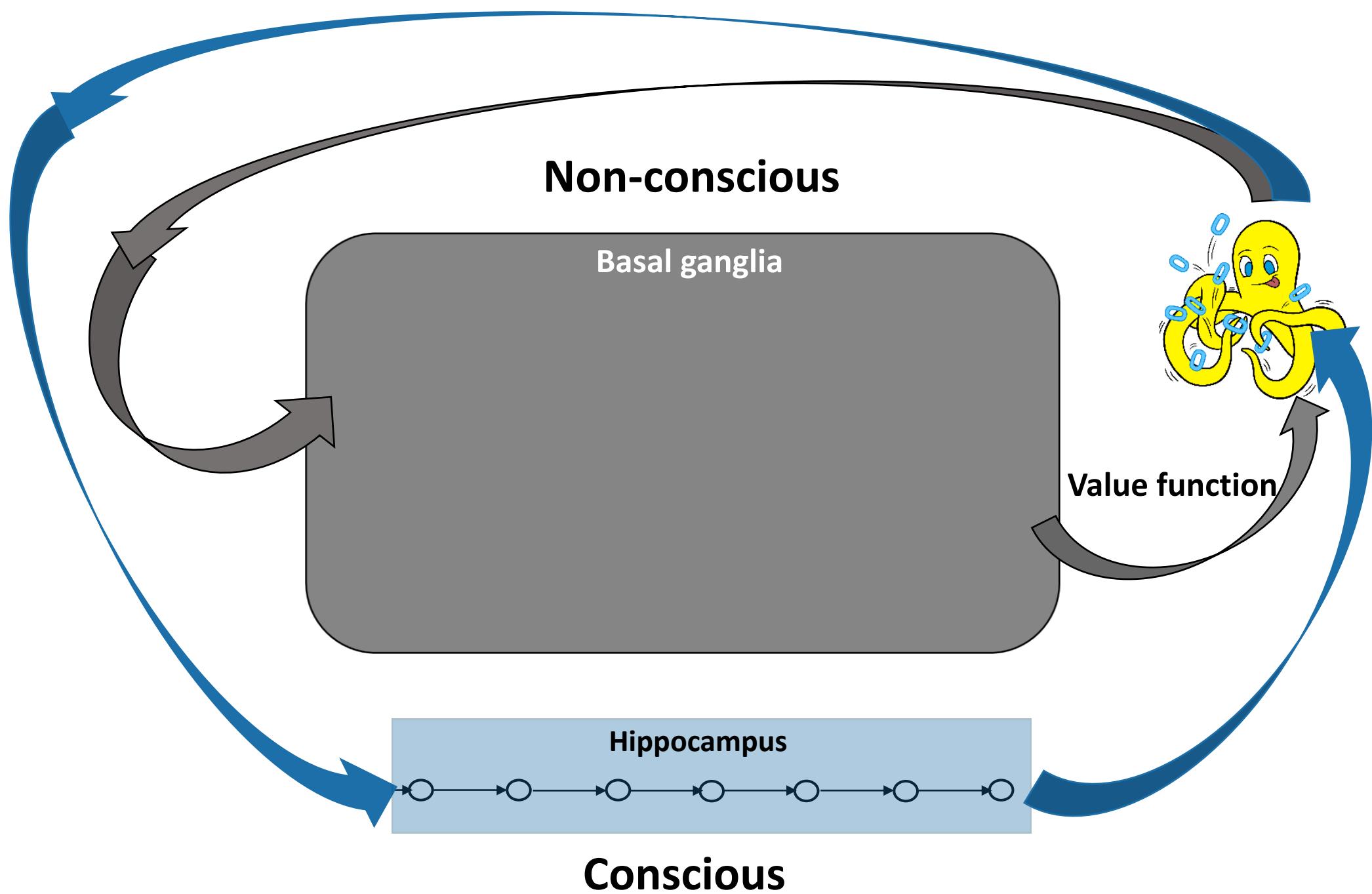
- Reason

DECLARATIVE

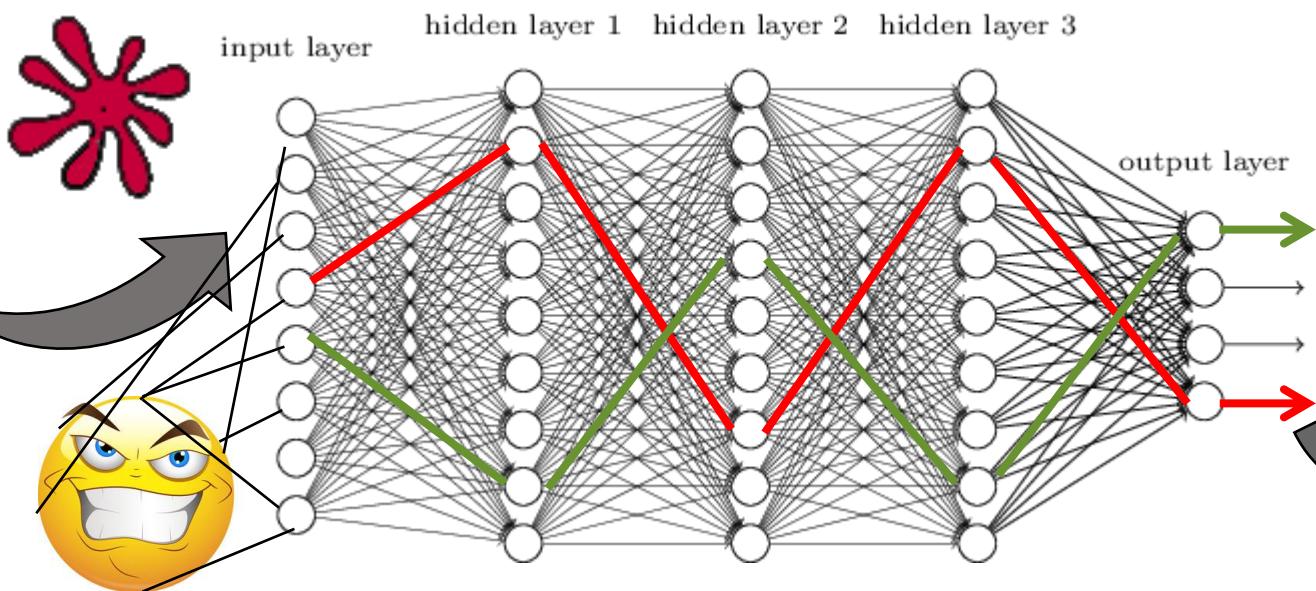
- Experience

PROCEDURAL





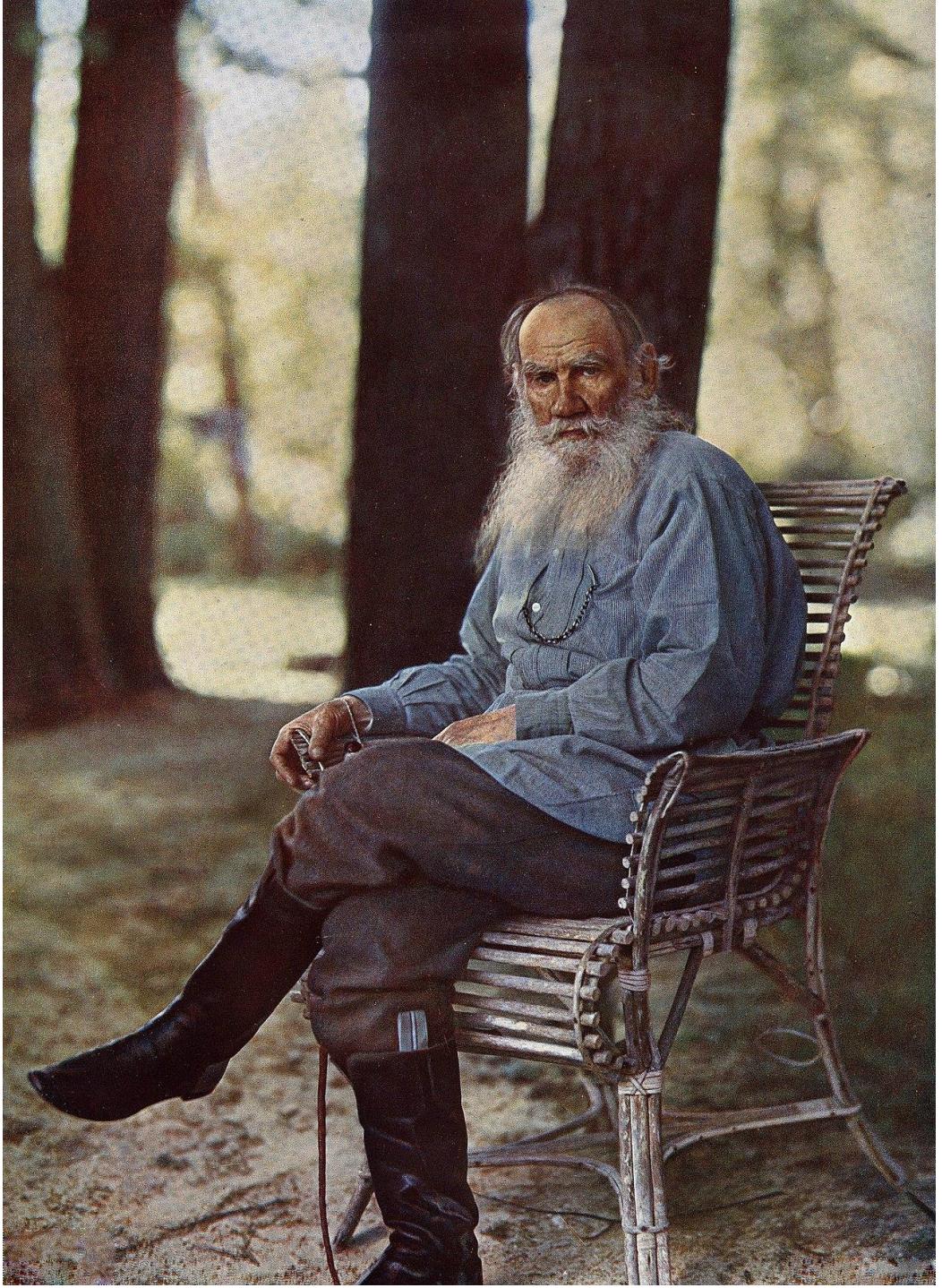
Non-conscious



Value function

Hippocampus

Conscious



Leo Tolstoy

“...the simplest thing cannot be made clear to the most intelligent man if he is firmly persuaded that he knows already, without a shadow of doubt, what is laid before him.”

**Technological progress in one area
can lead to surprising backward
steps in other areas.**



UNITED STATES WELCOMES YOU
TO THE SOUTH POLE







One of these things is not like the other. Which one?

