Scientific Teaching

TDSB Eureka Conference 2017

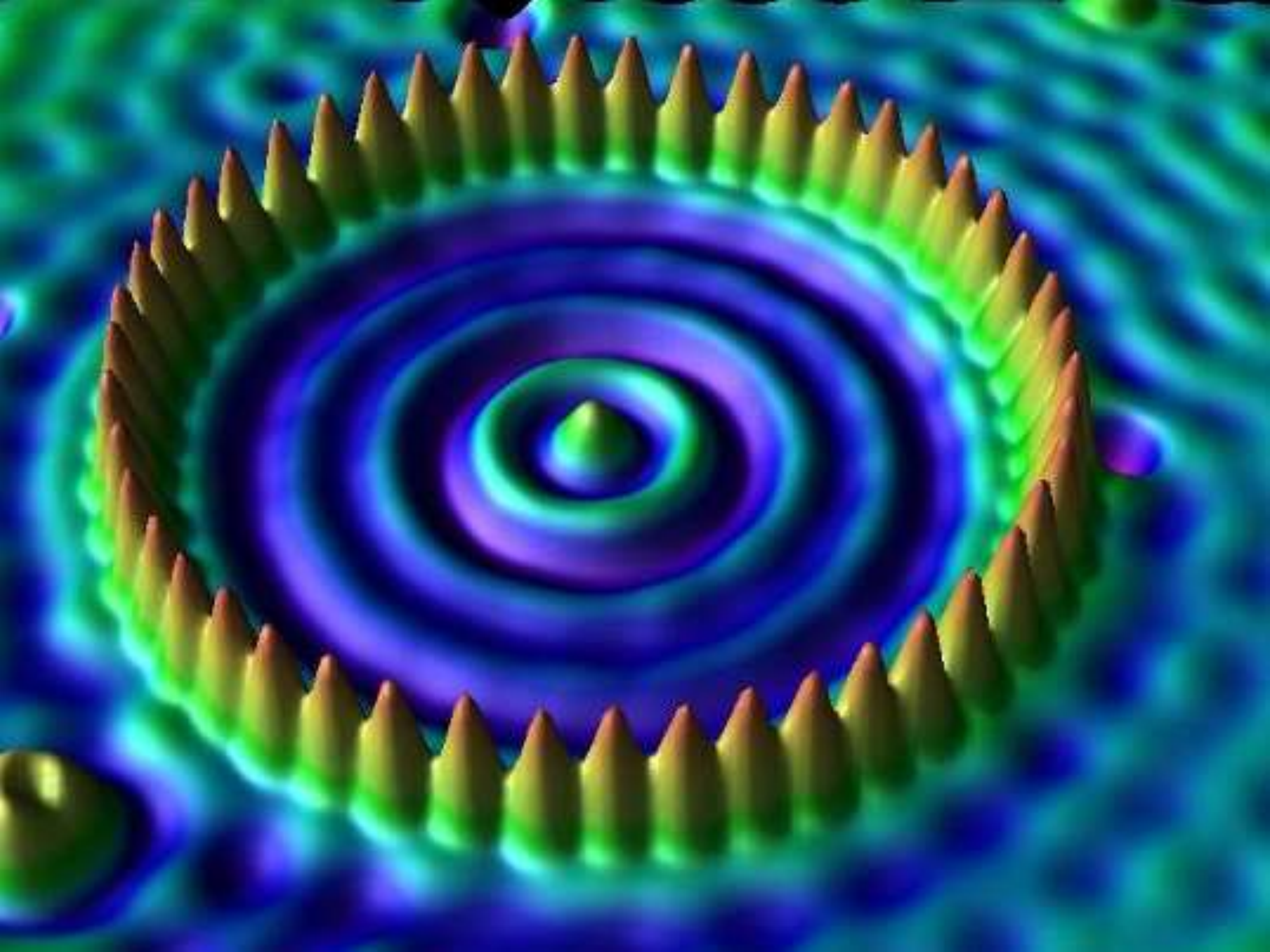
Chris Meyer
christopher.meyer@tdsb.on.ca
York Mills C. I., Toronto
www.meyercreations.com/physics

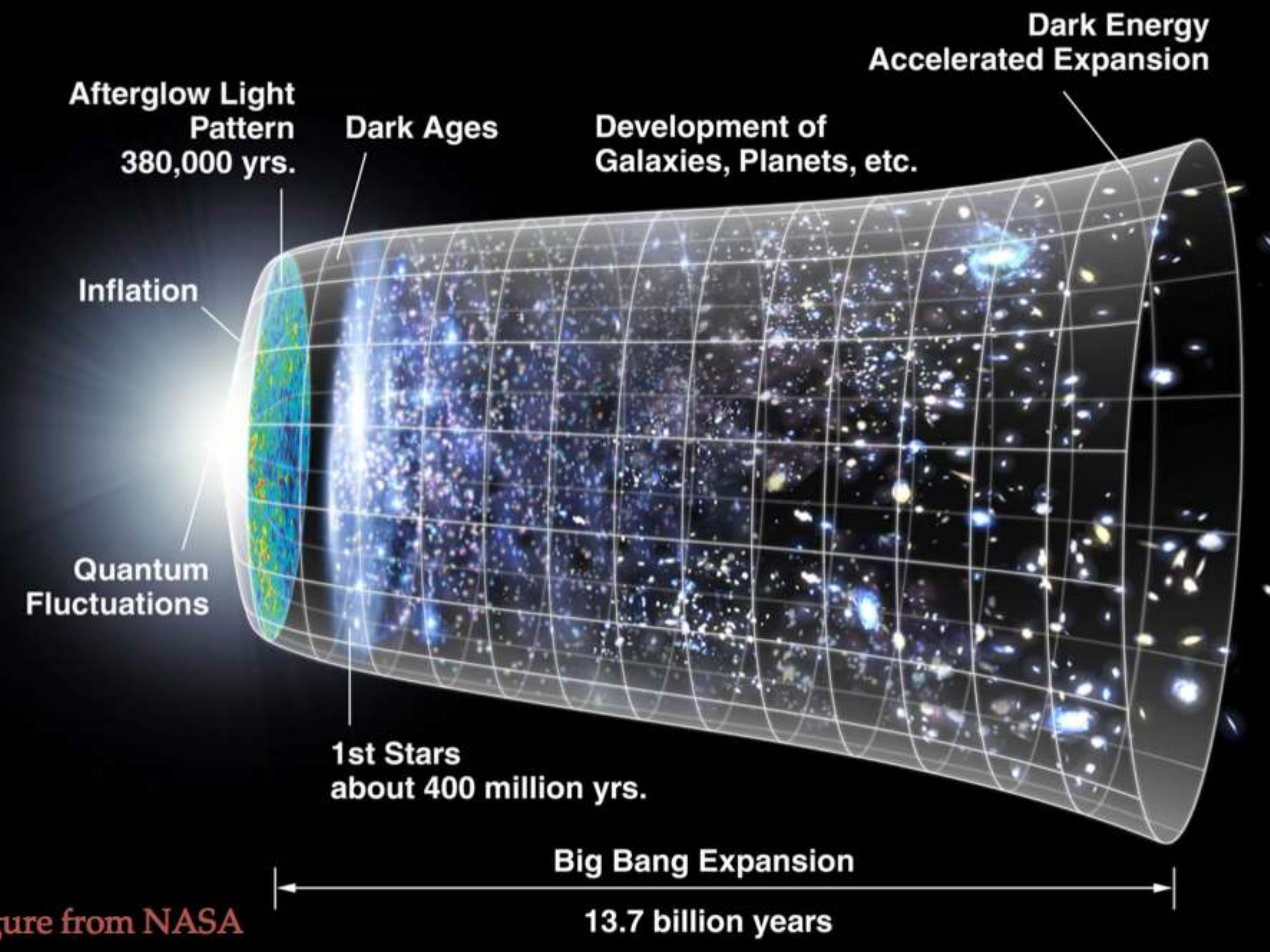
I

A

PHYSICIST

cktail Party



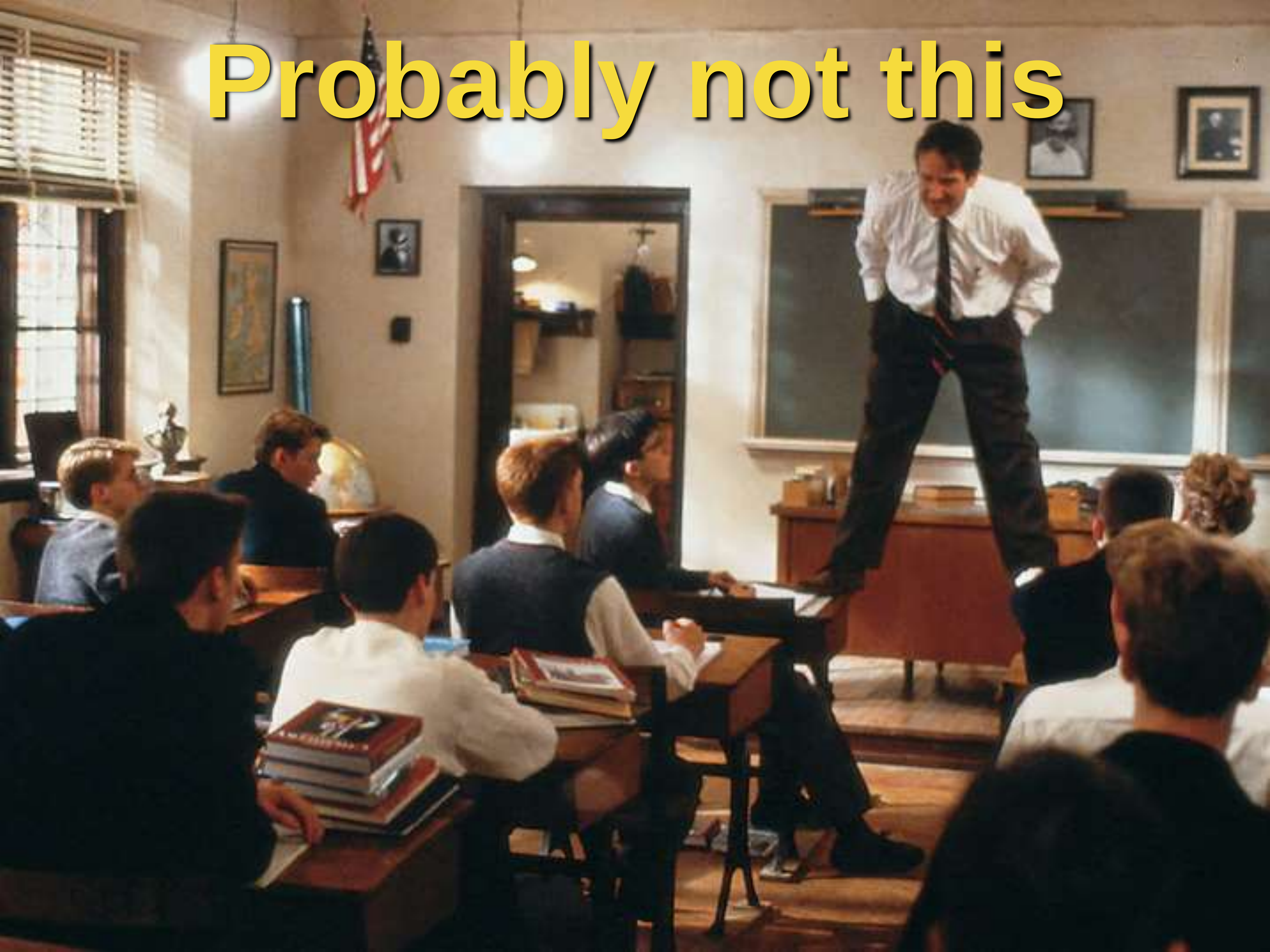


gure from NASA

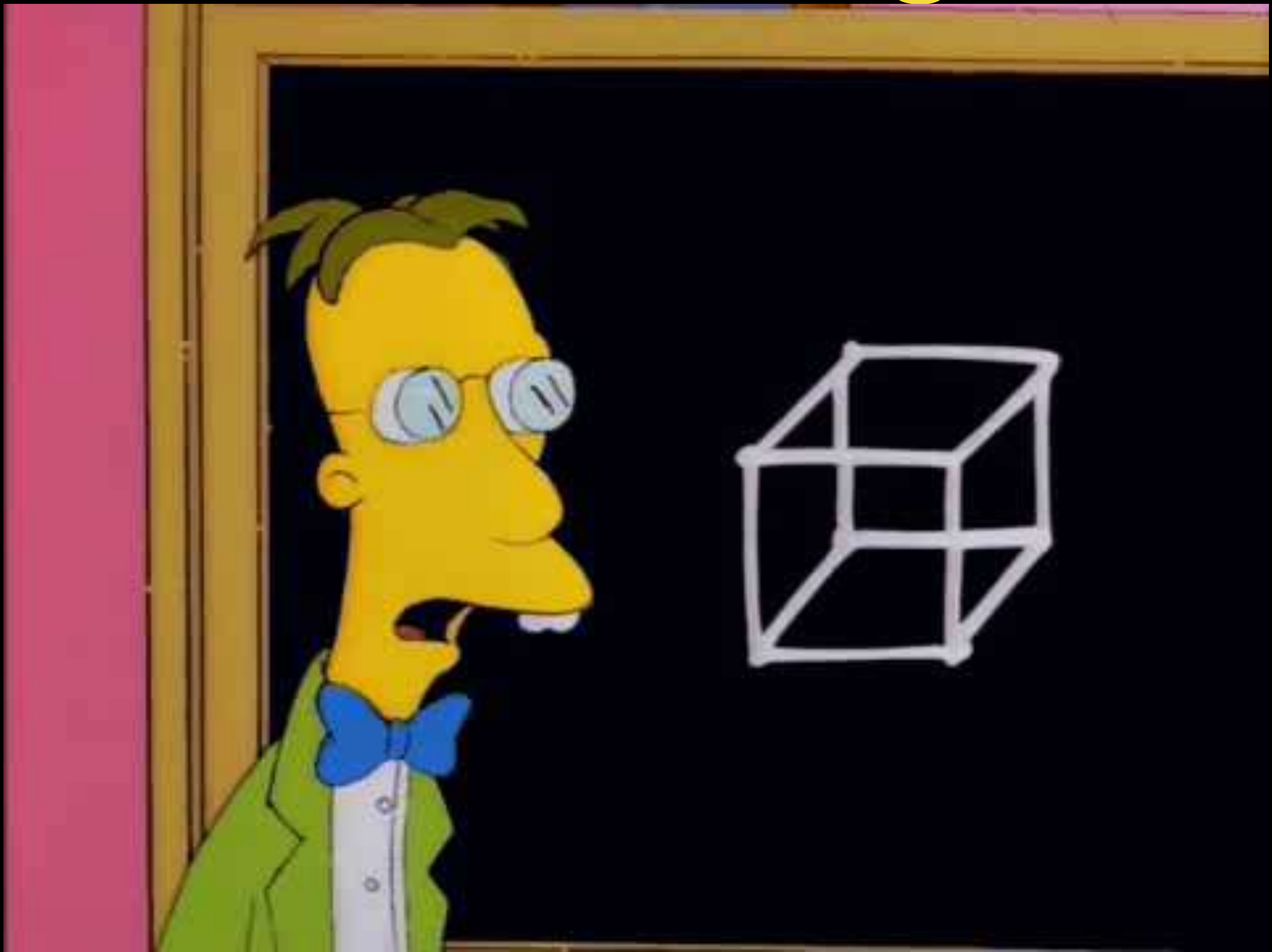

DATABASE SERVERS
PC DESKTOP
WORLD WIDE WEB
SERVERS
ISSUE DE SECOURS
EMERGENCY EXIT
Windows 2000 Servers
CERN
openlab
SIEMENS
egee
Enabling Grids
for E-sciencE

What about teaching?

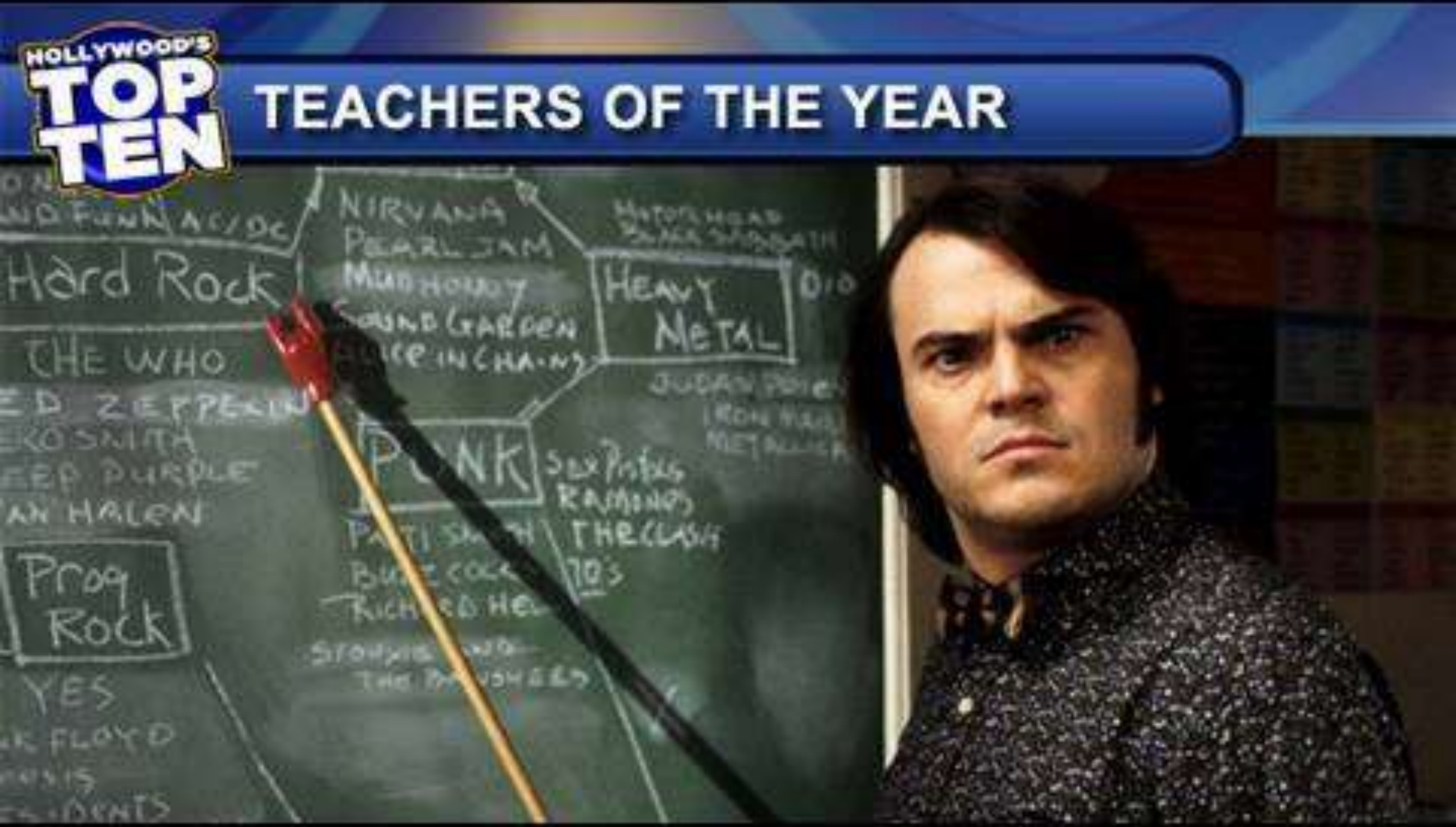
Probably not this



You’re thinking this



But we think this!




Force Concept Inventory

Force Concept Inventory

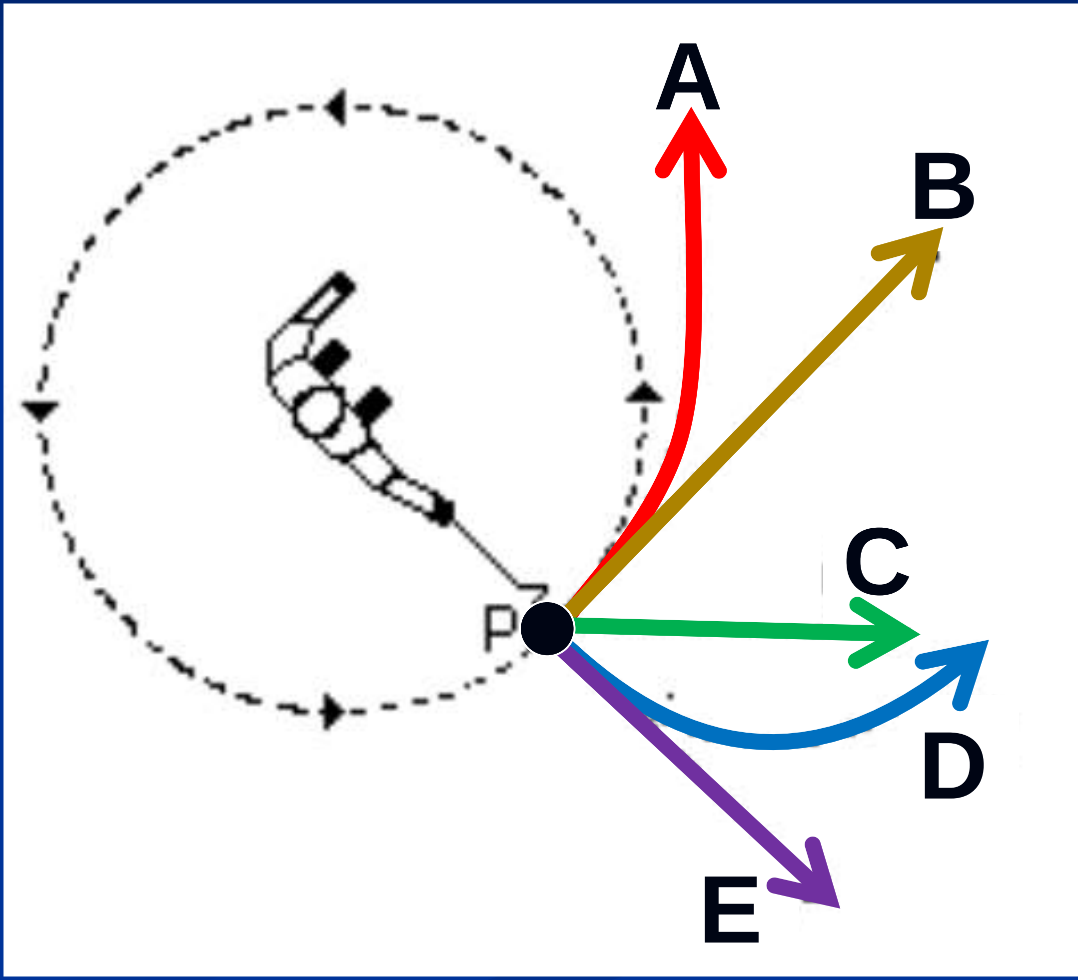
1:00

Stop

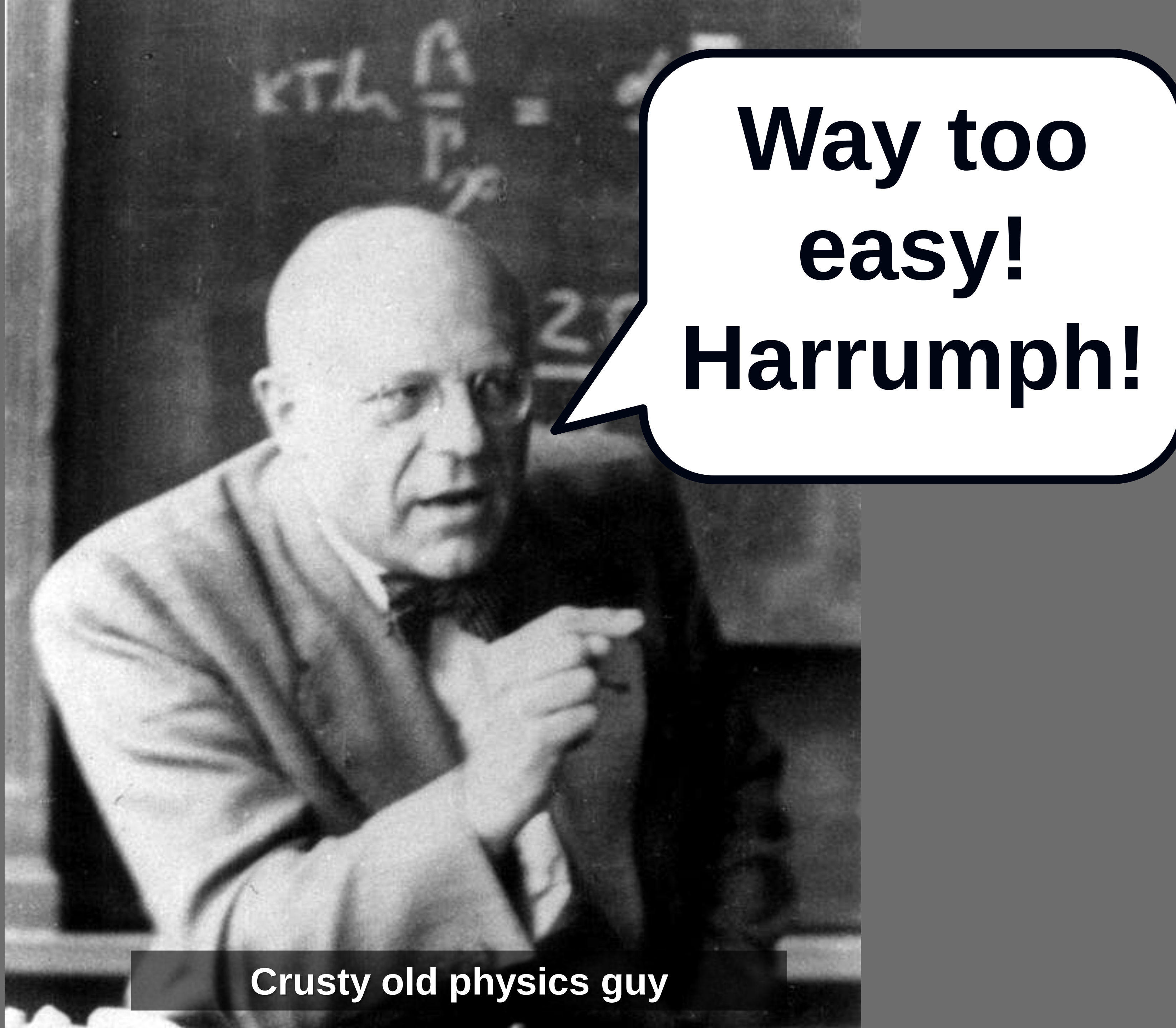
A ball on a string is swung in a horizontal circle.