**Ons of possession
lest we forget the dread vanities?**

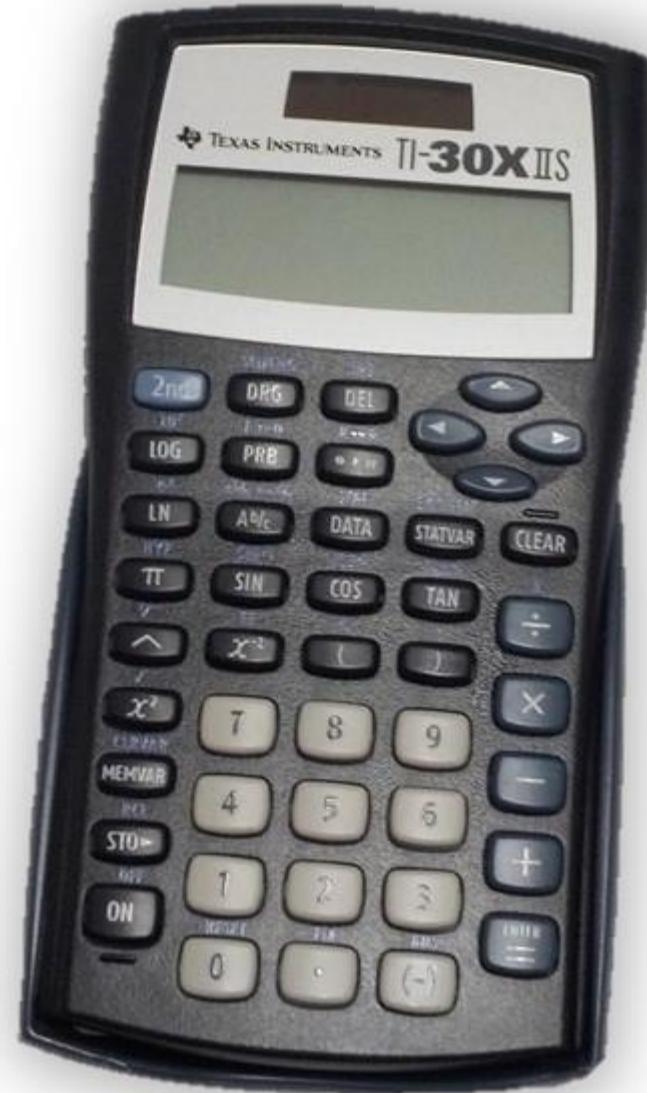
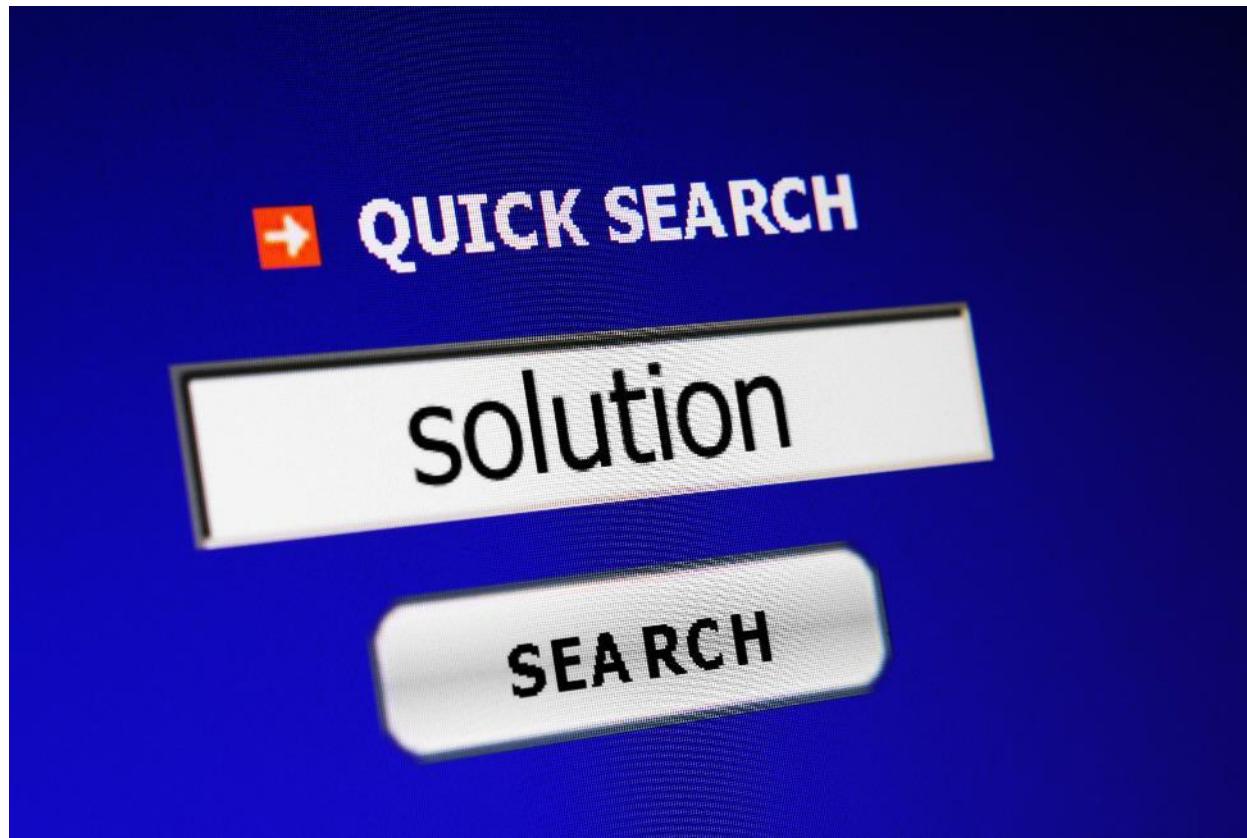
Is it possible to forget major advances?