At point P, the string breaks.

Which path would the ball most closely follow, observed from above?

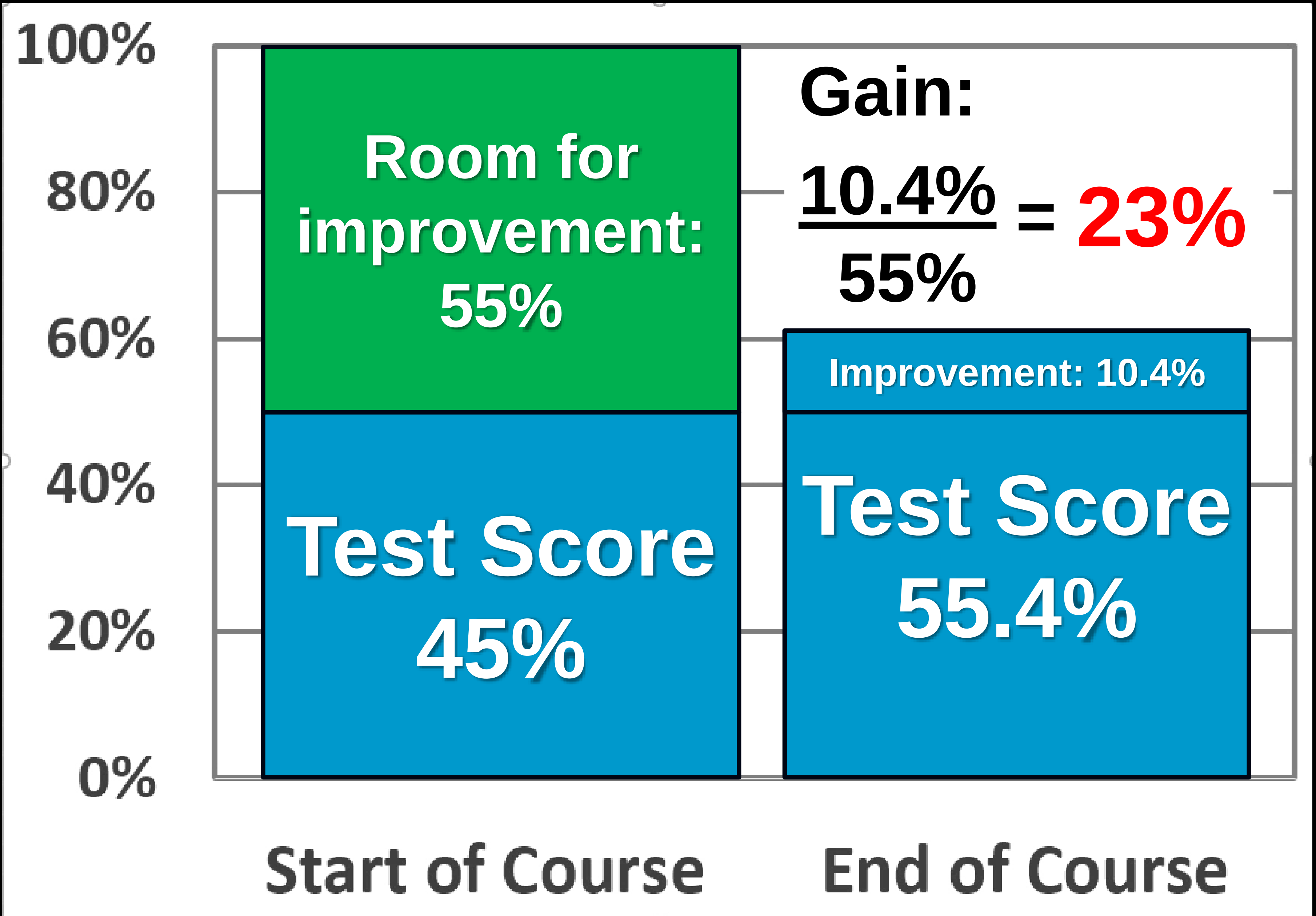


Hestenes, D., Wells, M., & Swackhamer, G. (1992). Force concept inventory. *The physics teacher*, *30*(3), 141-158.



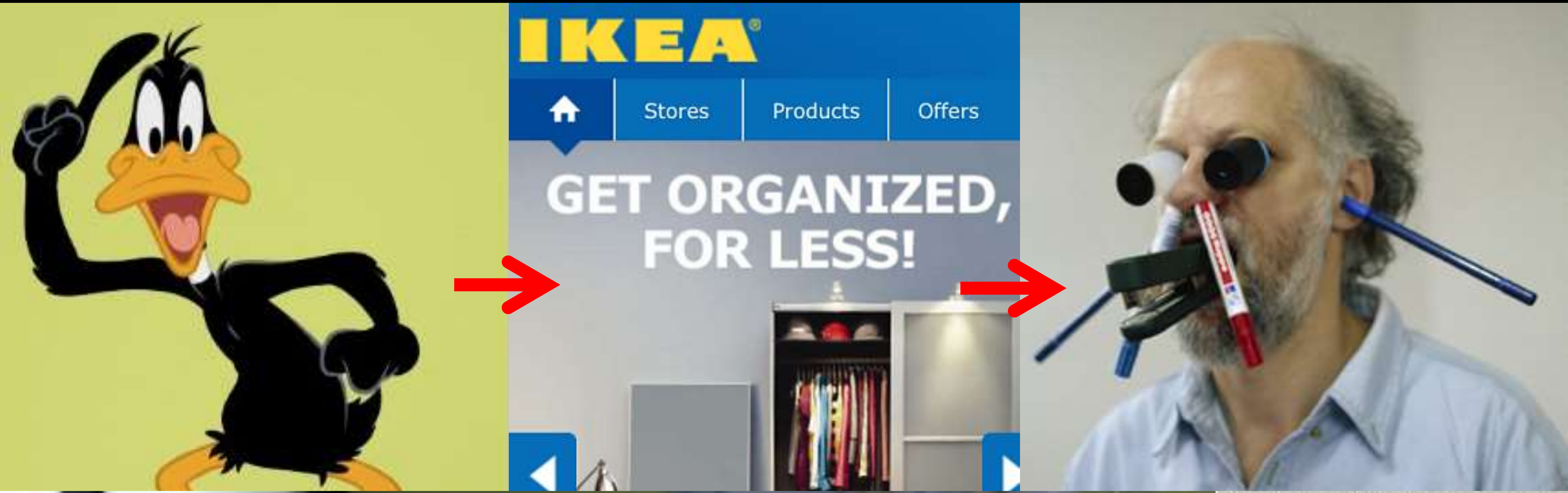
Crusty old physics guy

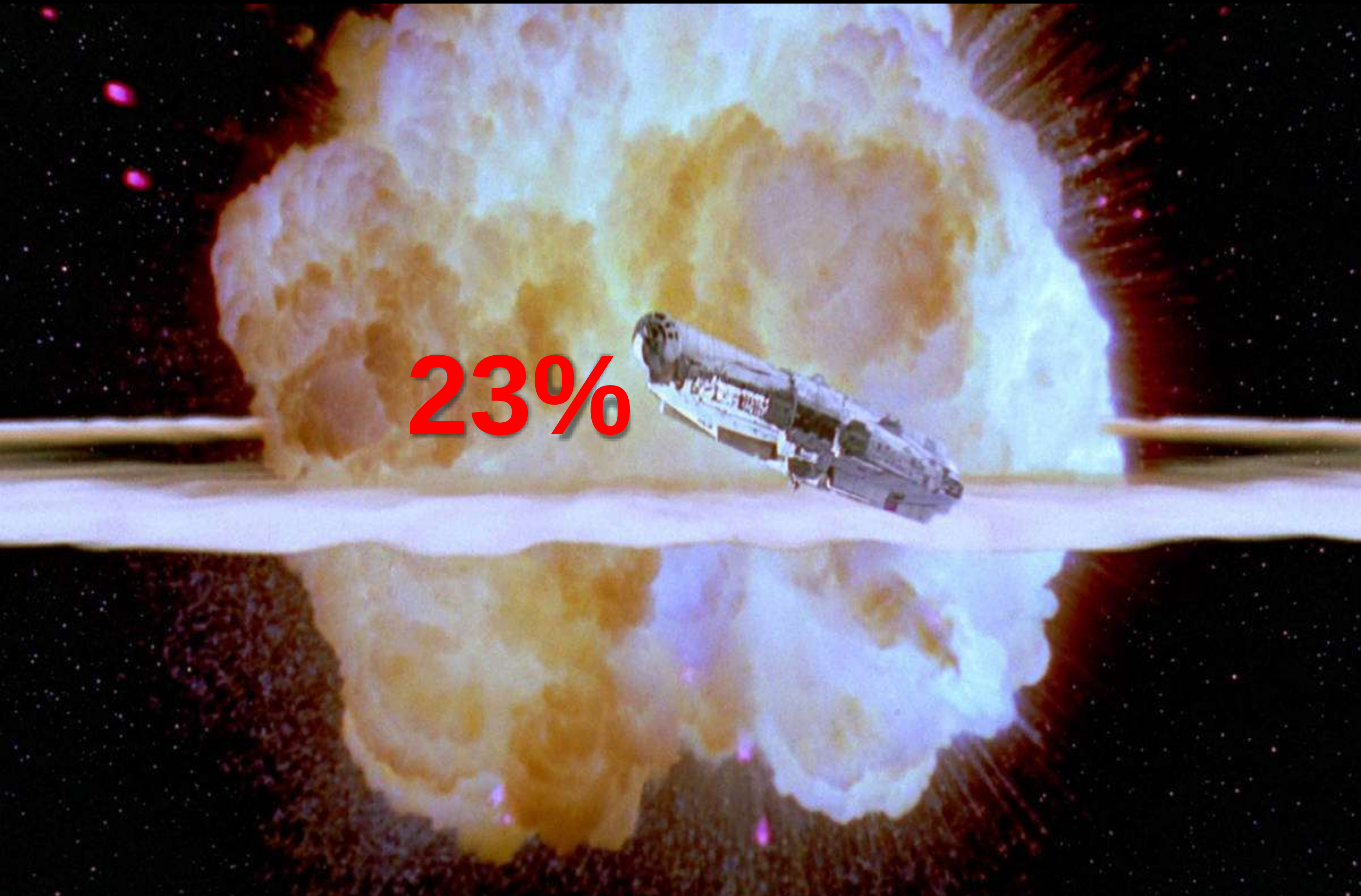
Force Concept Inventory Scores



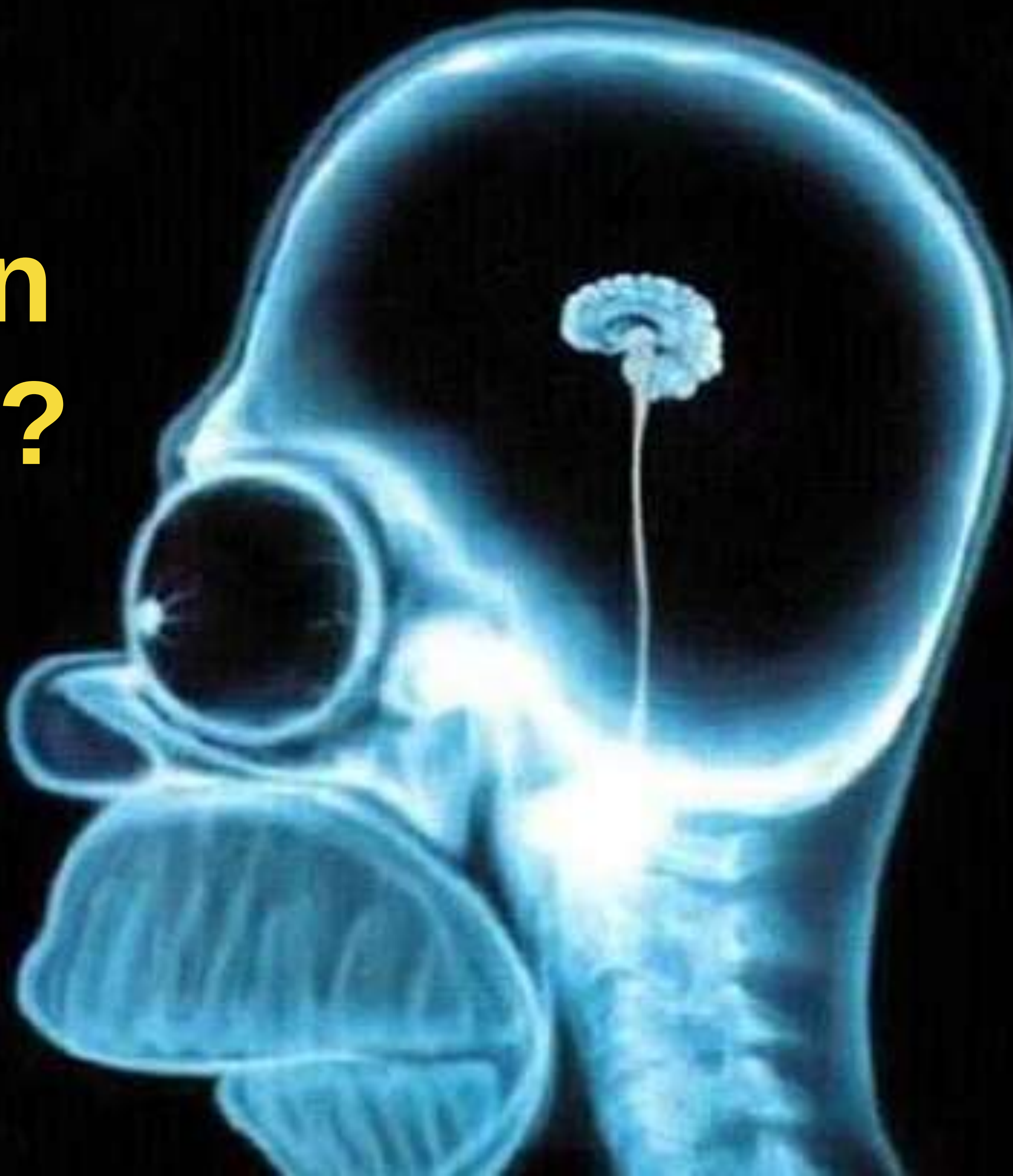
Even with our best teachers: 23%

Even with our best lessons…

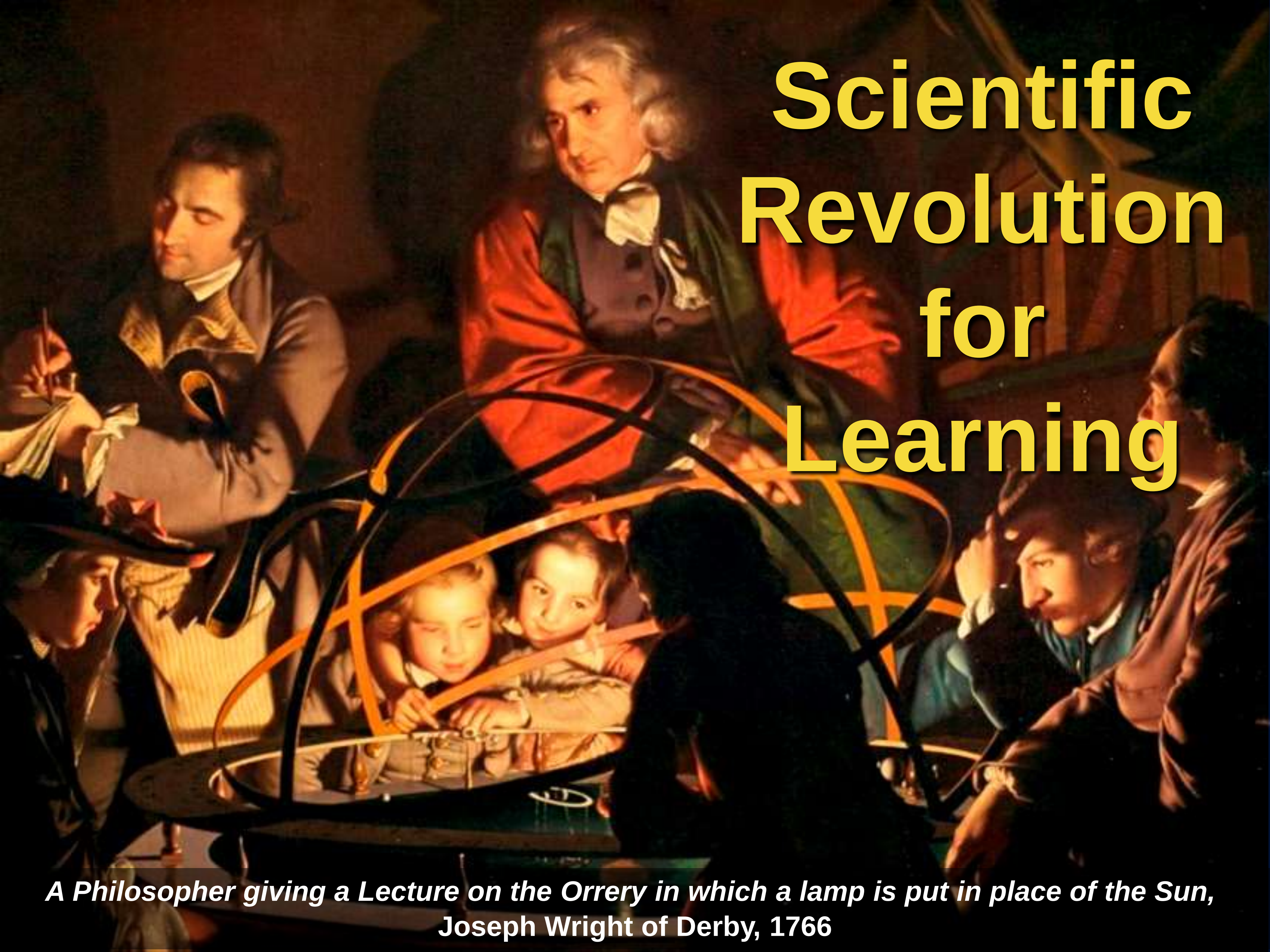



23%

What's going on upstairs?



Scientific Revolution for Learning

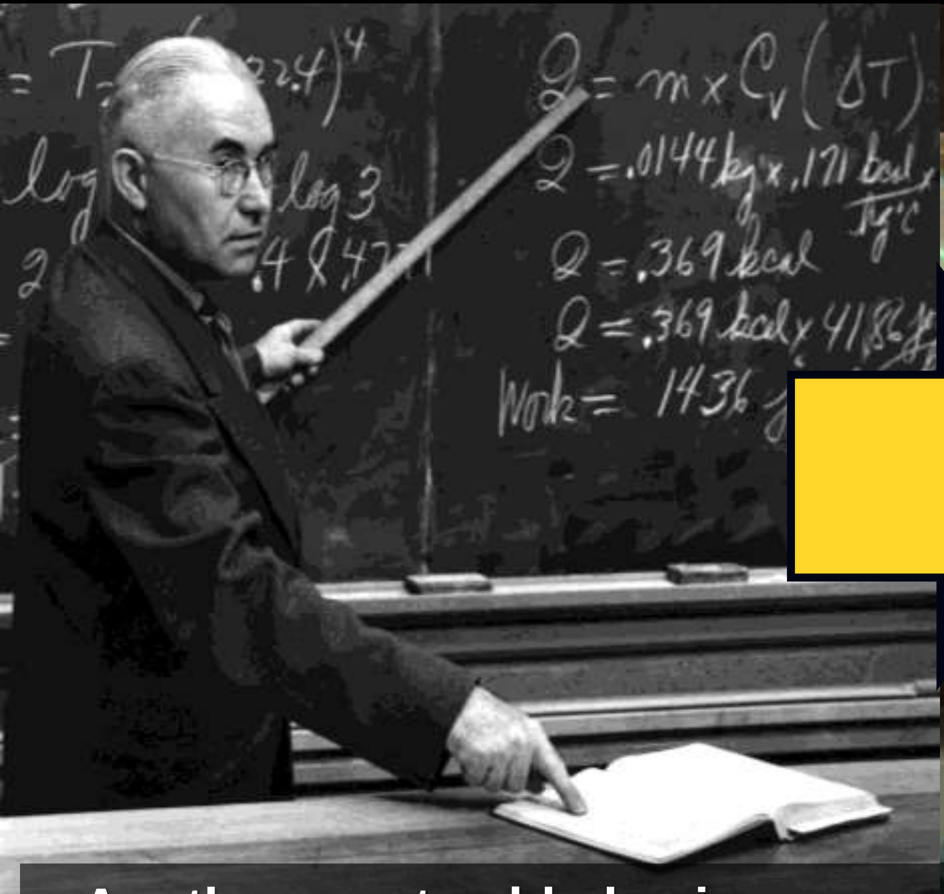


A Philosopher giving a Lecture on the Orrery in which a lamp is put in place of the Sun,
Joseph Wright of Derby, 1766

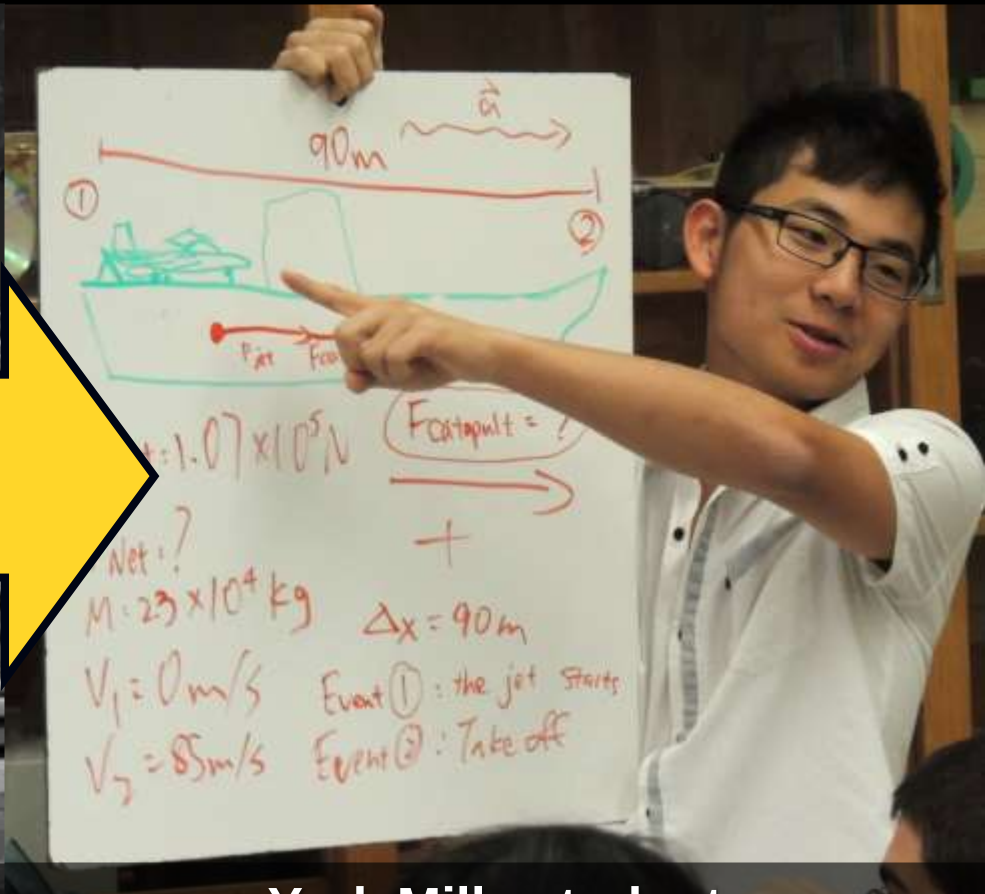
30 Year Journey

How to teach physics better?

How to help humans learn?

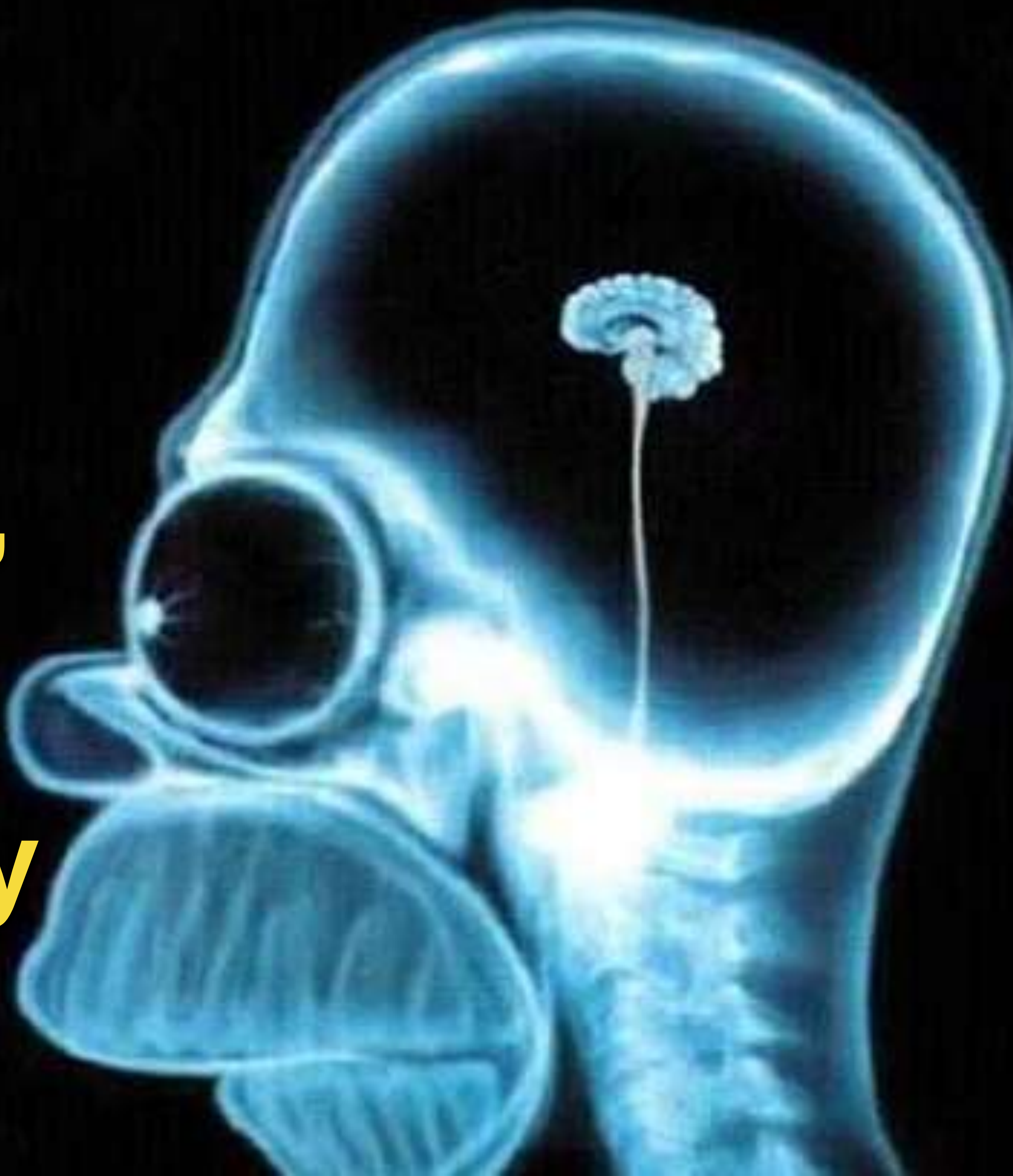


Another crusty old physics guy

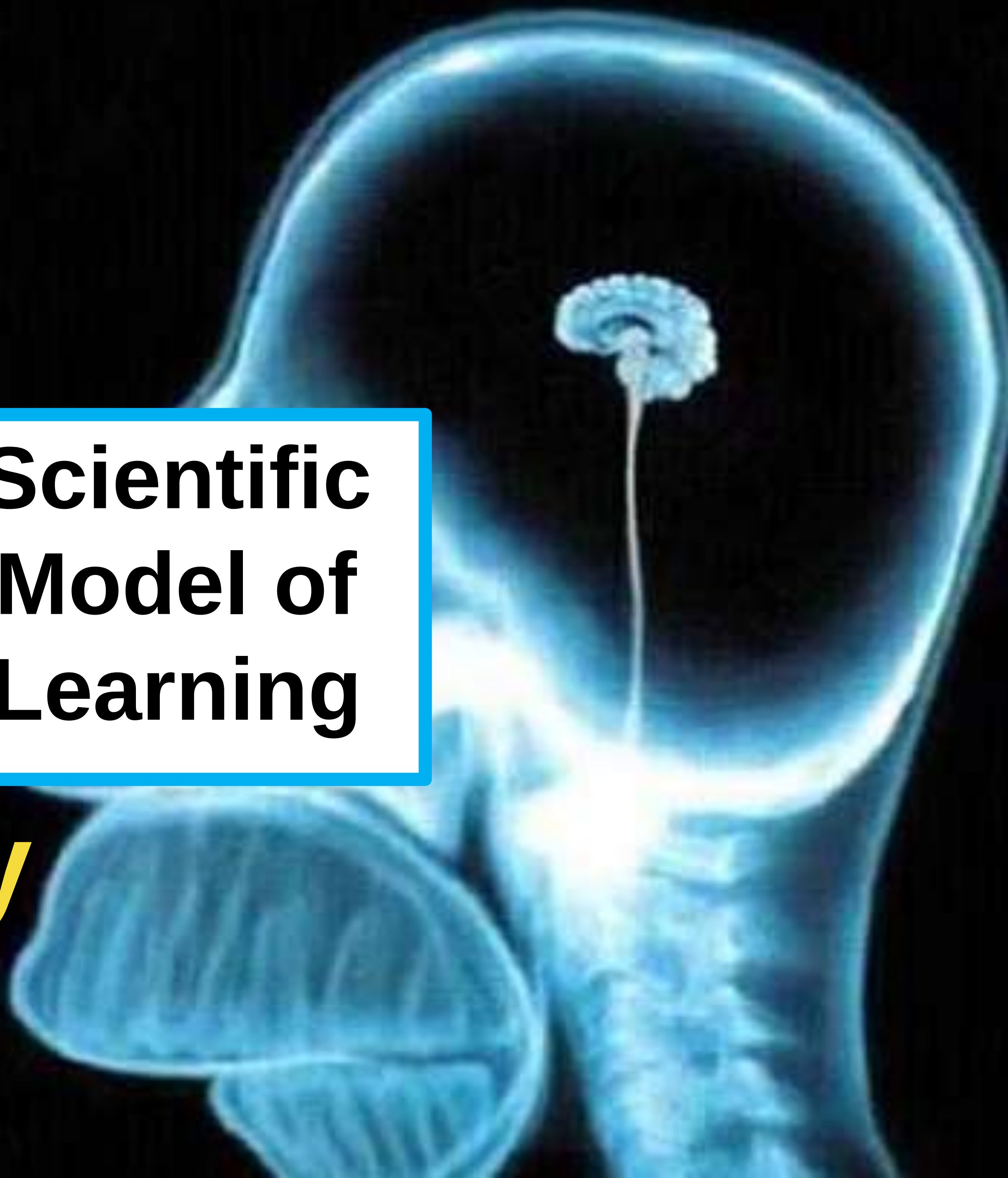


York Mills student

What happens in students' brains when they learn?



What happens in students brains when they learn?



Scientific Model of Learning

Medicine is extremely complex

Teaching is extremely complex

I am doing <u>my</u> job: teaching

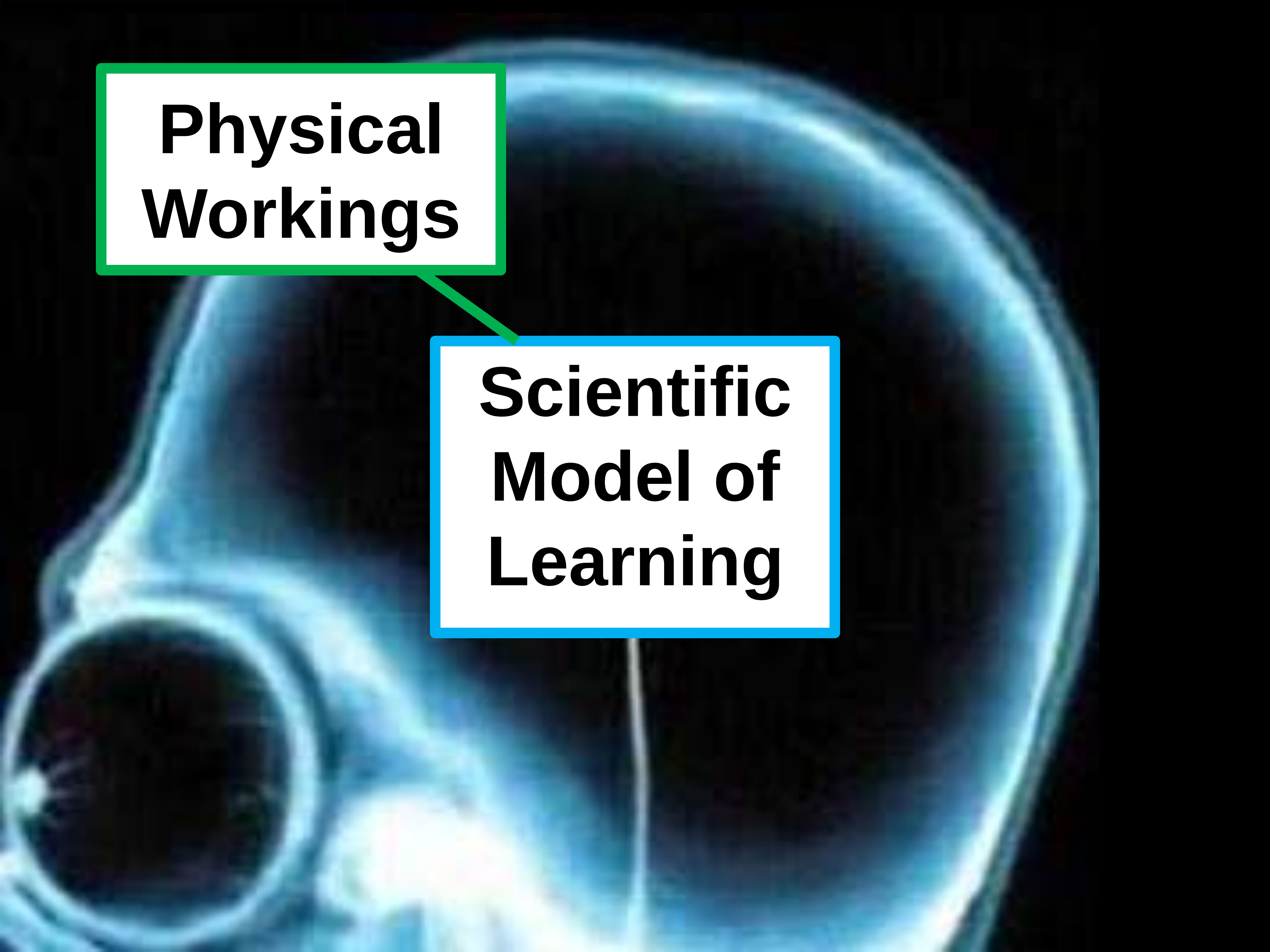
Ane

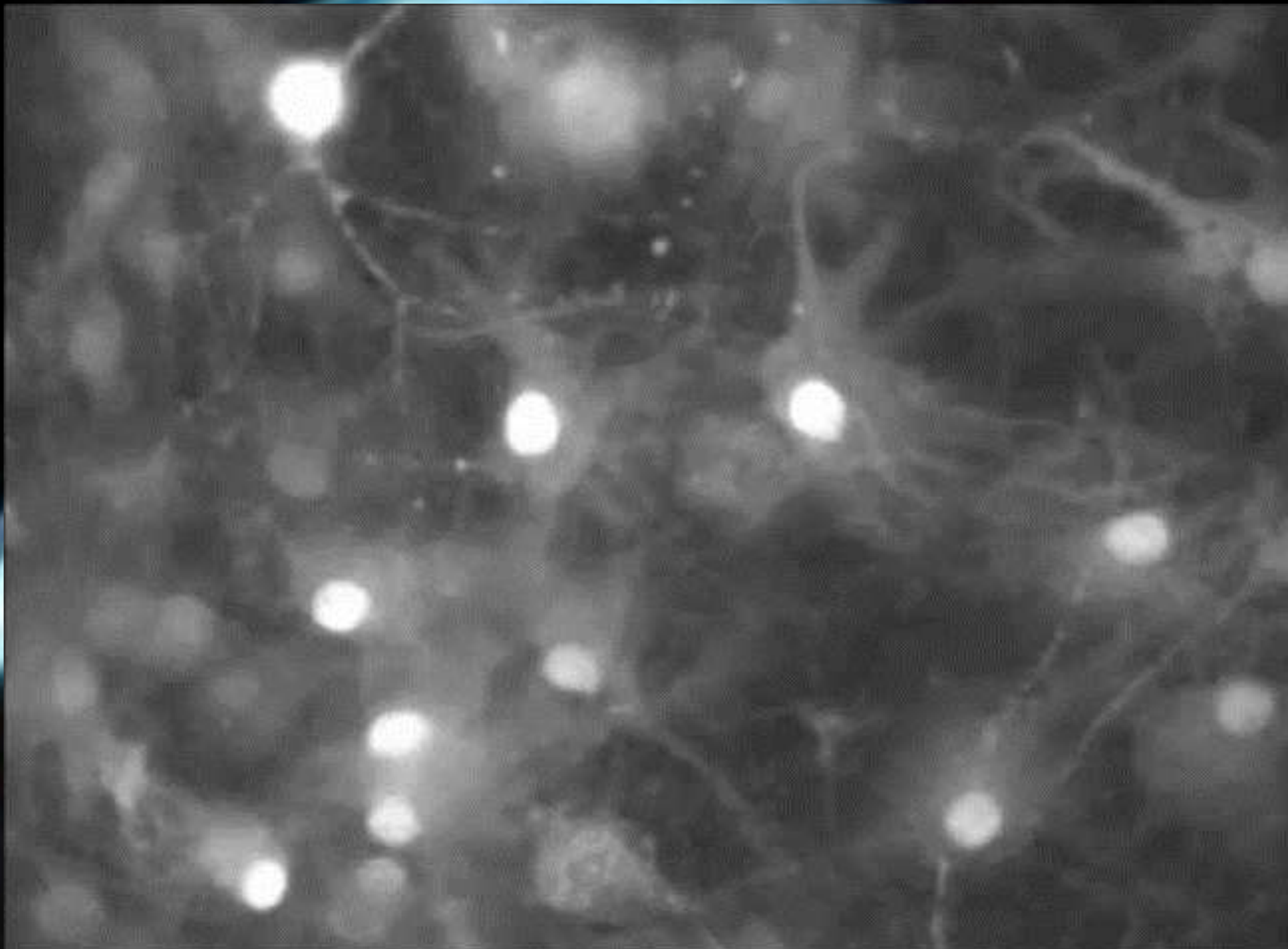
Pedagogical Fads

es

Illicit Substances


PX-47
ANTIDOTE
Scientific Teaching

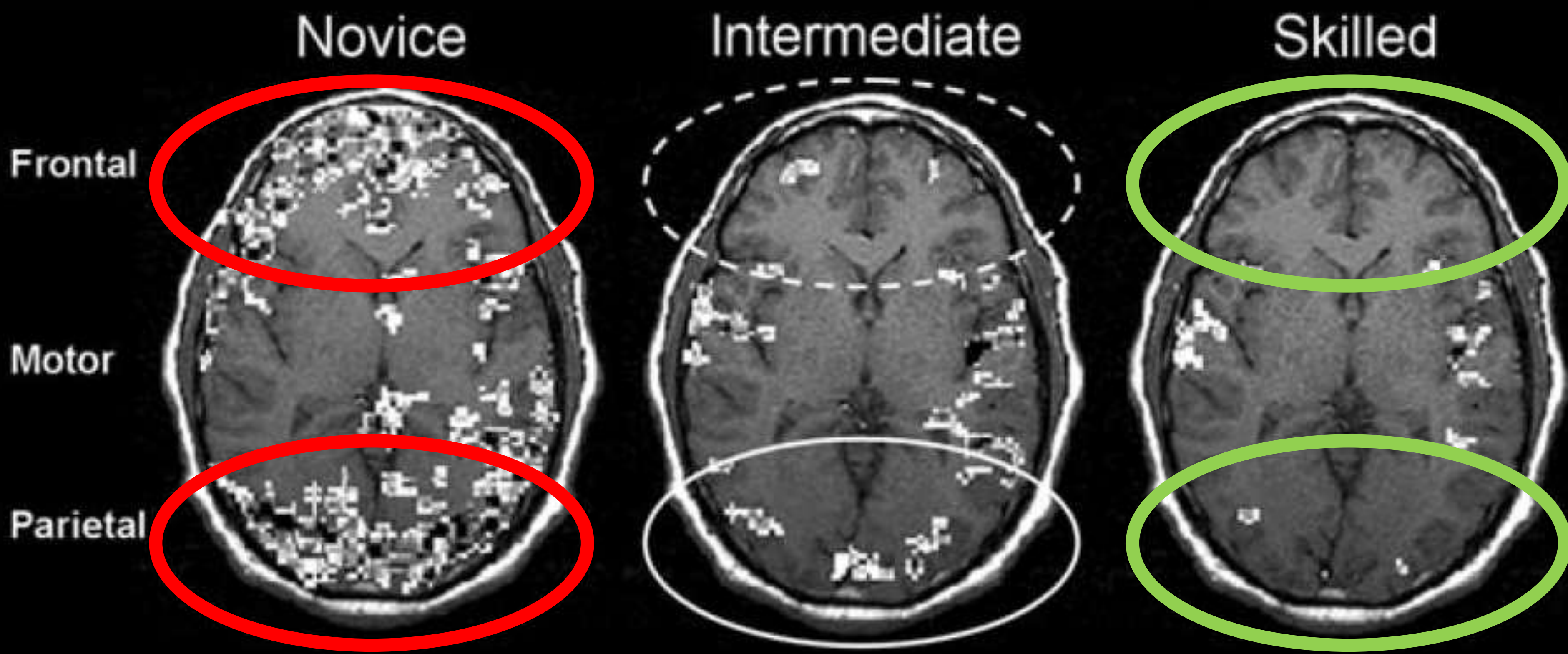

Physical Workings
Scientific Model of Learning



Learning is a Physical Process

Zatorre, R. J., Fields, R. D., & Johansen-Berg, H. (2012). Plasticity in gray and white: neuroimaging changes in brain structure during learning. *Nature neuroscience*, *15*(4), 528-536.

Brain Workload



Learning something new is
energy intensive = tiring

Ericsson, K. Anders, et al., eds. *The Cambridge handbook of expertise and expert performance.* Cambridge University Press, 2006.

Implications for Teaching

Learning

- neurons making connections
- feels tiring, confusing!