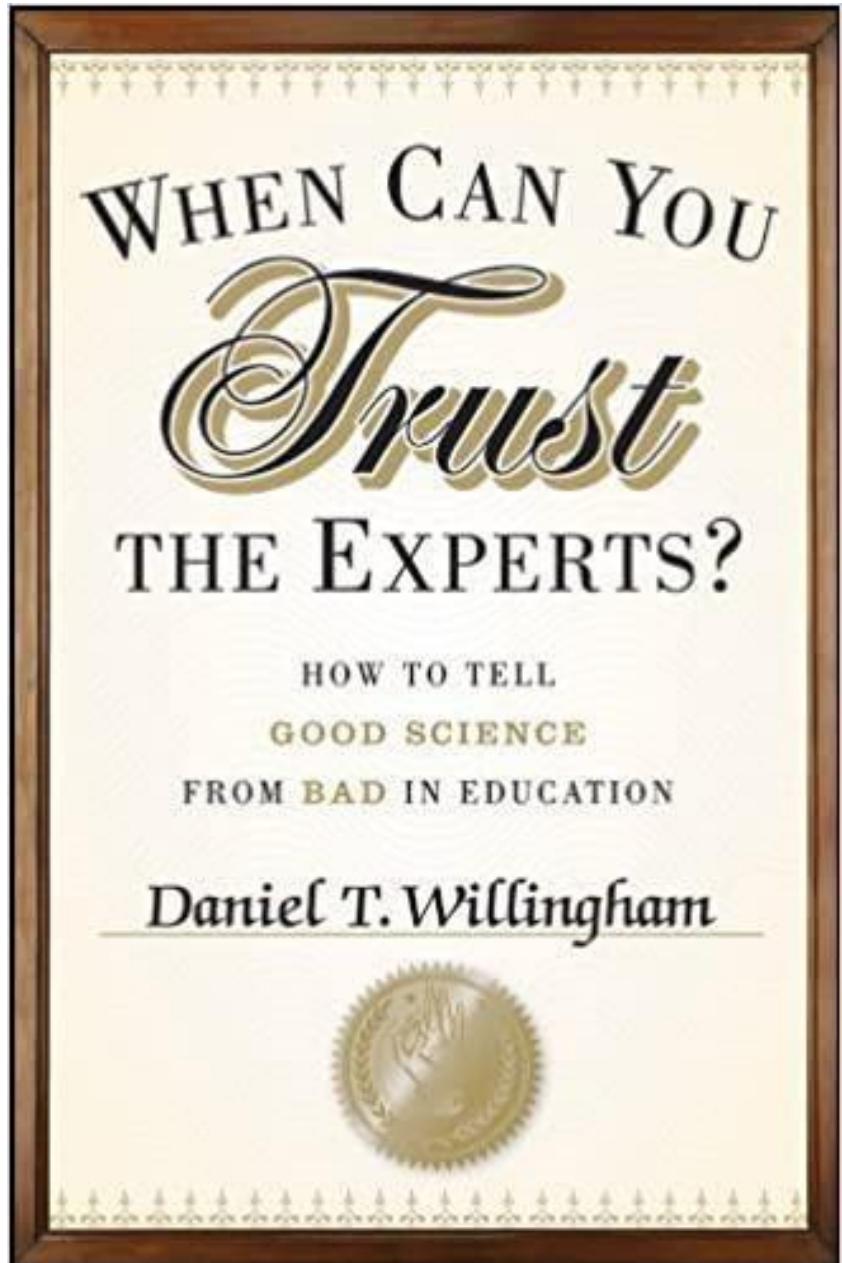


James Lund, ~1747



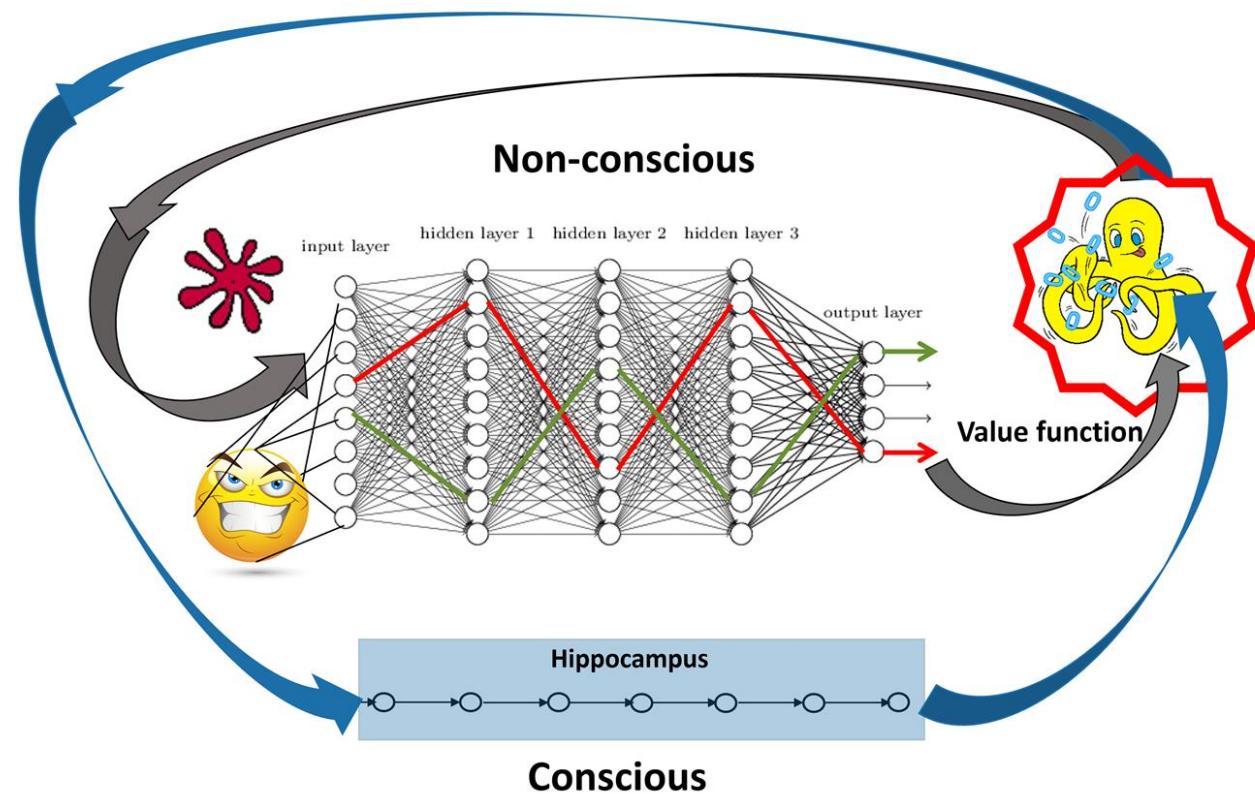
Robert Falcon Scott and his ill-fated team at the South Pole in Antarctica in 1912