Practice

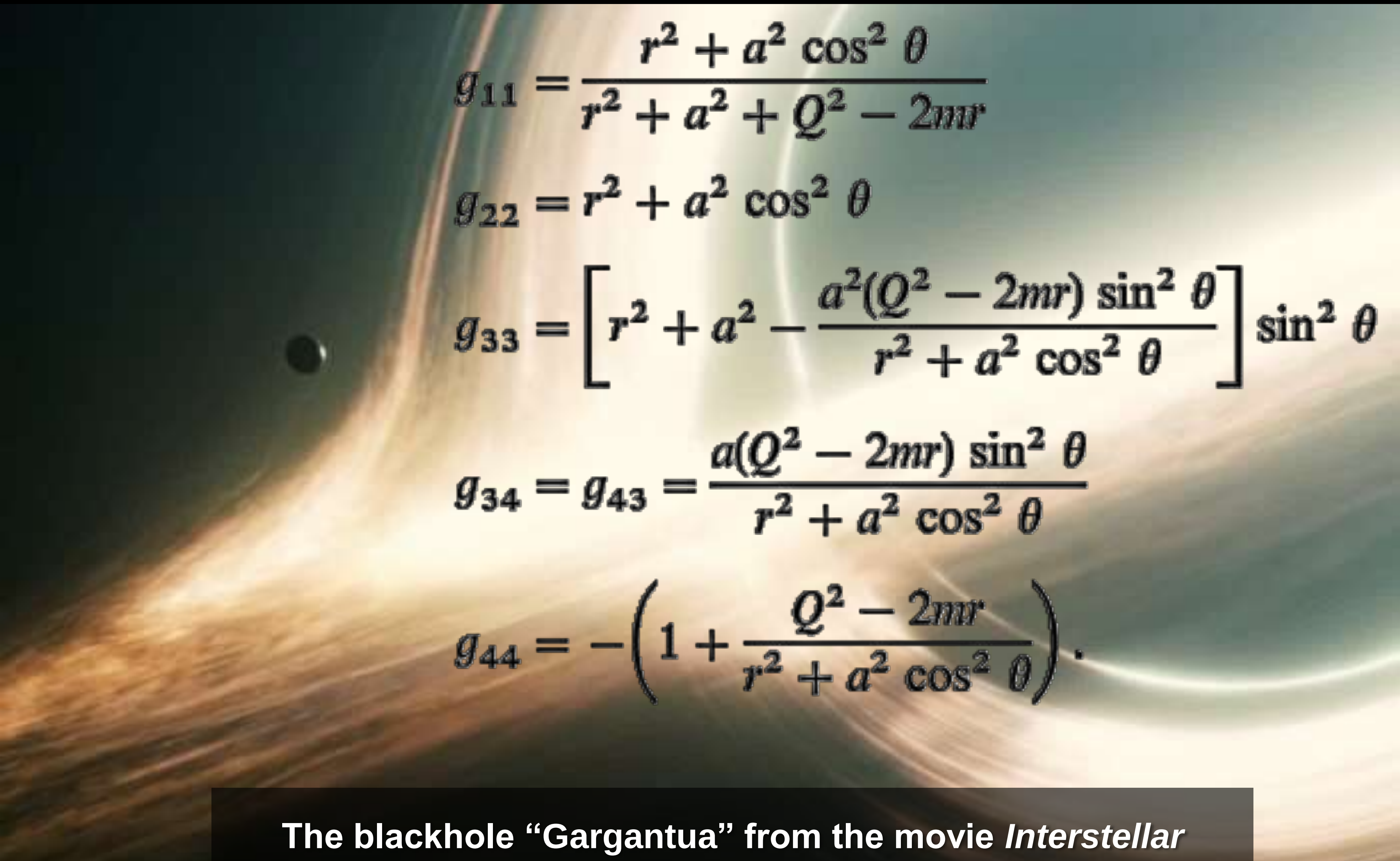
- neurons reinforcing connections
- takes time, begins to feel easier!

Disuse

- connections weaken, forgetting!

Random Toddler from the Internet

From Babies to General Relativity



$$g_{11} = \frac{r^2 + a^2 \cos^2\theta}{r^2 + a^2 + Q^2 - 2mr}$$

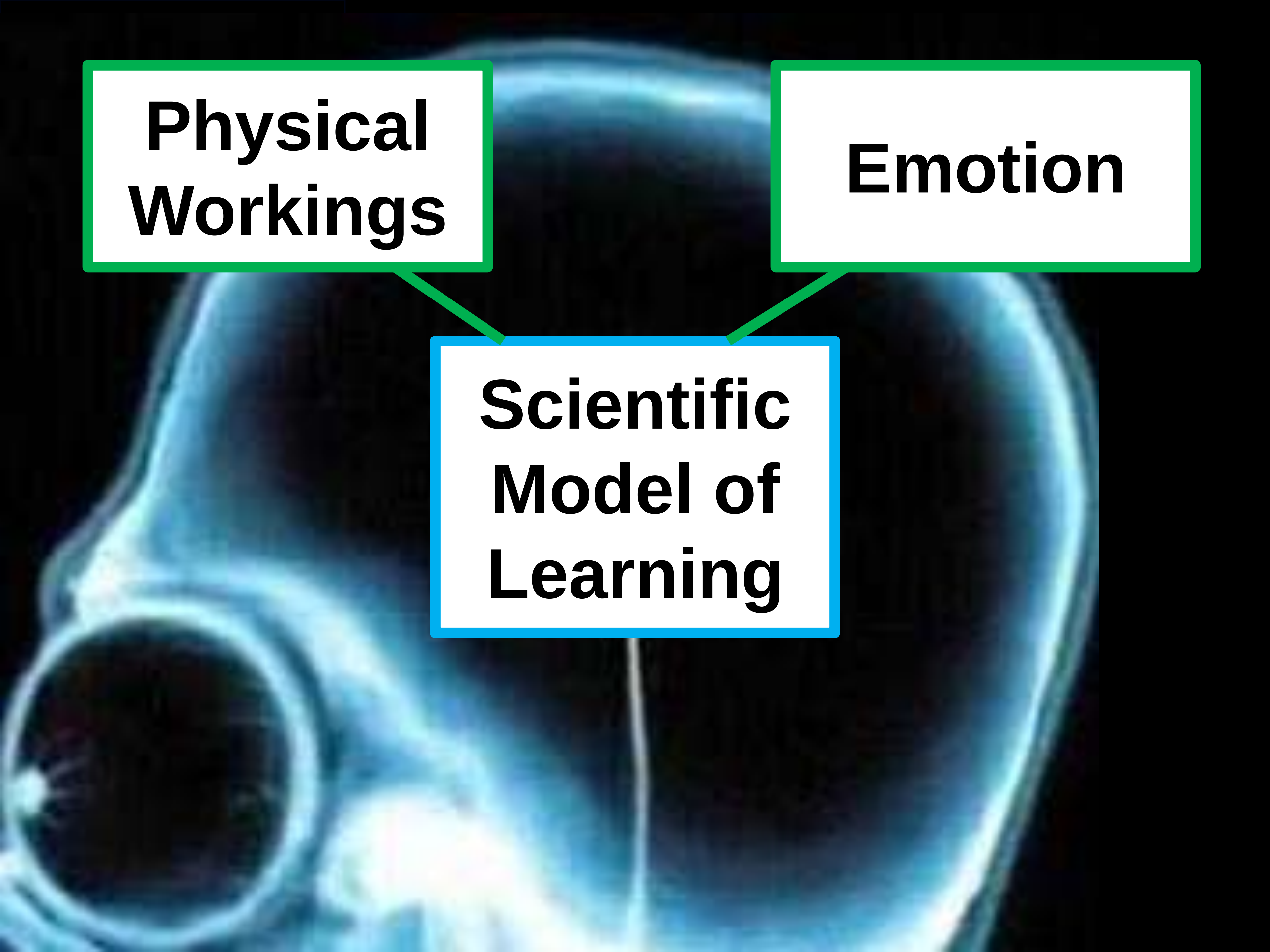
$$g_{22} = r^2 + a^2 \cos^2\theta$$

$$g_{33} = \left[r^2 + a^2 - \frac{a^2(Q^2 - 2mr)\sin^2\theta}{r^2 + a^2\cos^2\theta}\right]\sin^2\theta$$

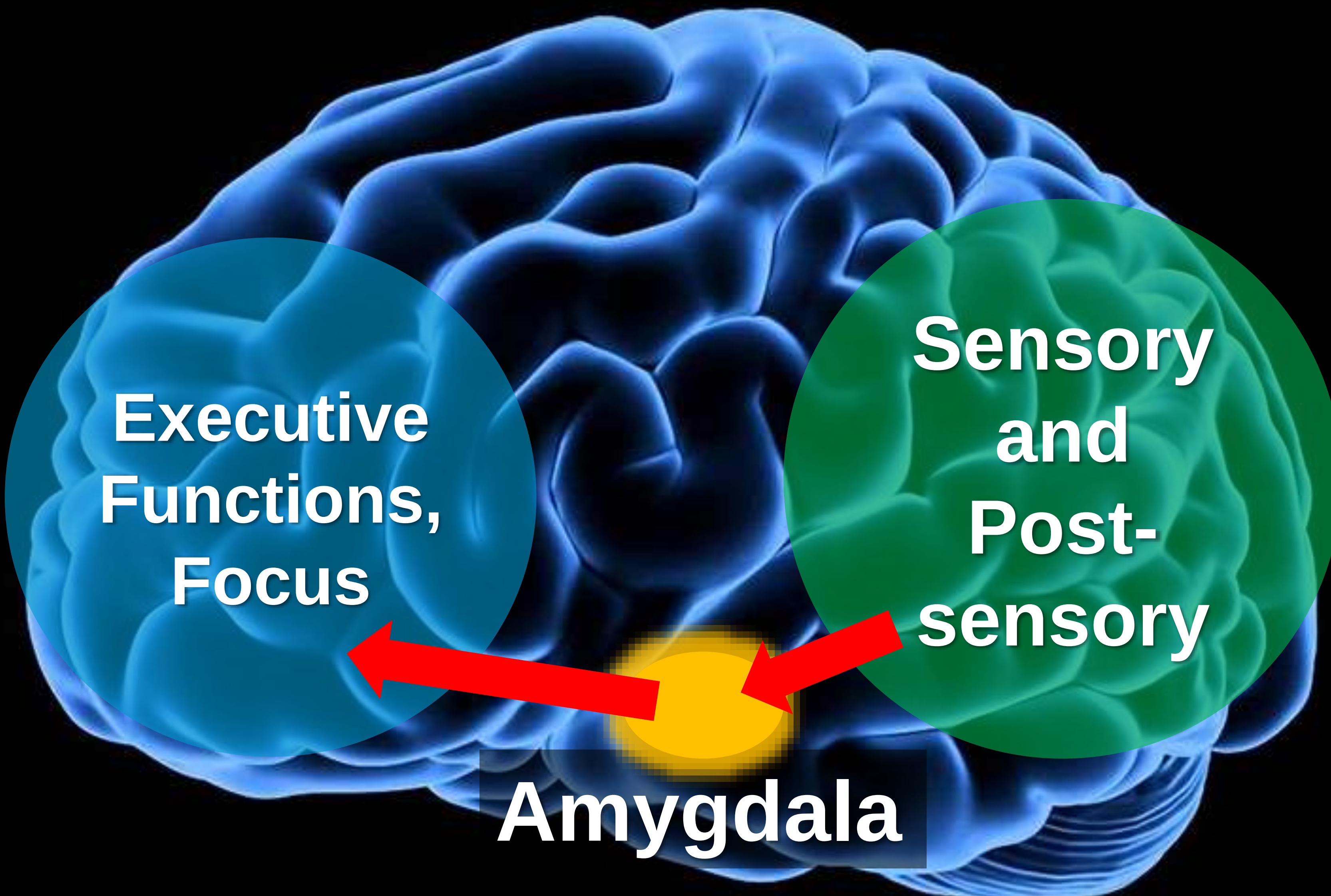
$$g_{34} = g_{43} = \frac{a(Q^2 - 2mr)\sin^2\theta}{r^2 + a^2\cos^2\theta}$$

$$g_{44} = -\left(1 + \frac{Q^2 - 2mr}{r^2 + a^2\cos^2\theta}\right).$$

The blackhole “Gargantua” from the movie *Interstellar*


Physical Workings
Emotion
Scientific Model of Learning

Emotions and the Brain



Emotions and the Brain

Emotional state affected by:

- Social learning environment
- Relevance of content
- Likelihood of success

Emotions and the Brain

Affects our student's ability to:

- Focus
- Encode memory
- Access memory and skills

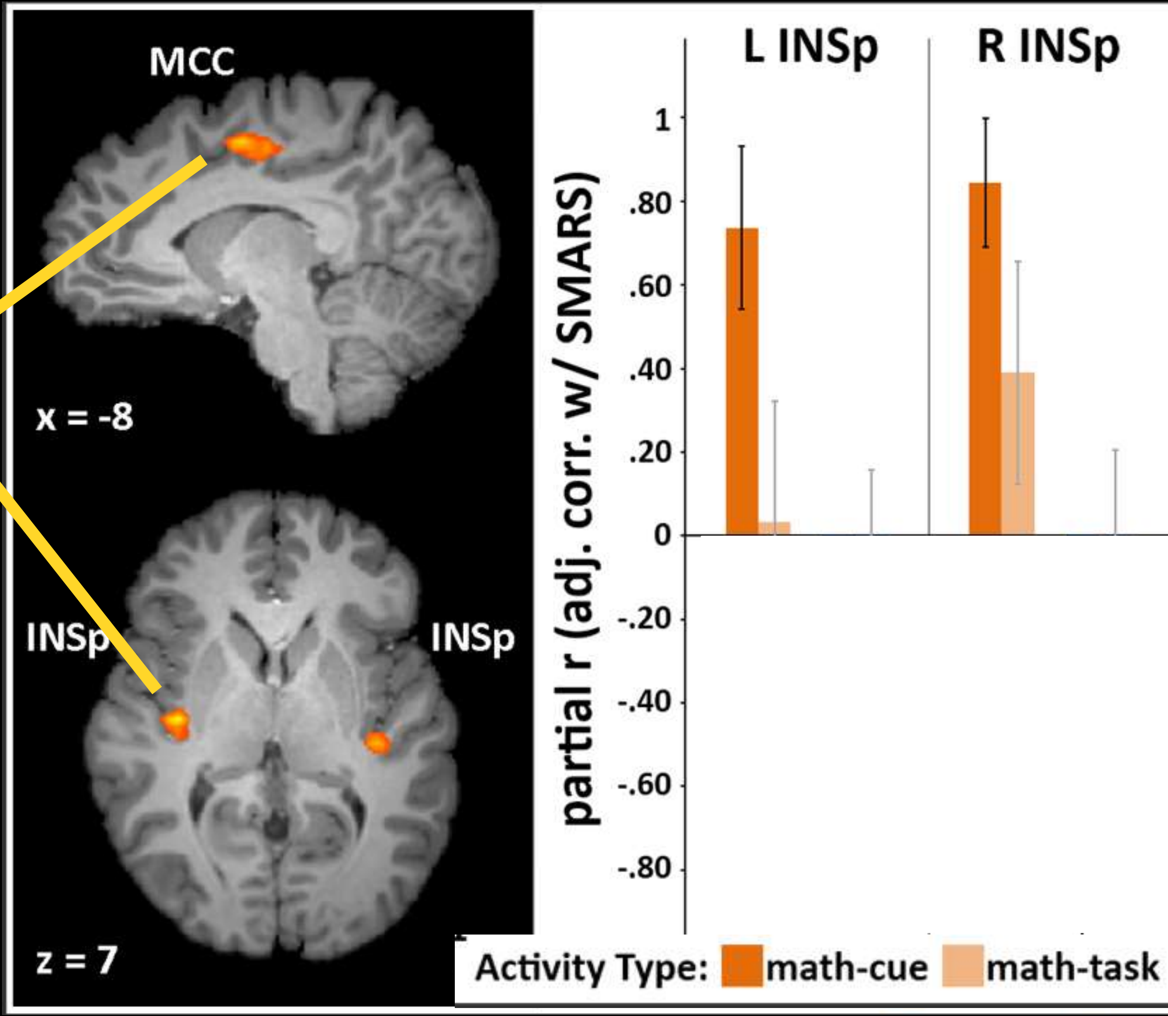
Quick Question!

$$(9 \times 5) - 17 = ?$$

Anxiety!

Anxiety!

Activation of brain regions associated with **physical pain perception** is strongest when **anticipating** a math task.



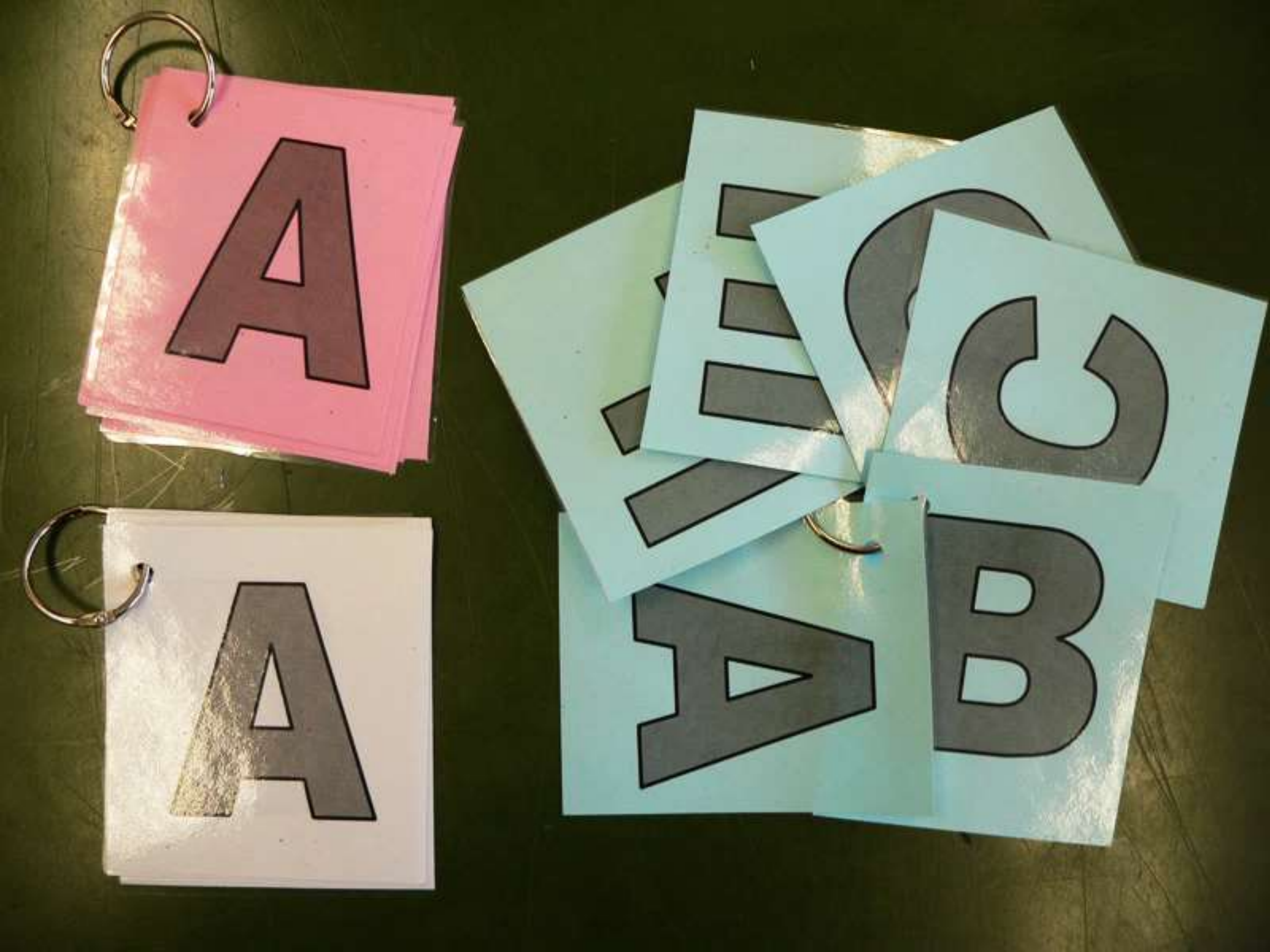
Lyons, I. M., & Beilock, S. L. (2012). When math hurts: math anxiety predicts pain network activation in anticipation of doing math. PloS one, 7(10), e48076

Teaching is extremely complex

Implications for Teaching

Nothing succeeds like success!

- Avoid: “This will be on the exam”
- Monitor student’s emotional states and feelings of success


A
A
C
B

Learning Check-Up

How was your learning today?

A: I'm confident about what I learned. I can explain it well to my neighbours.

B: I'm pretty good with what I learned. I'm OK at explaining it.

C: I'm not too sure about what I learned. It would be tough to explain it!

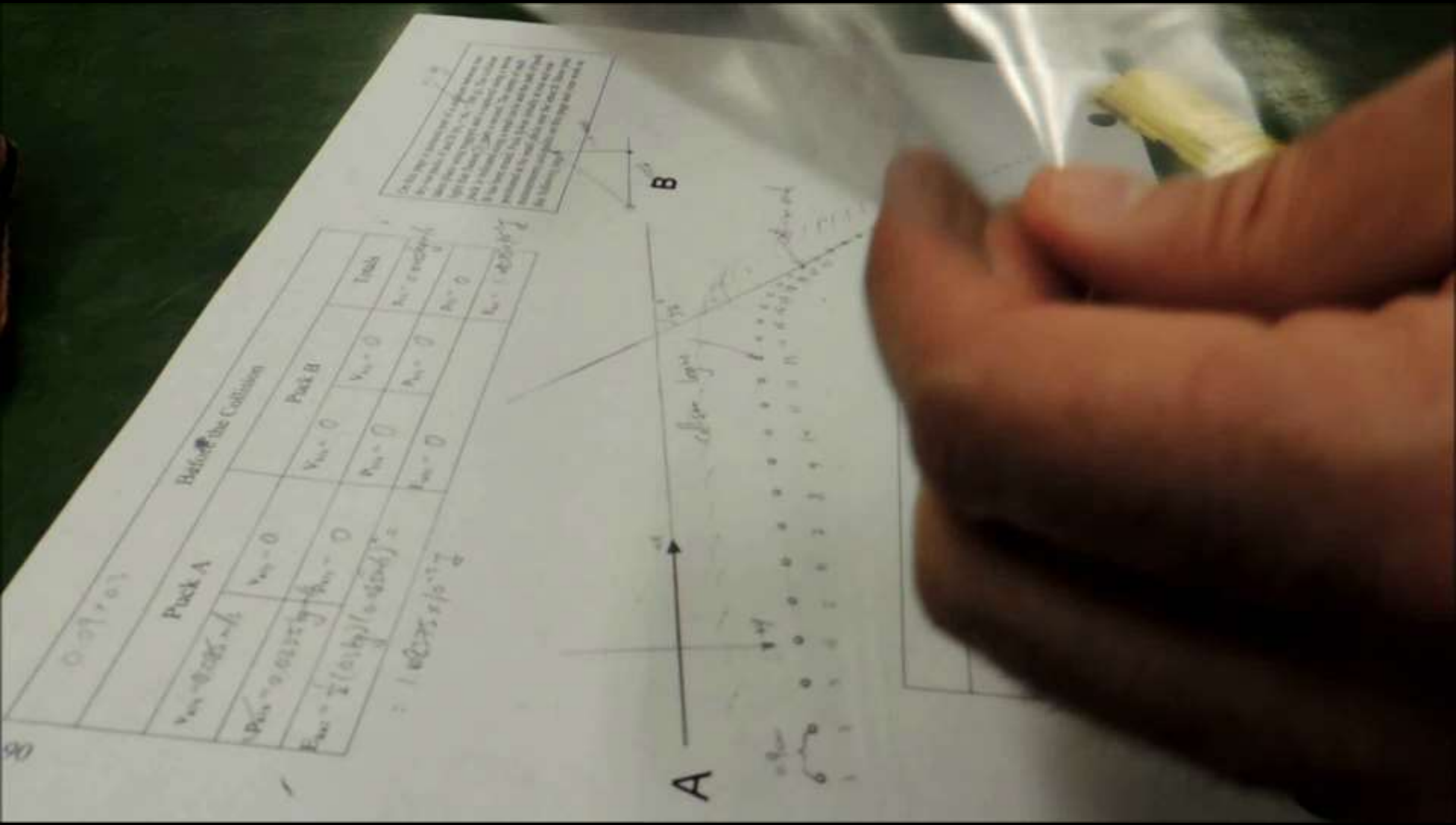
D: I think I had difficulties with some of what I learned. I am not yet able to explain it.

Implications for Teaching

Nothing succeeds like success!

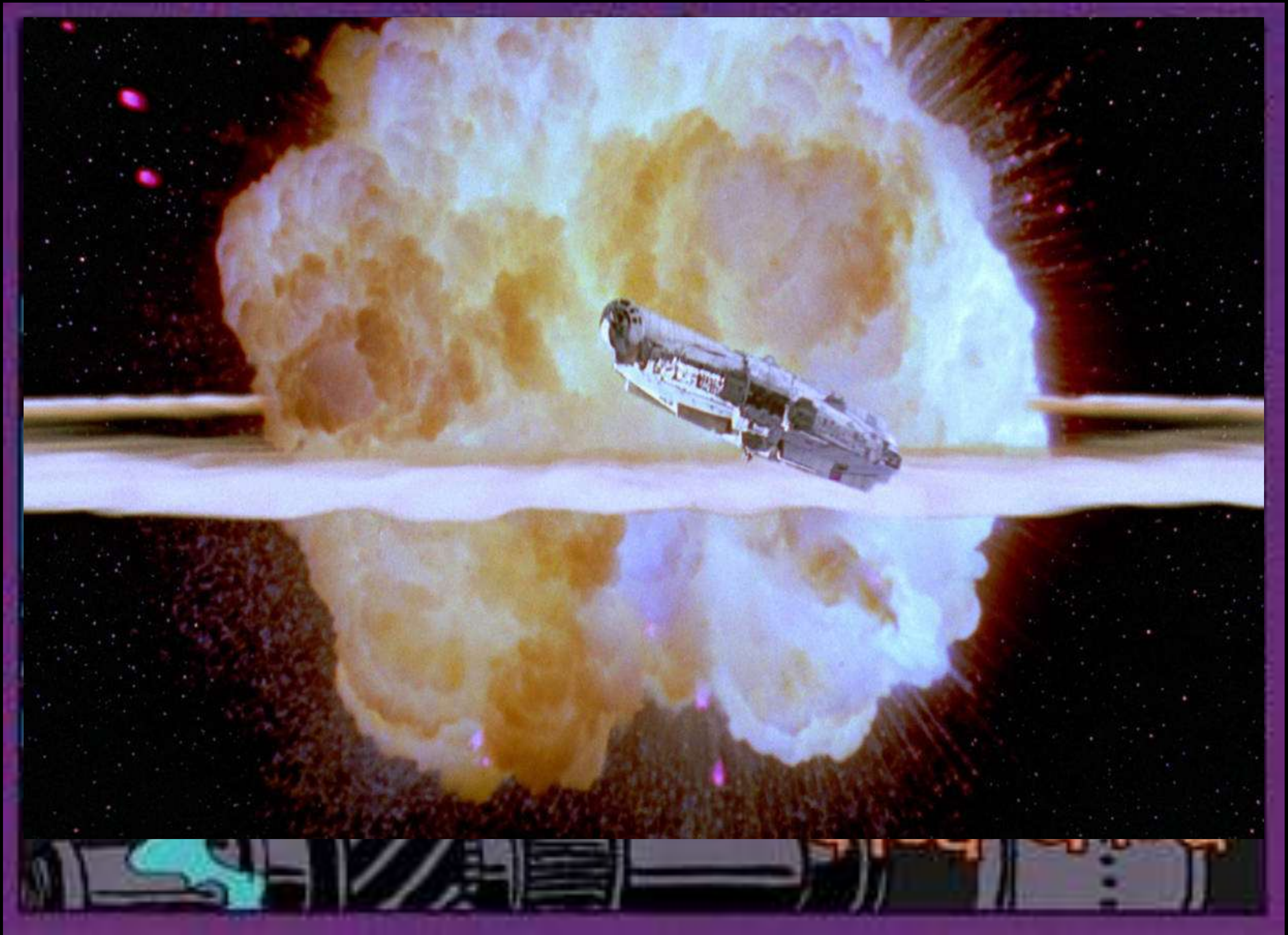
- Avoid: “This will be on the exam”
- Monitor student’s emotional states and feelings of success
- Allow students to discover they are successful

Make Testable Predictions!



Even with our best lessons…

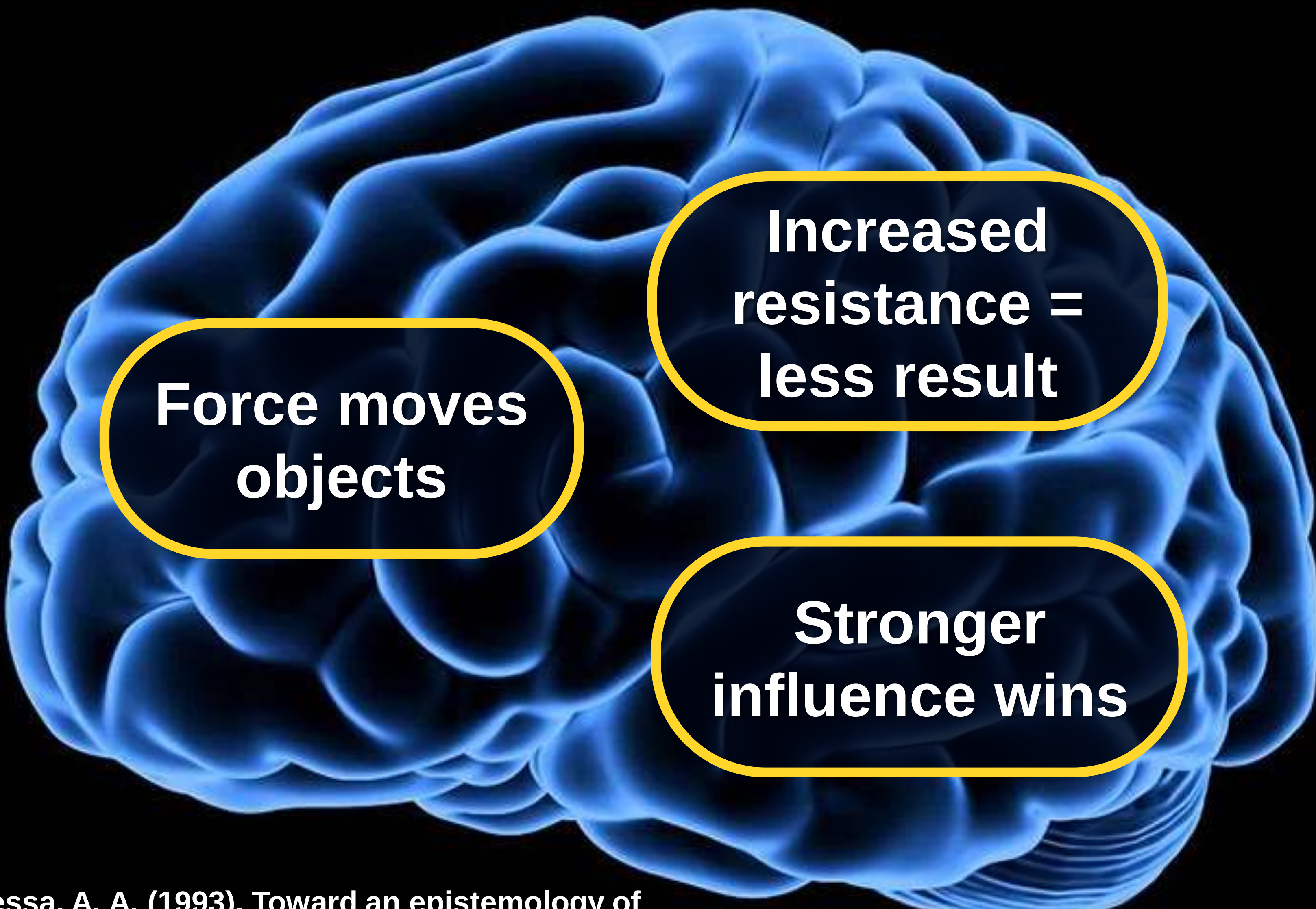
Traditional Learning Model



Scientific Learning Model

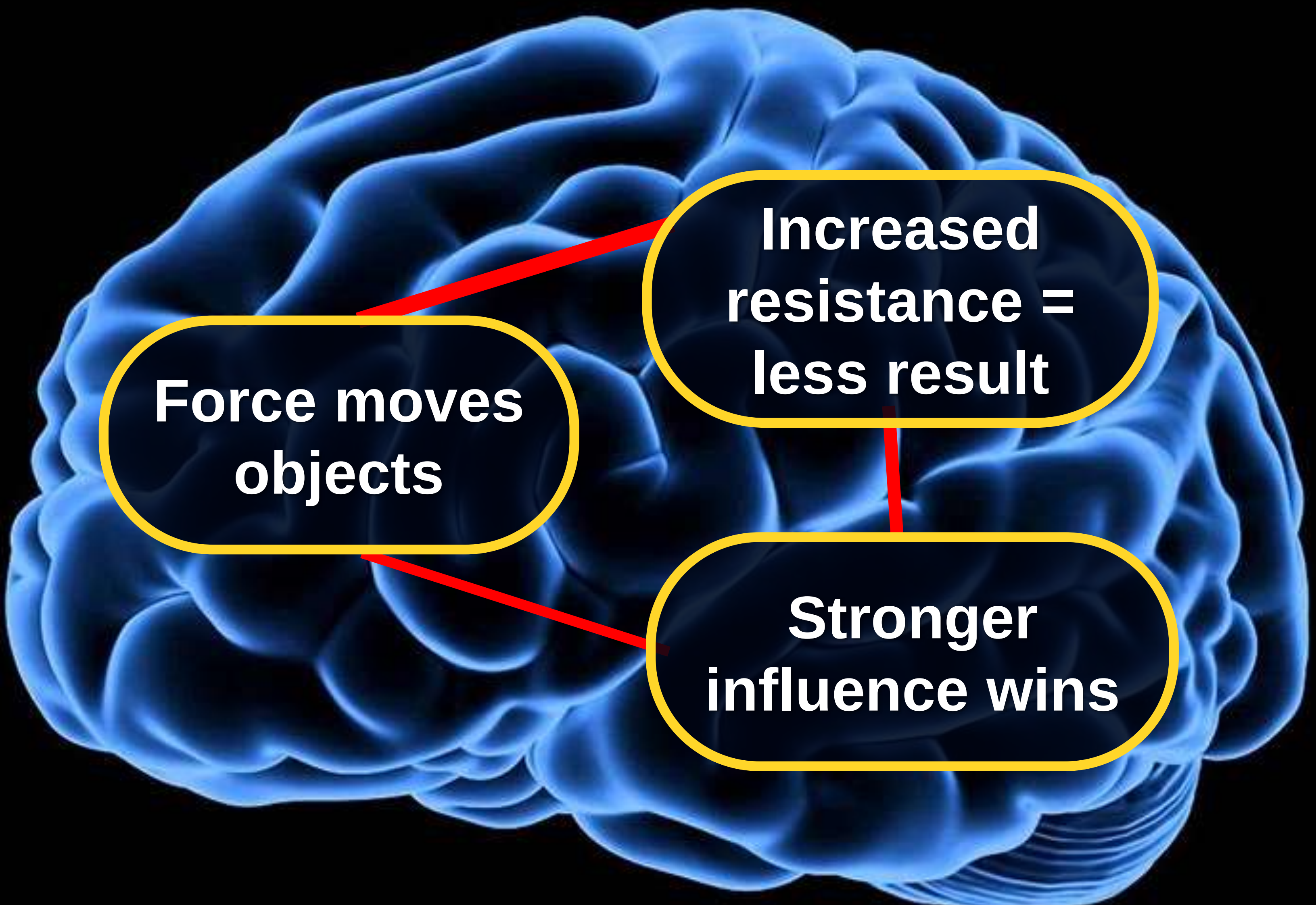
DiSessa, A. A. (1993). Toward an epistemology of physics. *Cognition and instruction*, *10*(2-3), 105-225.

Knowledge is built from primitive pieces

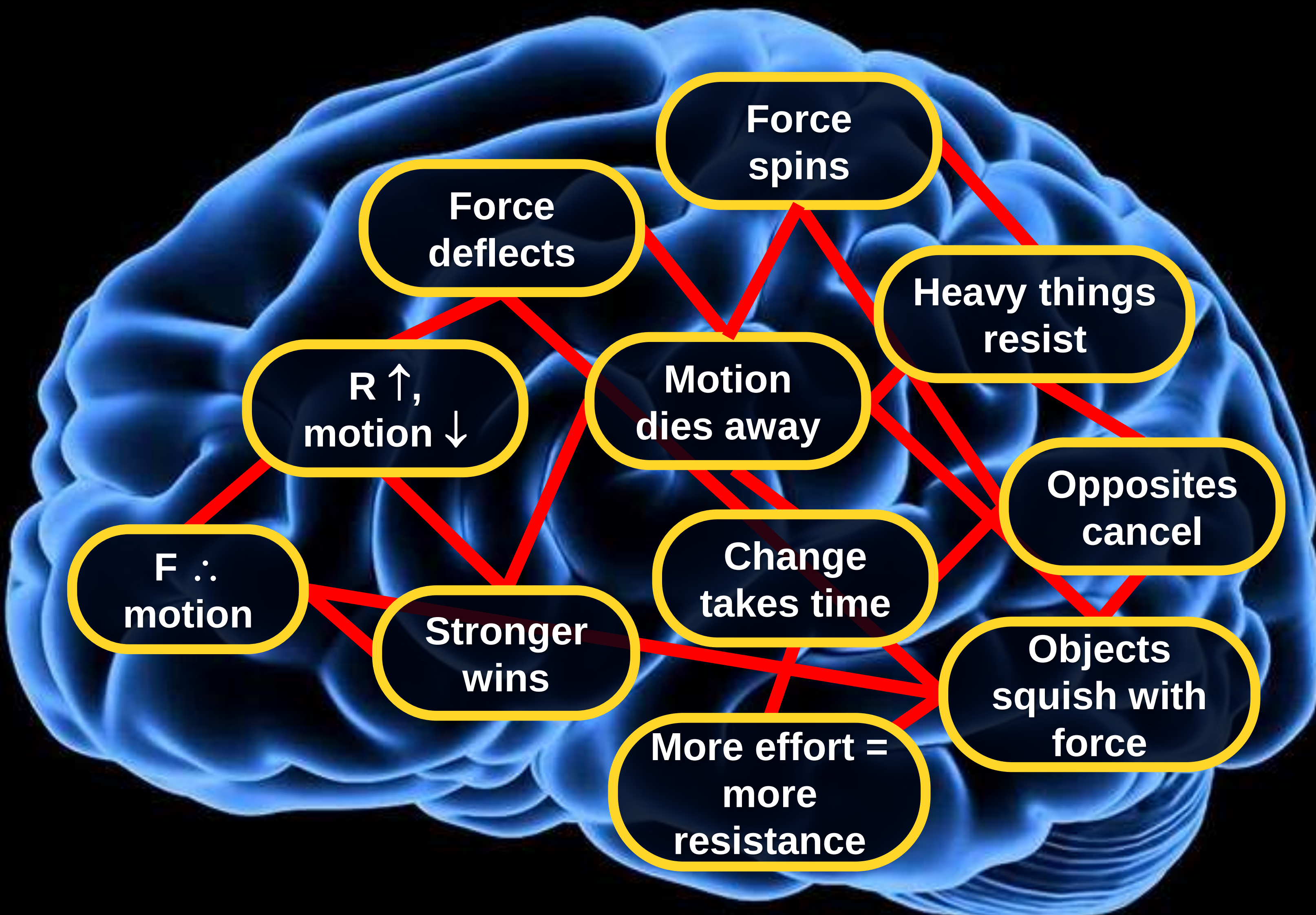


DiSessa, A. A. (1993). Toward an epistemology of physics. *Cognition and instruction*, *10*(2-3), 105-225.

As we learn, connections grow



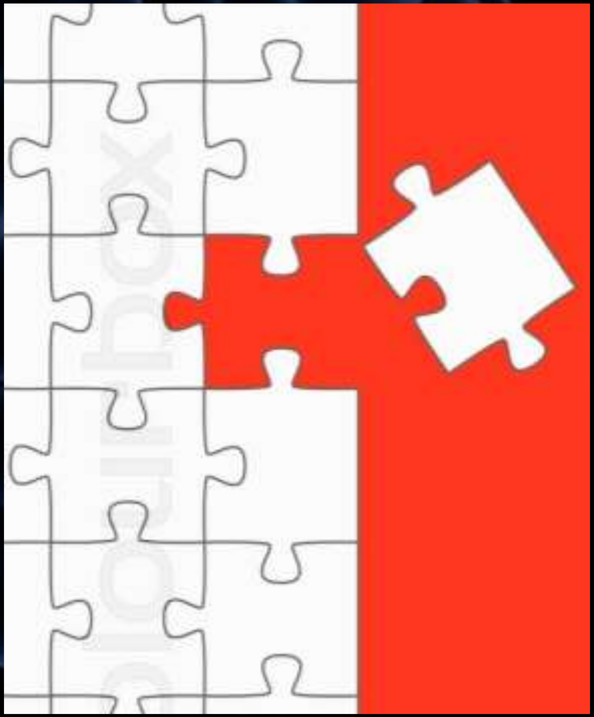
Networks of knowledge resources form

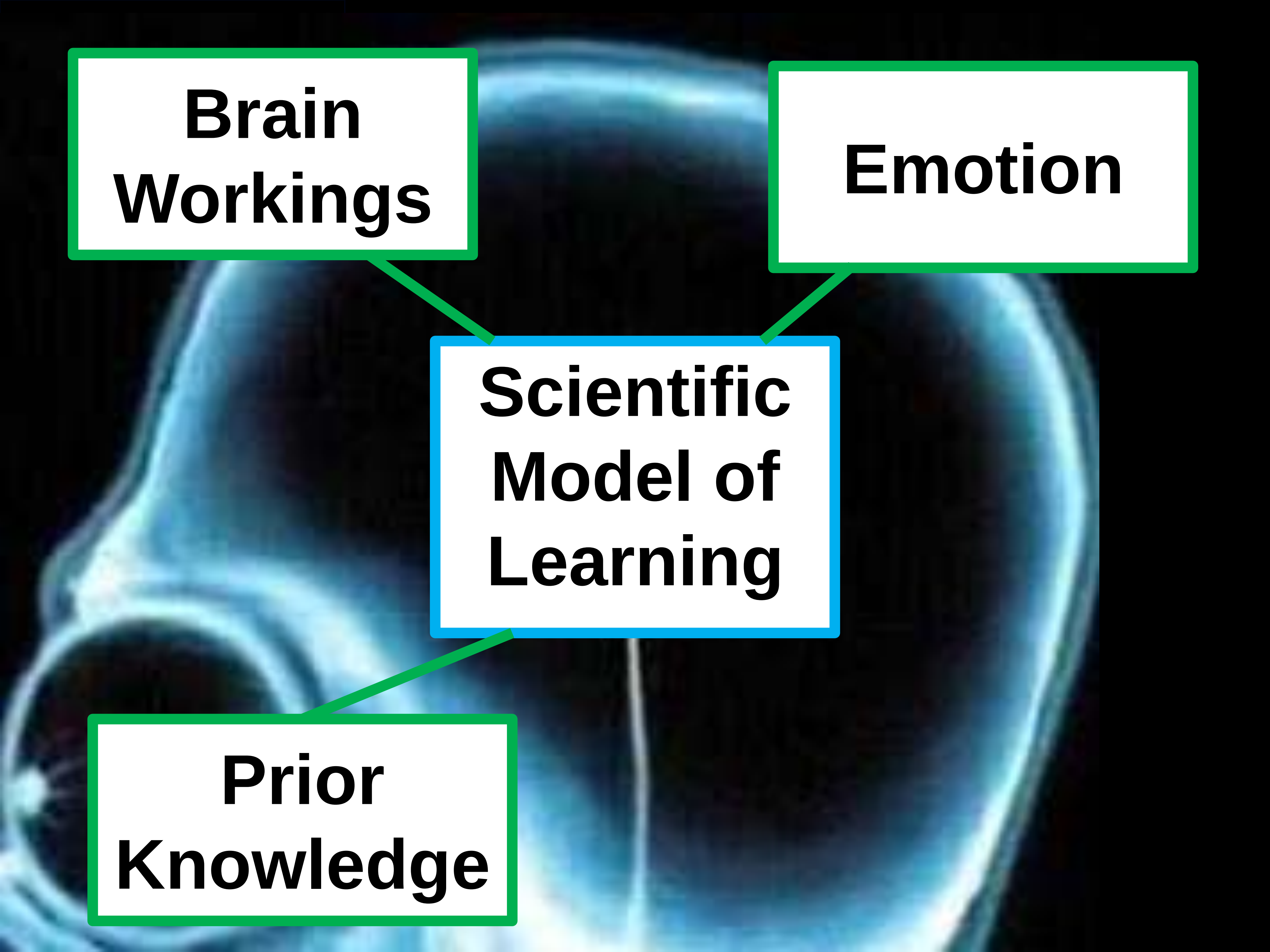


Prior Knowledge

We make sense of new ideas by making connections to our prior knowledge

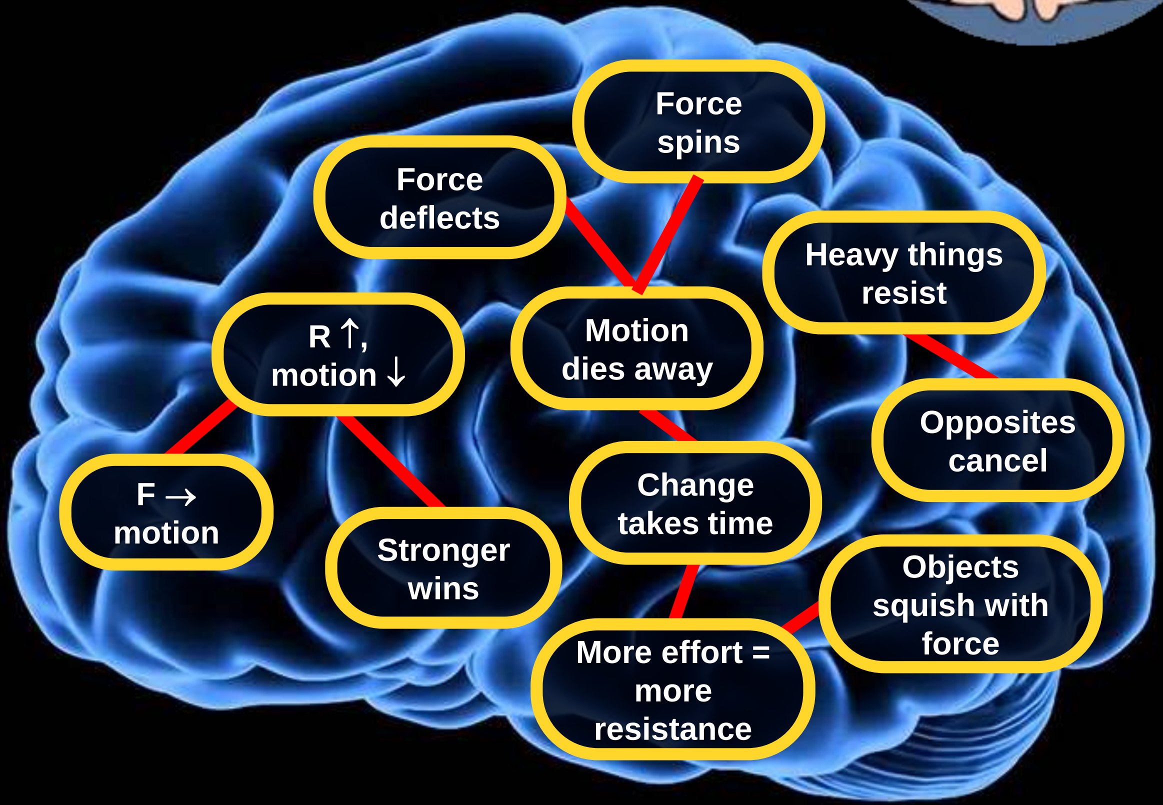
If prior knowledge is not ready, students cannot make use of expert knowledge.