Educators understand the world through:

- **Reason**
- **Experience**





Santiago
Ramón y Cajal

**YOU can help
re-establish education**

- Persistent
- Flexible

Credits

- Jack Horner Date: 29th May 2012 Venue: Museo di Storia Naturale, Milan, Italy www.meetthemediaguru.org
Twitter: @mmguru / #MMGHorner Photo by Paolo Sacchi,
[https://en.wikipedia.org/wiki/Jack_Horner_\(paleontologist\)#/media/File:Jack_Horner_with_bird.jpg](https://en.wikipedia.org/wiki/Jack_Horner_(paleontologist)#/media/File:Jack_Horner_with_bird.jpg)
- Bust photographic portrait of Muhammad Ali in 1967. World Journal Tribune photo by Ira Rosenberg.
https://en.wikipedia.org/wiki/Muhammad_Ali#/media/File:Muhammad_Ali_NYWTS.jpg,
- Steven Spielberg speaking at the 2017, by Gage Skidmore,
https://en.wikipedia.org/wiki/Steven_Spielberg#/media/File:Steven_Spielberg_by_Gage_Skidmore.jpg.
- Octavia Estelle Butler signing a copy of Fledgling after speaking and answering questions from the audience. Photo by Nikolas, Coukouma.https://en.wikipedia.org/wiki/Octavia_E._Butler#/media/File:Butler_signing.jpg.
- James Lovelock, scientist and author best known for the Gaia hypothesis. Photograph taken in 2005 by Bruno Comby of Association of Environmentalists For Nuclear Energy. Original at <http://www.ecolo.org/lovelock/>. Released under the Creative Commons Attribution-ShareAlike license versions 2.5, 2.0, and 1.0.
[https://commons.wikimedia.org/wiki/File:James_Lovelock,_2005_\(cropped\).jpg#/media/File:James_Lovelock_in_2005.jpg](https://commons.wikimedia.org/wiki/File:James_Lovelock,_2005_(cropped).jpg#/media/File:James_Lovelock_in_2005.jpg)
- Albert Einstein during a lecture in Vienna in 1921, by F Schmutzer – restoration.
https://en.wikipedia.org/wiki/Albert_Einstein#/media/File:Einstein_1921_by_F_Schmutzer_-_restoration.jpg.
- Photograph of Elon Musk, 2018, by [Duncan.Hull](#),
[https://commons.wikimedia.org/wiki/File:Elon_Musk_Royal_Society_\(cropped\).jpg](https://commons.wikimedia.org/wiki/File:Elon_Musk_Royal_Society_(cropped).jpg)
- Maria Skłodowska-Curie sometime prior to 1907, unknown author,
https://commons.wikimedia.org/wiki/File:Marie_Curie_c._1898.jpg.

To find research references for this presentation:

[https://barbaraoakley.com/
presentation-and-
references/](https://barbaraoakley.com/presentation-and-references/)