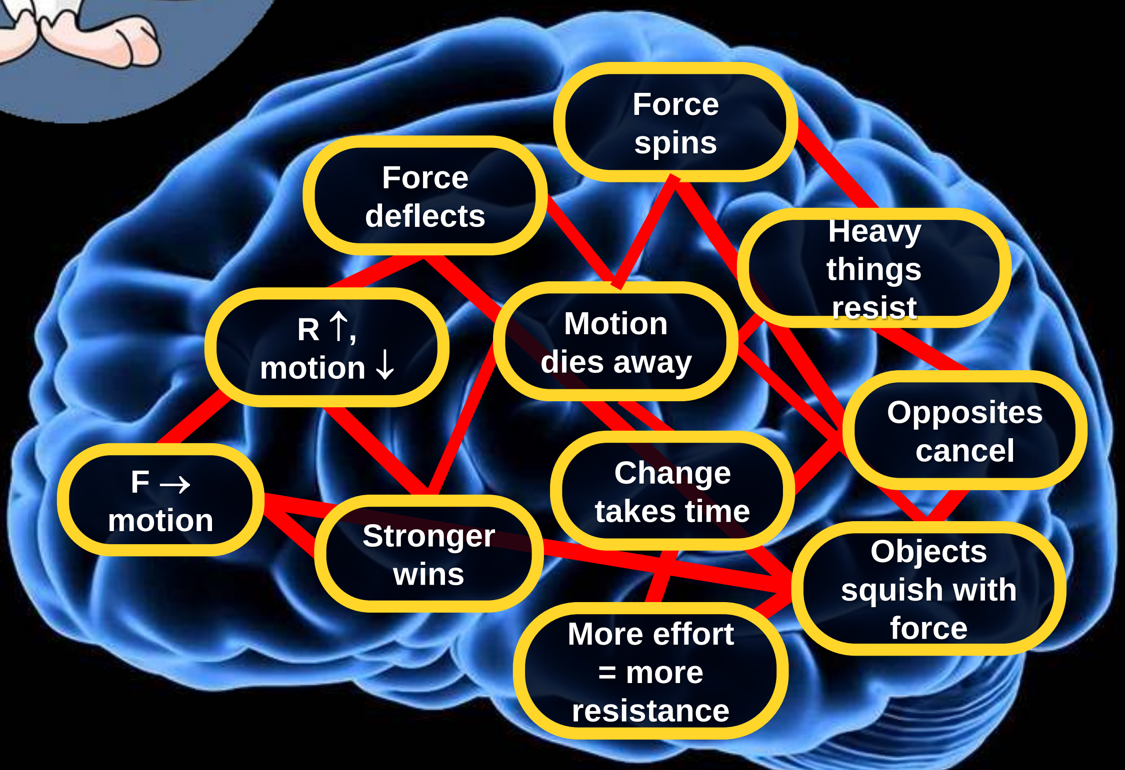

Brain Workings
Emotion
Scientific Model of Learning
Prior Knowledge

The Novice

- Scientific knowledge fragmented
- Little context
- Fewer useful “hooks” to attach new ideas
- Skills are effortful



The Expert



- Rich webs of connections
- Highly contextual
- See “big picture”
- Fluent / invisible skills

Implications for Teaching

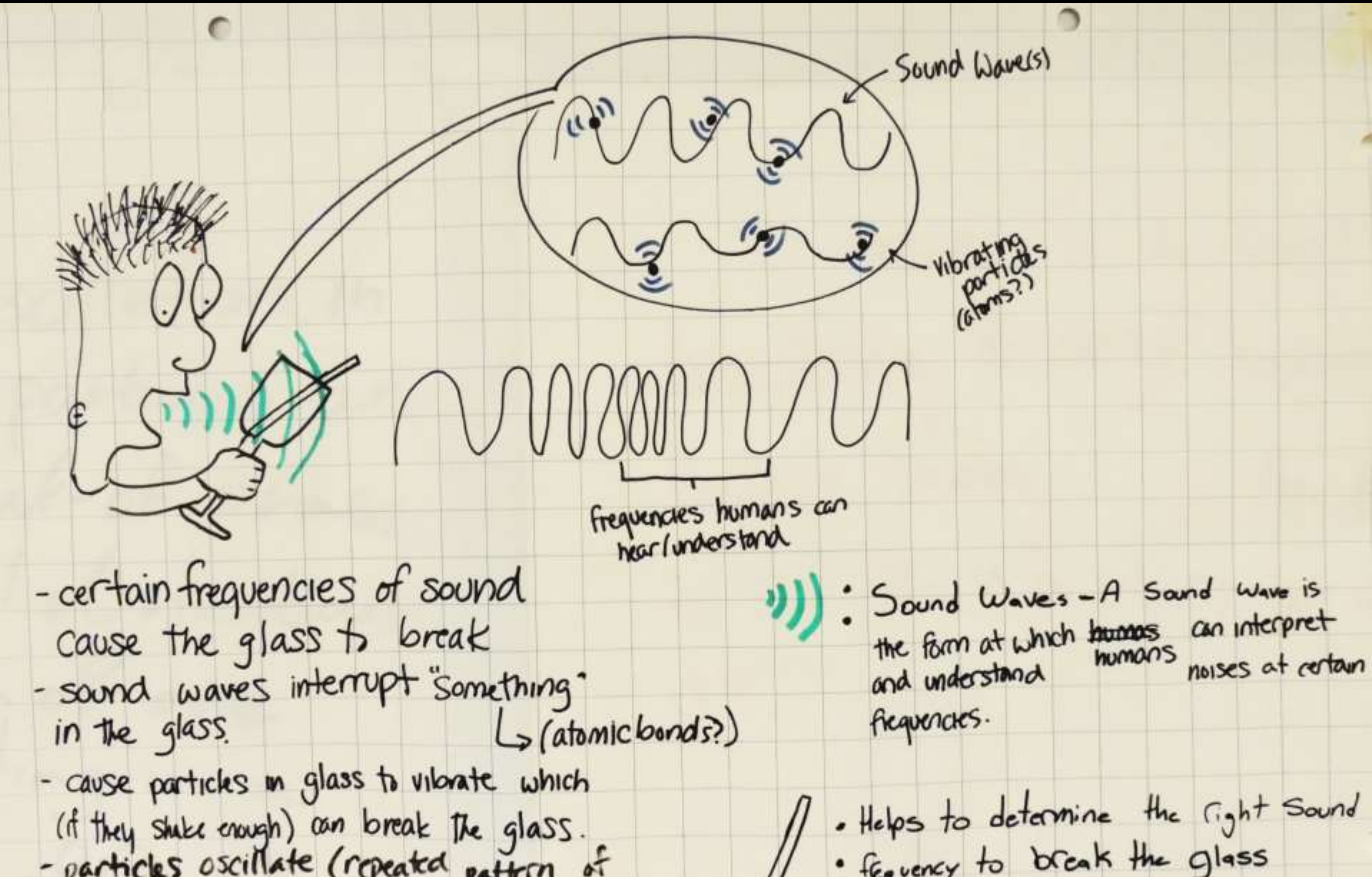
Students arrive in our classes with their brains **prewired** based on their **life experiences** and **prior schooling**.

Implications for Teaching

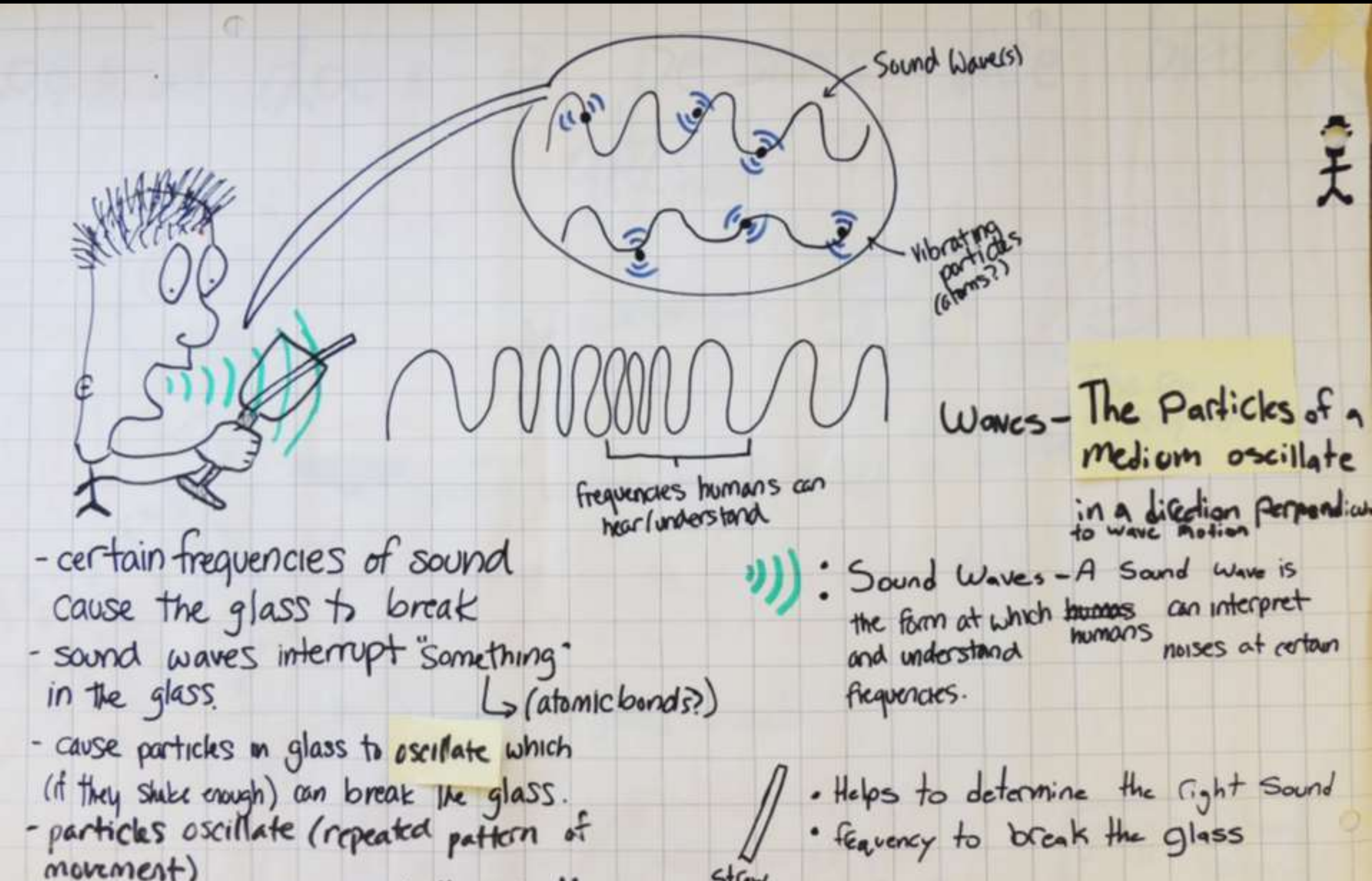
Educators must understand students' prior knowledge ~~to successfully teach~~ for students to learn.

Activate Prior Knowledge

Make Prior Knowledge Visible



Build on and add to knowledge



Implications for Teaching

- Learning begins with students' prior knowledge
- An engaging context best activates prior knowledge

Time for a test

Learn This!

┘ = 1	⊏ = 6
⊔ = 2	┐ = 7
└ = 3	⊓ = 8
⊐ = 4	┌ = 9
□ = 5	⊡ = 0

Test Time!

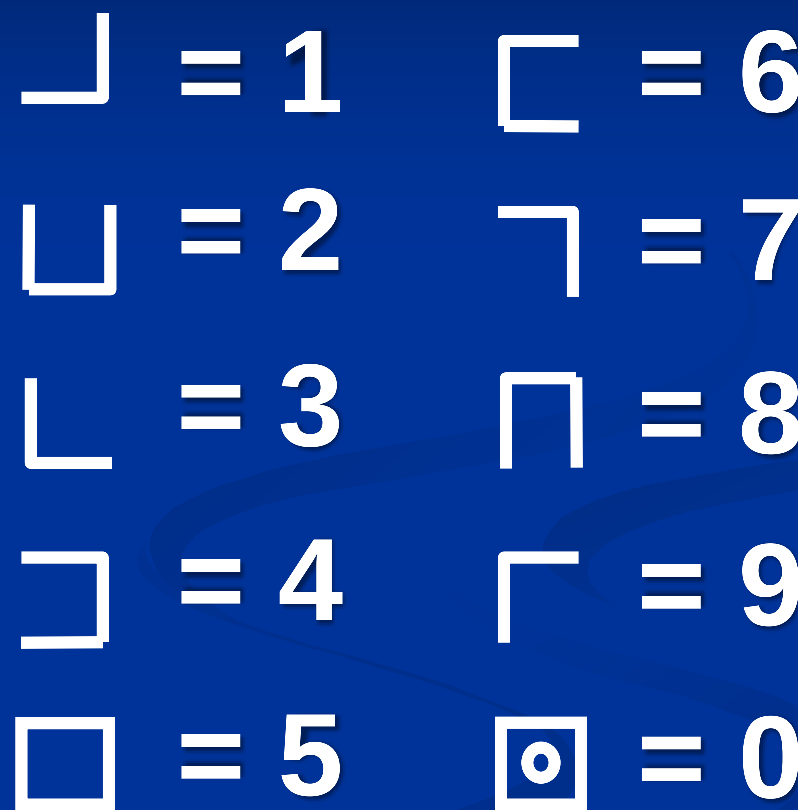
 = **38**

 = **27**

 = **40**

Discuss!

Discuss any patterns you find amongst the numbers and shapes.



The Pattern

1	2	3
4	5	6
7	8	9

Test Time!

⊔ ∟ = **23**

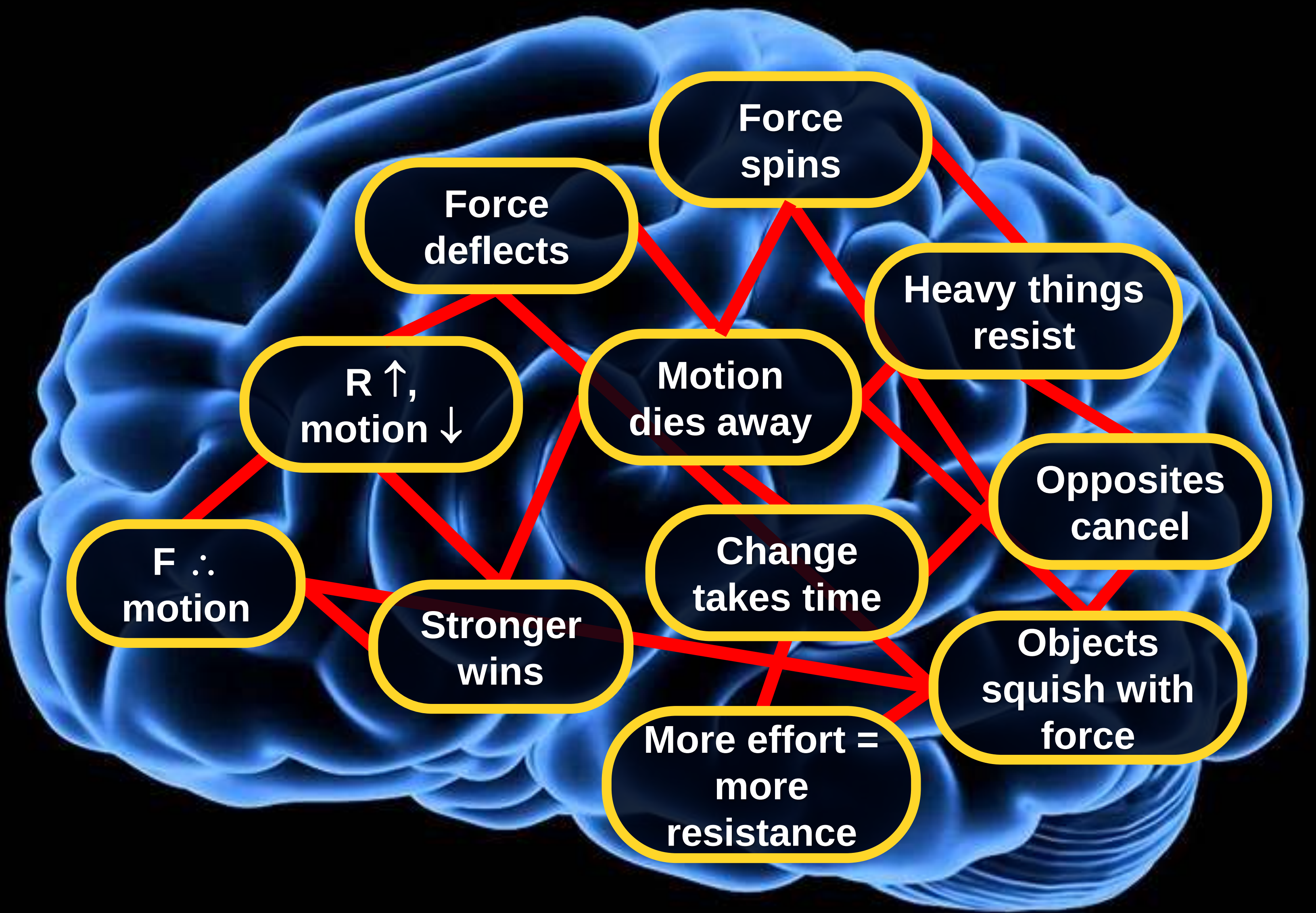
⊐ ⊓ = **48**

┘ □ = **15**

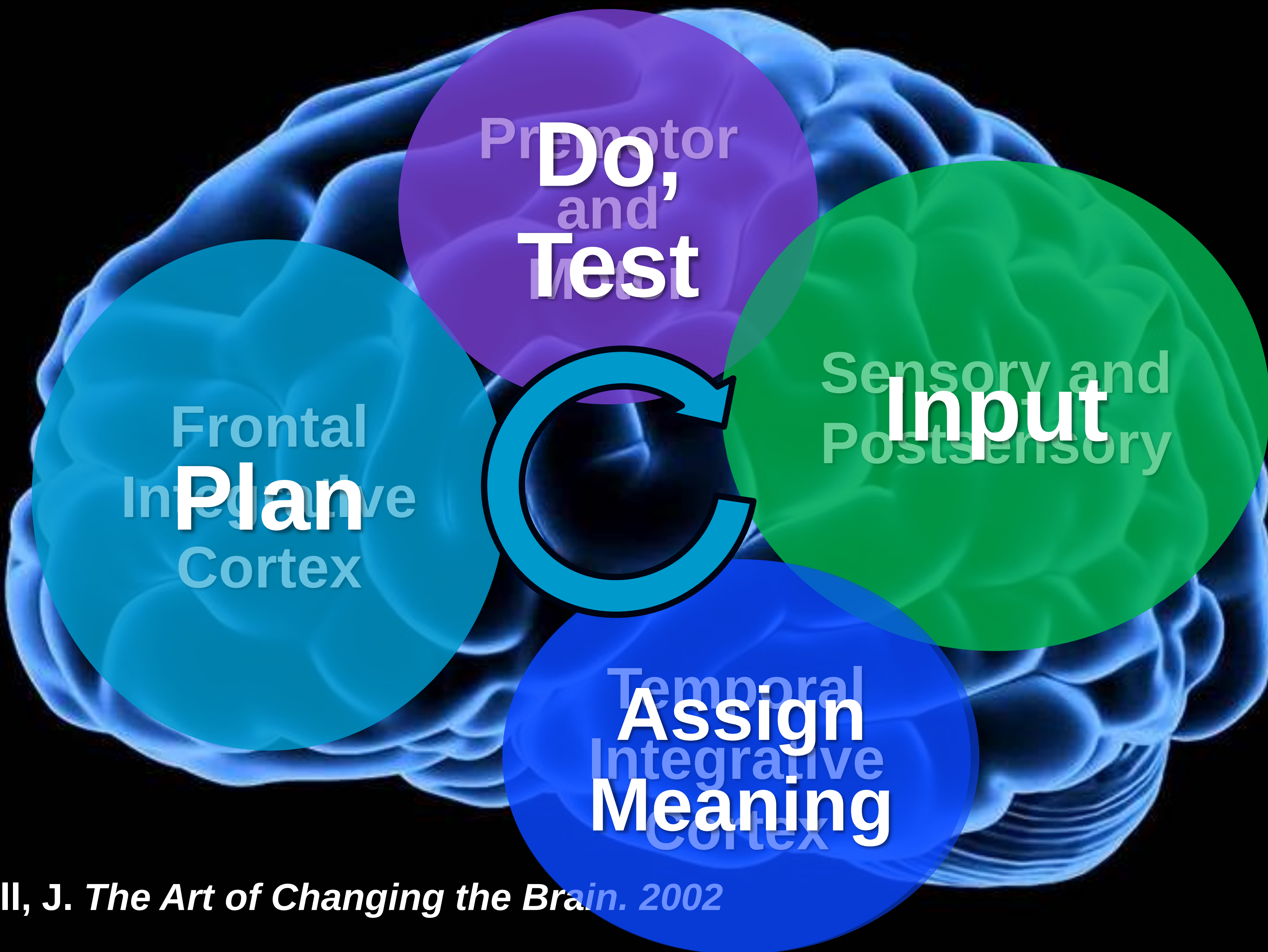
Implications for Teaching

- Discrete facts get stored with little processing
- Learning really begins with ideas that connect facts

How do you make connections?

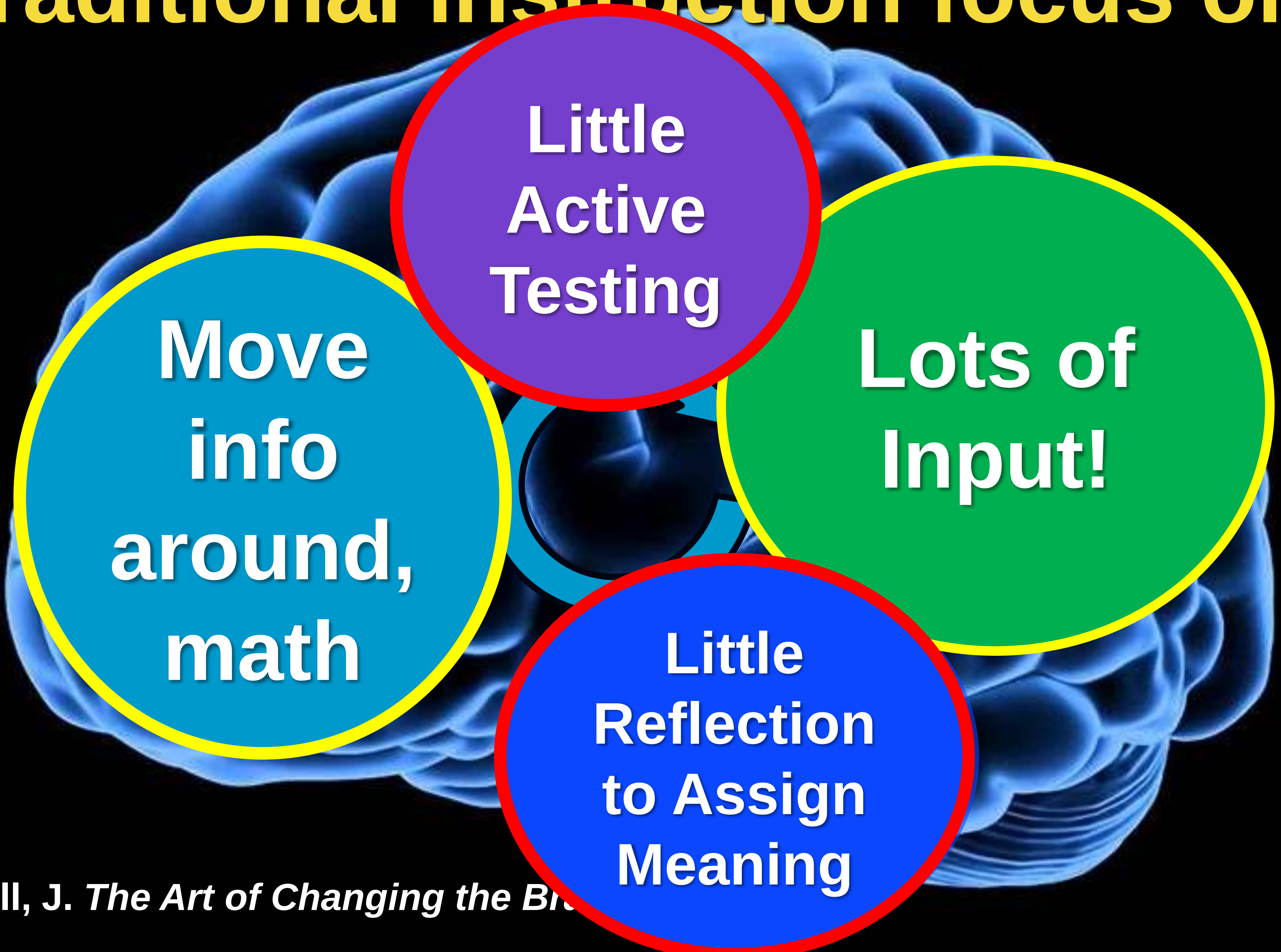


Cognitive Learning Cycle

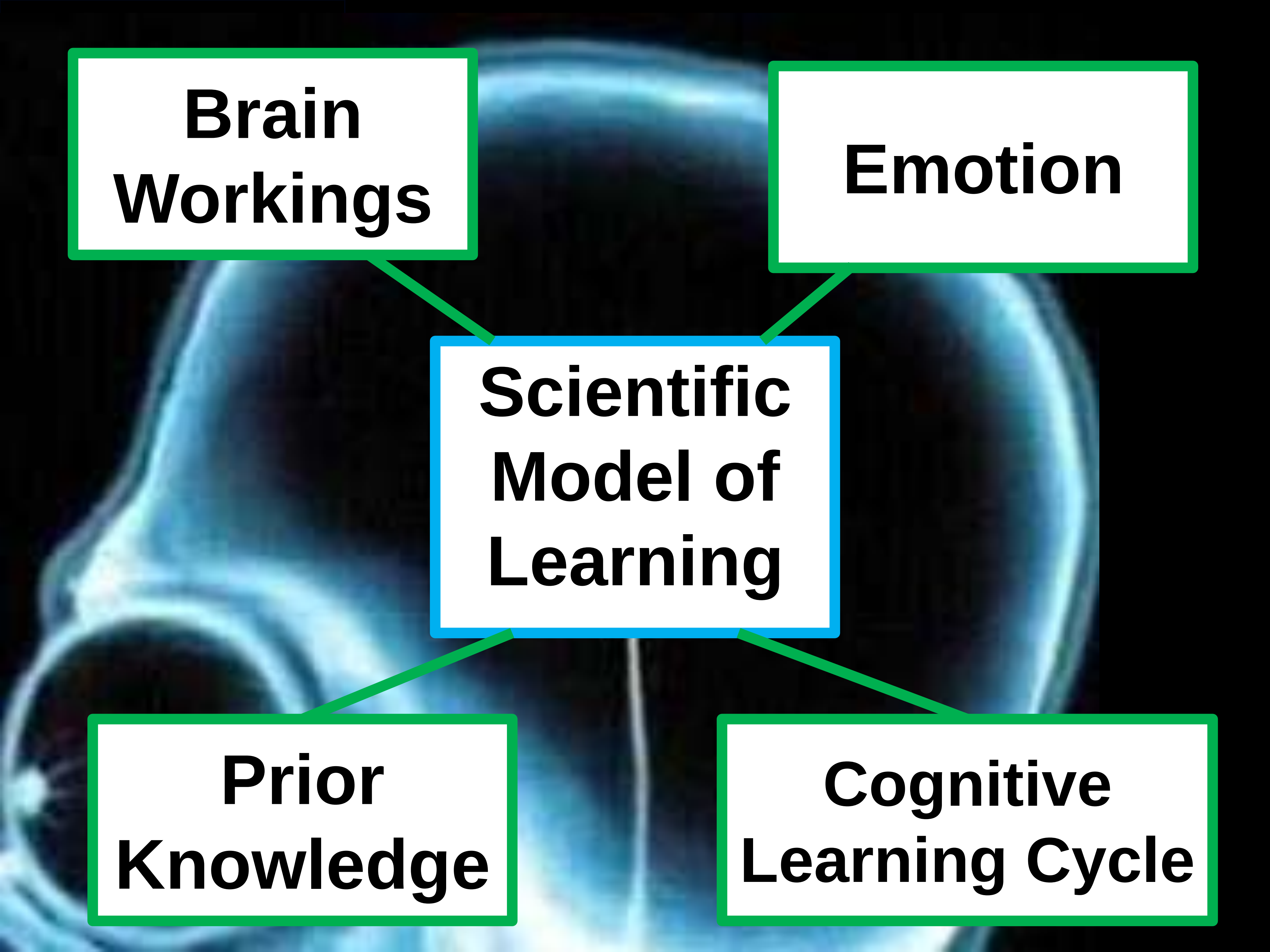


Zull, J. *The Art of Changing the Brain. 2002*

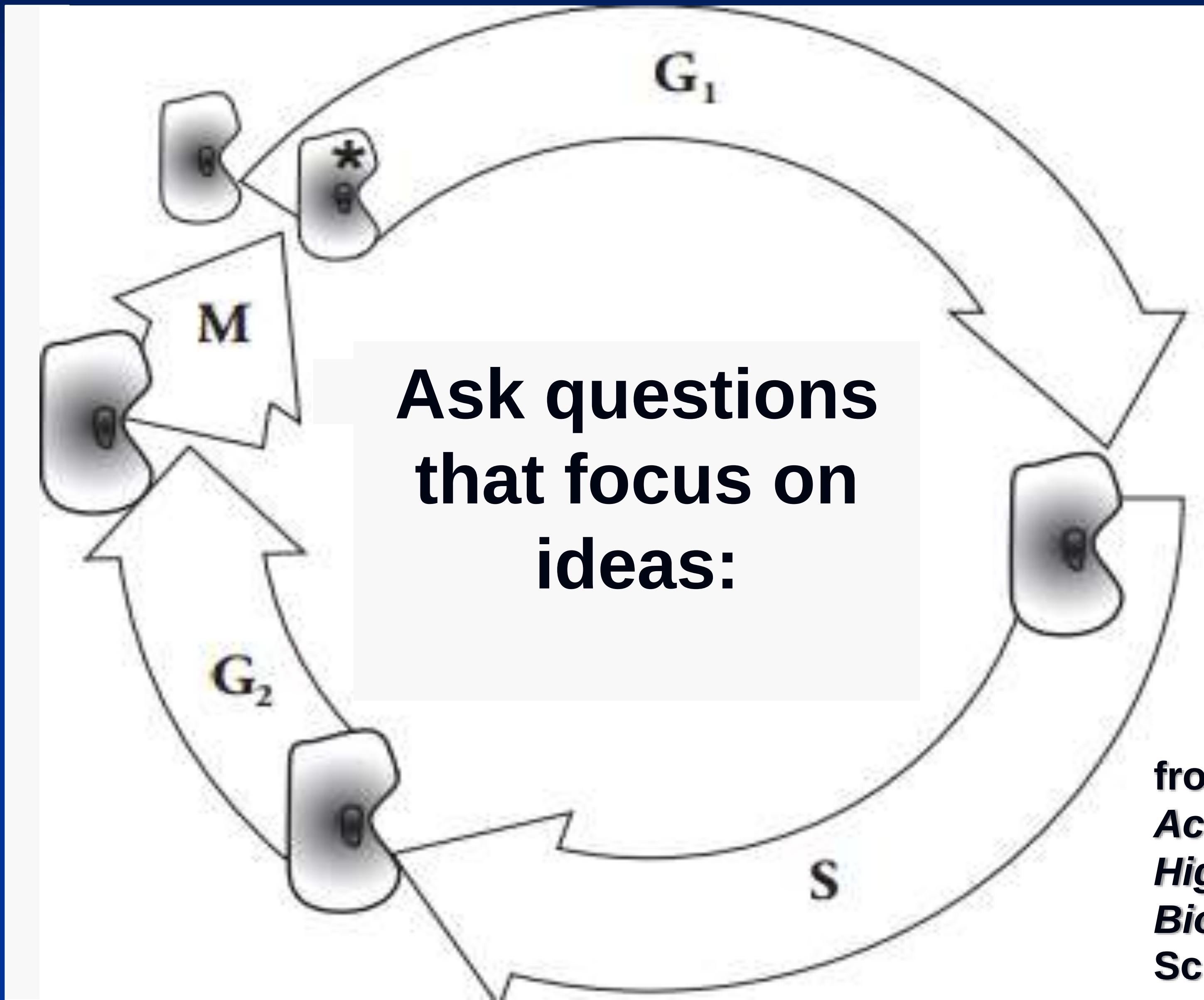
Which parts of the cycle does traditional instruction focus on?



Zull, J. *The Art of Changing the Br*


Brain Workings
Emotion
Scientific Model of Learning
Prior Knowledge
Cognitive Learning Cycle

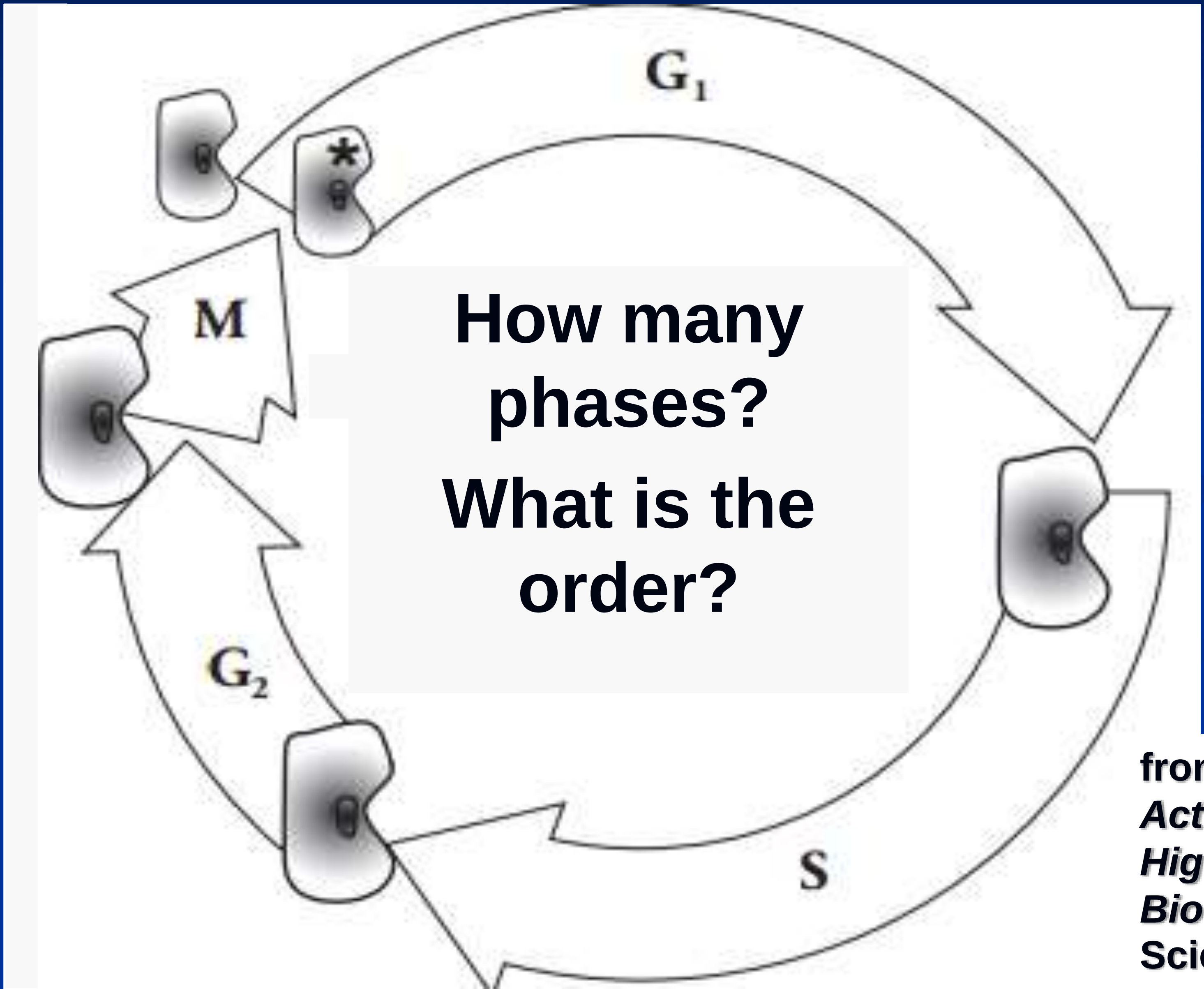
Life Cycle of a Cell



Ask questions that focus on ideas:

from: *POGIL Activities for High School Biology*, Flinn Scientific Inc.

Simple Questions

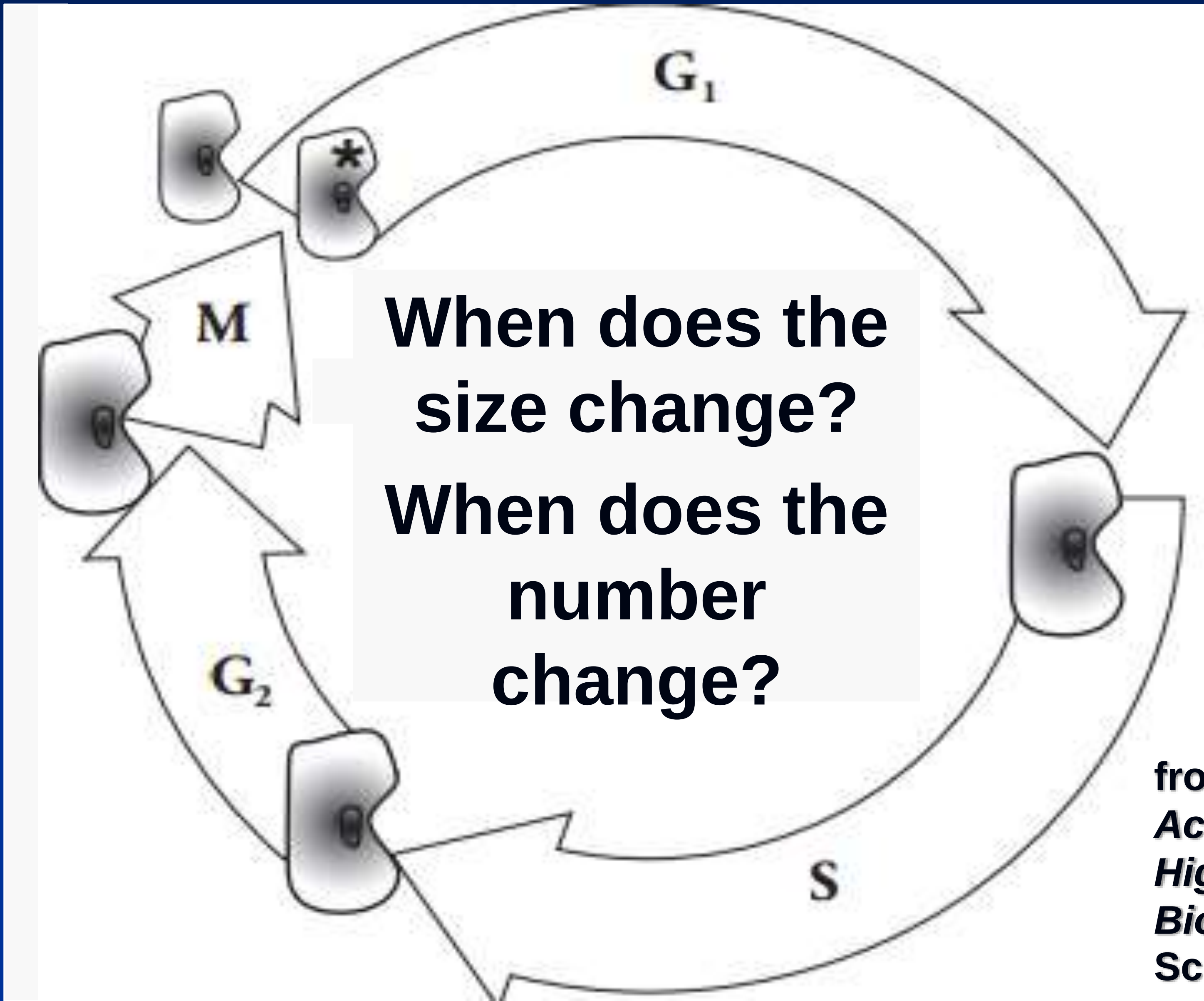


How many phases?

What is the order?

from: *POGIL Activities for High School Biology*, Flinn Scientific Inc.

Key Ideas

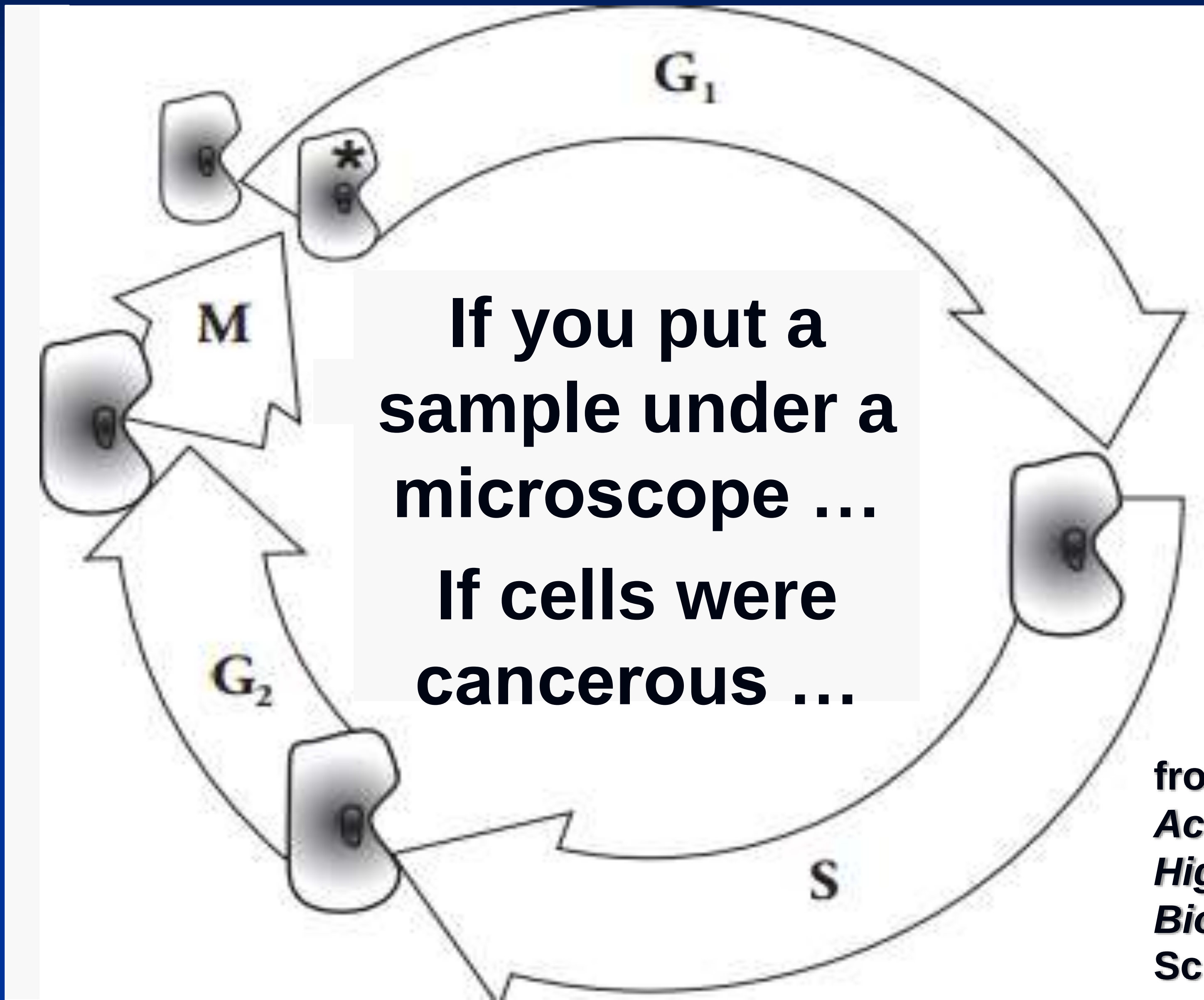


When does the size change?

When does the number change?

from: *POGIL Activities for High School Biology*, Flinn Scientific Inc.

Deeper Questions

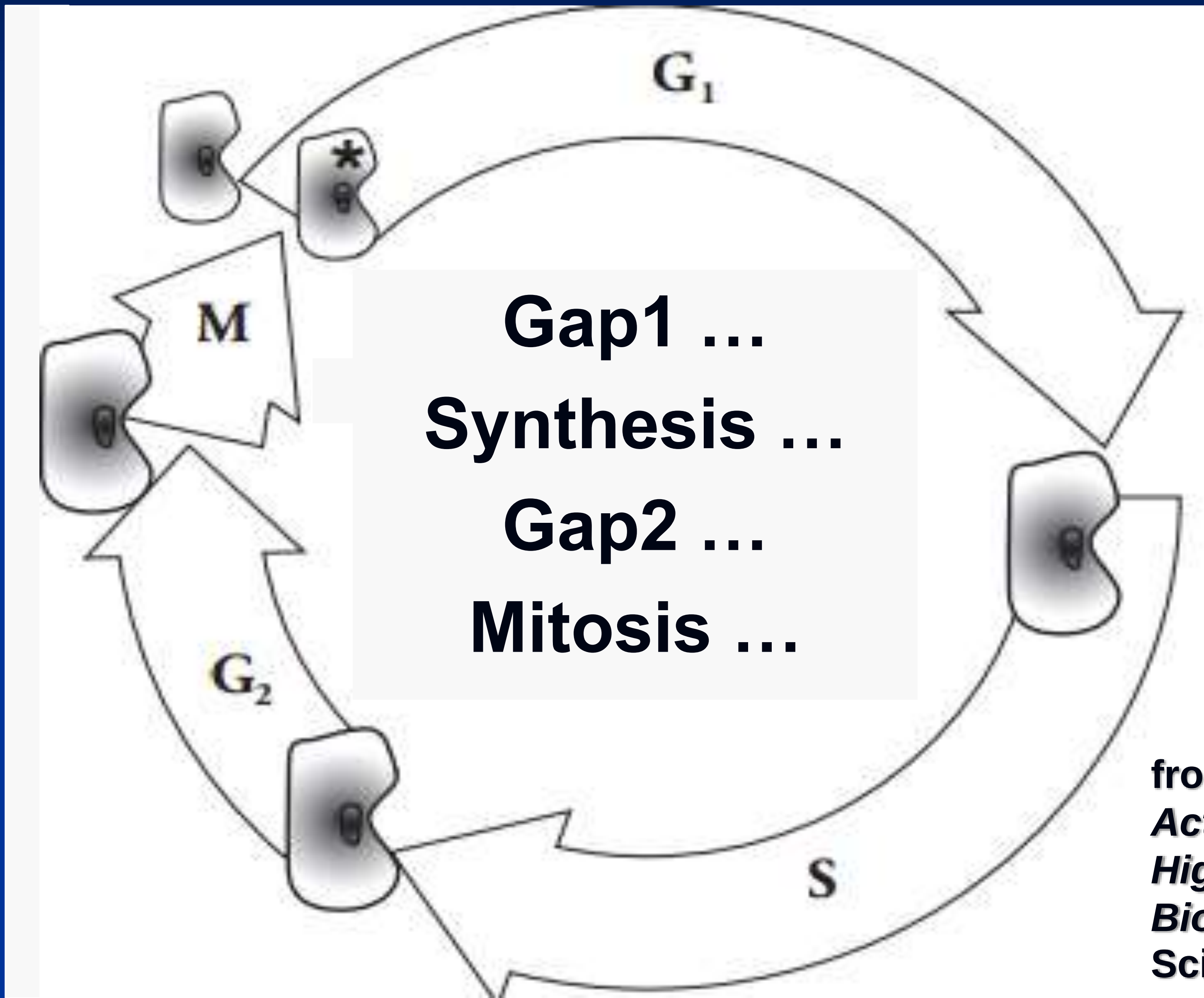


If you put a sample under a microscope …

If cells were cancerous …

from: ***POGIL Activities for High School Biology***, Flinn Scientific Inc.

Formalism, Labels, Facts

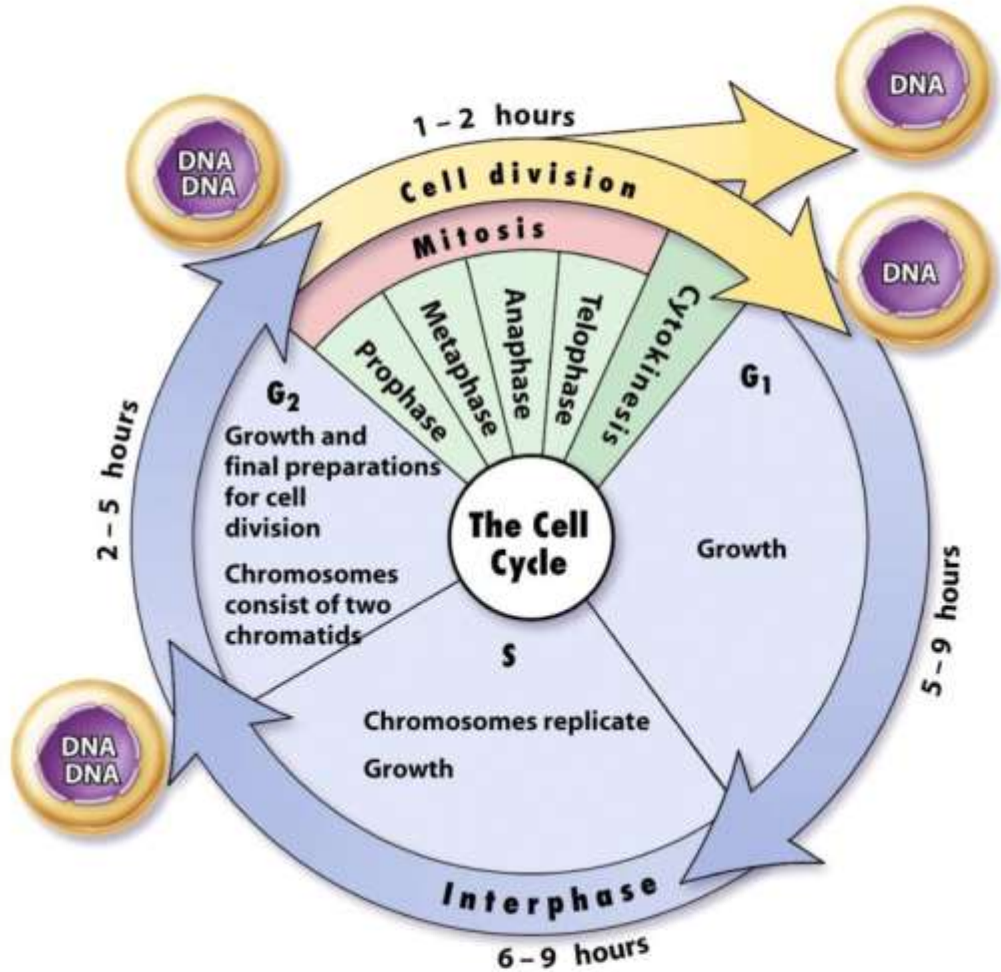


from: *POGIL Activities for High School Biology*, Flinn Scientific Inc.

Cell Cycle – 4 Phases
G_1 (& G_0) – S – G_2 - M

- *G1 (Gap 1) phase*
  - characterized by resumption of bio-synthesis
  - growth and production of proteins for DNA synthesis
  - duration is highly variable

- *S phase*
  - Amount of DNA effectively doubled → cell replicates its DNA
  - Each chromosome replicated → sister chromatids



The Zoo Exhibit Challenge

Photo by William C. Miller III, www.theazaleaworks.com
Used with permission

Squirrel
25 cm long, 8 cm wide
400 g

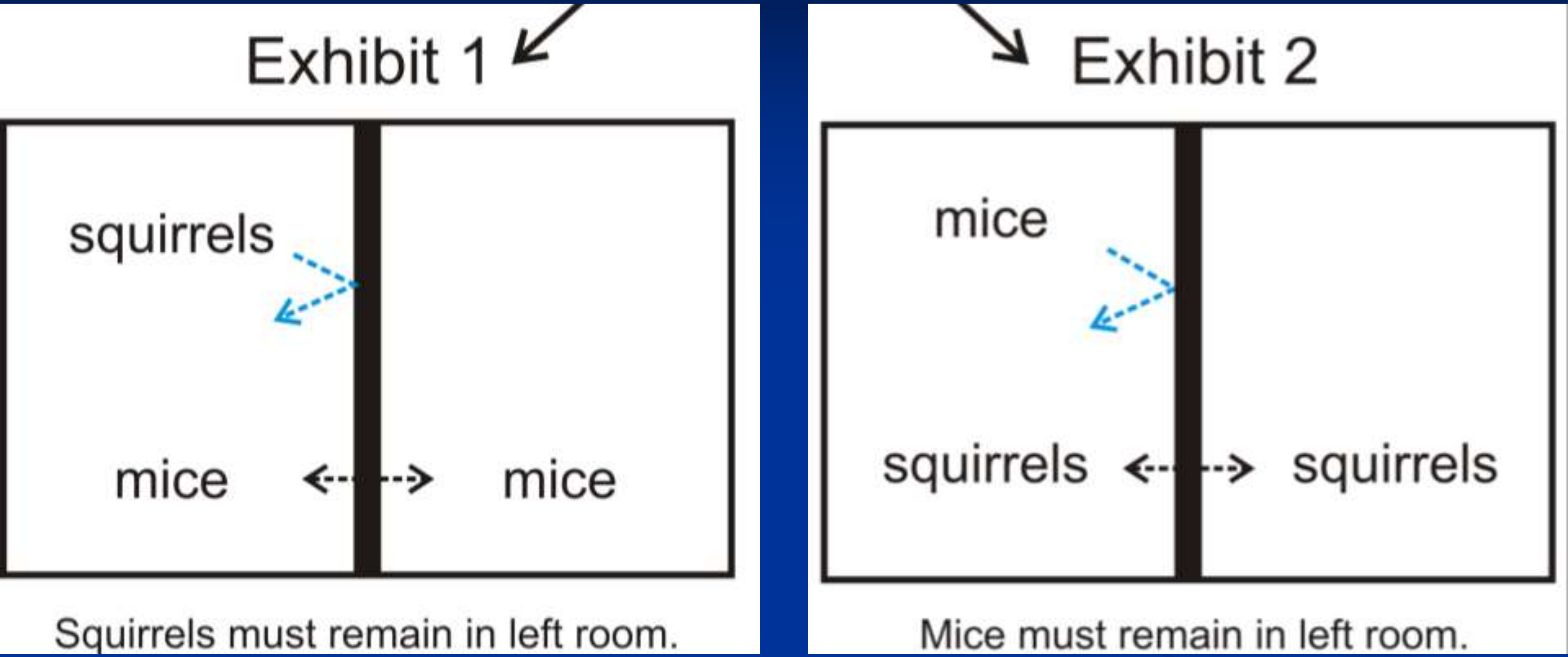
Photo by Michael Pereckas, www.mspland.com
Used with permission

Mouse
7 cm long, 2 cm wide
20 g

From: *Invention Activities for University Cell Biology*, CWSEI at UBC

The Zoo Exhibit Challenge

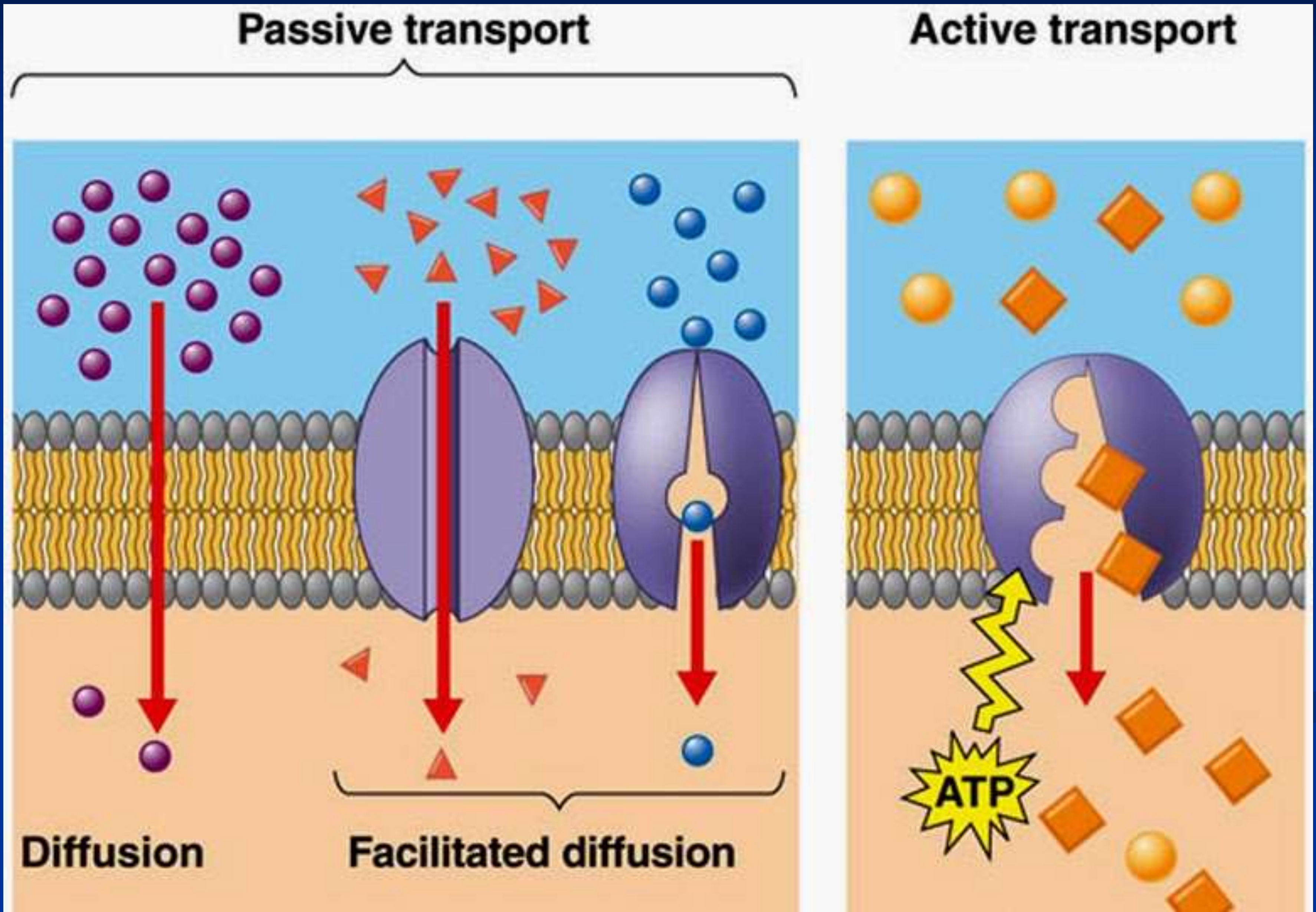
01:30



(1) How would you build a barrier between the two halves of each exhibit?

(2) What science concept does this model?

Transport Across Cell Membranes

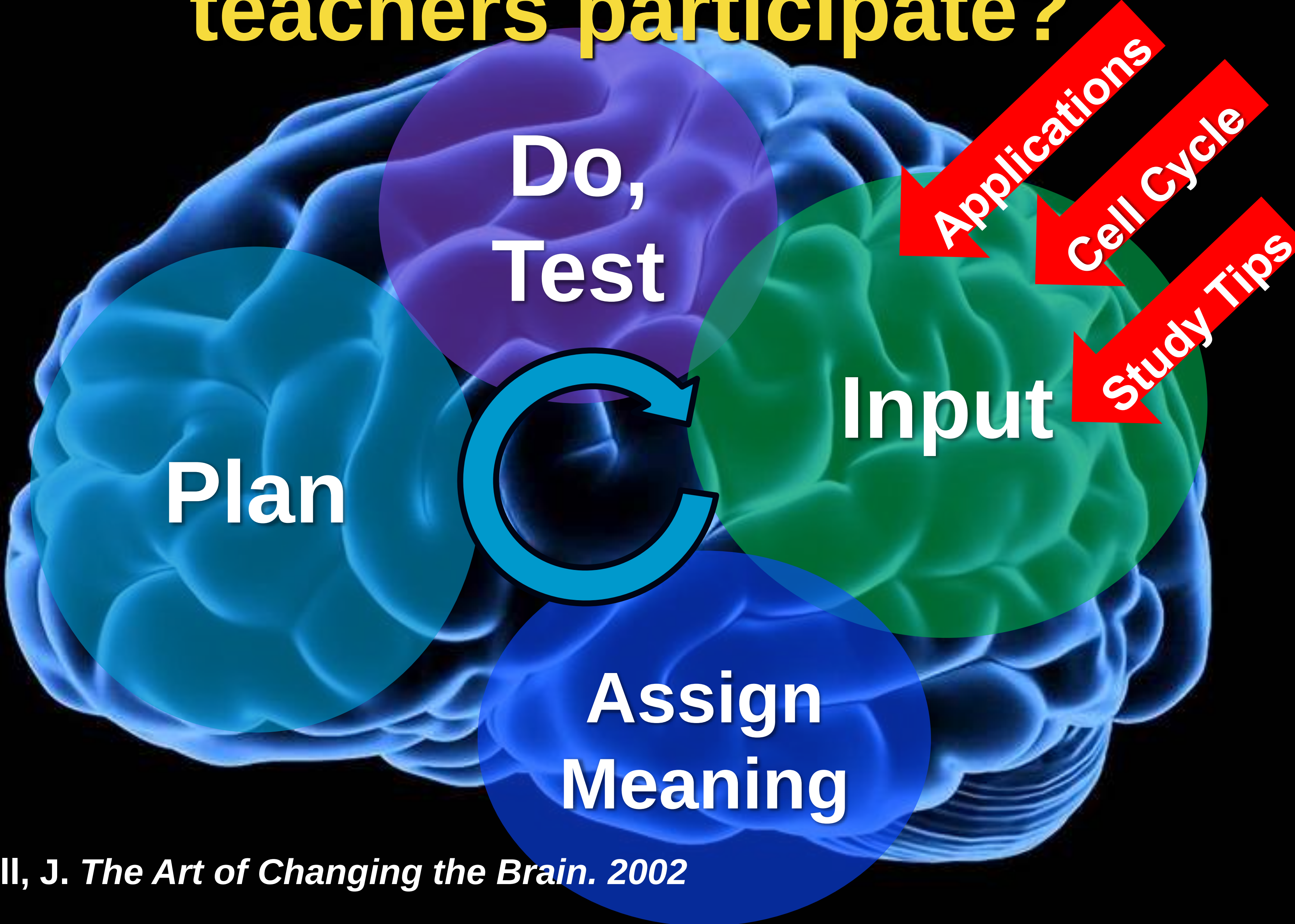


Implications for Teaching

Constructivism

- First: explore ideas
- Second: learn labels or facts
- Third: work out math
- Works! Follows cognitive learning cycle

In which part of this cycle can teachers participate?



Zull, J. *The Art of Changing the Brain. 2002*

Implications for Teaching

Constructivism

- First: students explore ideas
- Second: learn labels or facts
- Third: work out math
- Works! Follows cognitive learning cycle

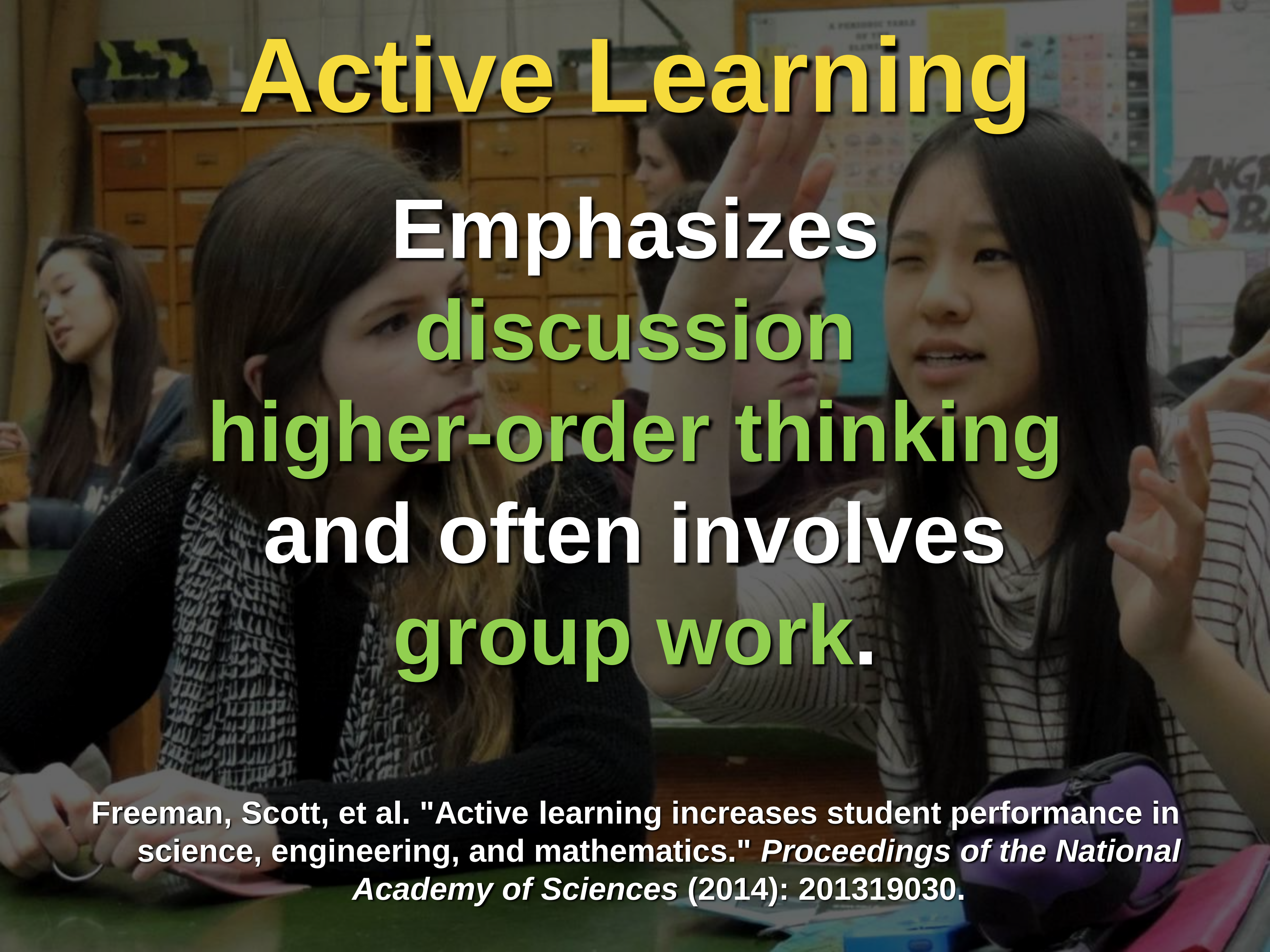
Implications for Teaching

Constructivism

- First: students explore ideas
- Second: learn labels or facts
- Third: work out math
- Works very, very well!

Active Learning

York Mills Students



Active Learning

Emphasizes discussion higher-order thinking and often involves group work.

Freeman, Scott, et al. "Active learning increases student performance in science, engineering, and mathematics." *Proceedings of the National Academy of Sciences* (2014): 201319030.

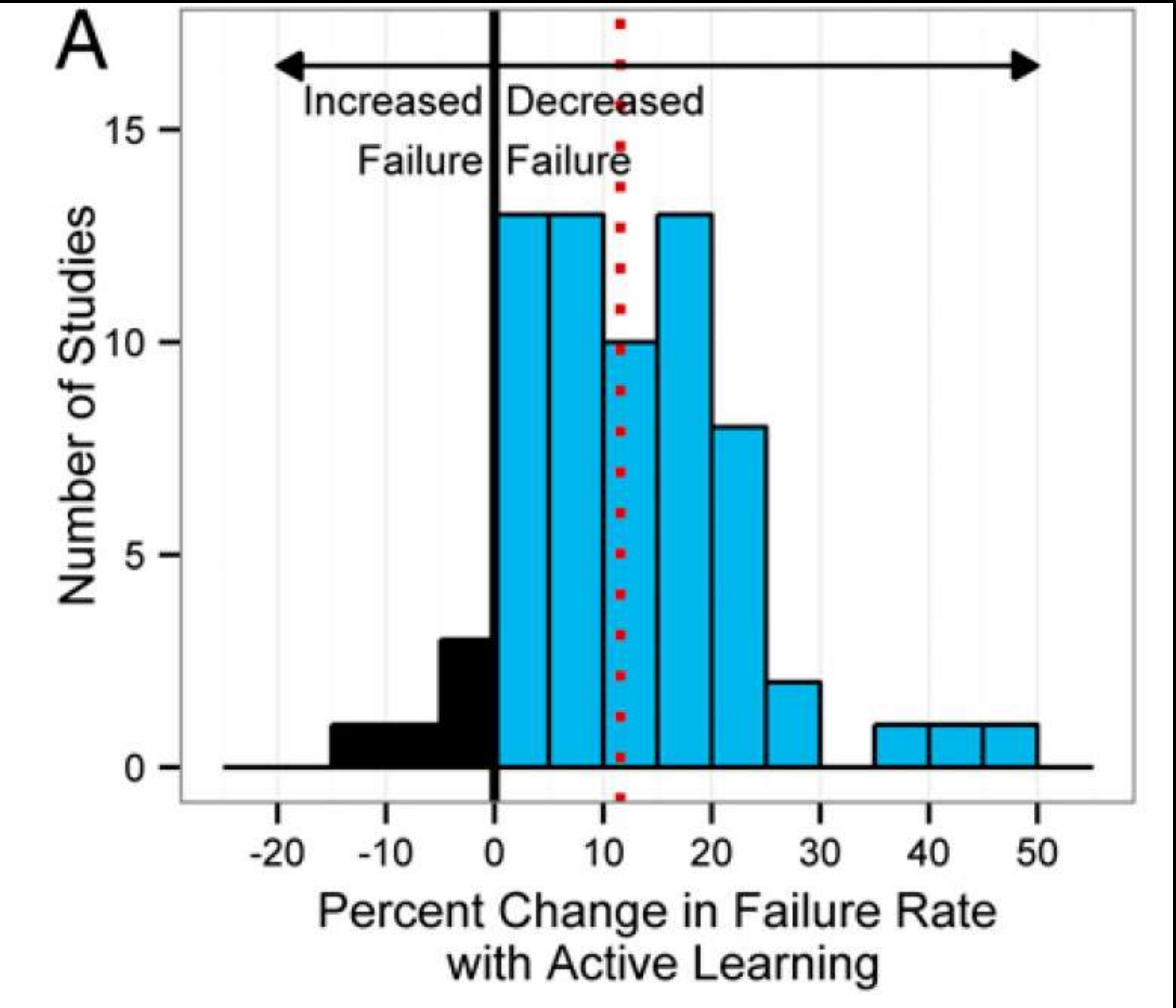
York Mills Students

Discussion!

What do you observe?

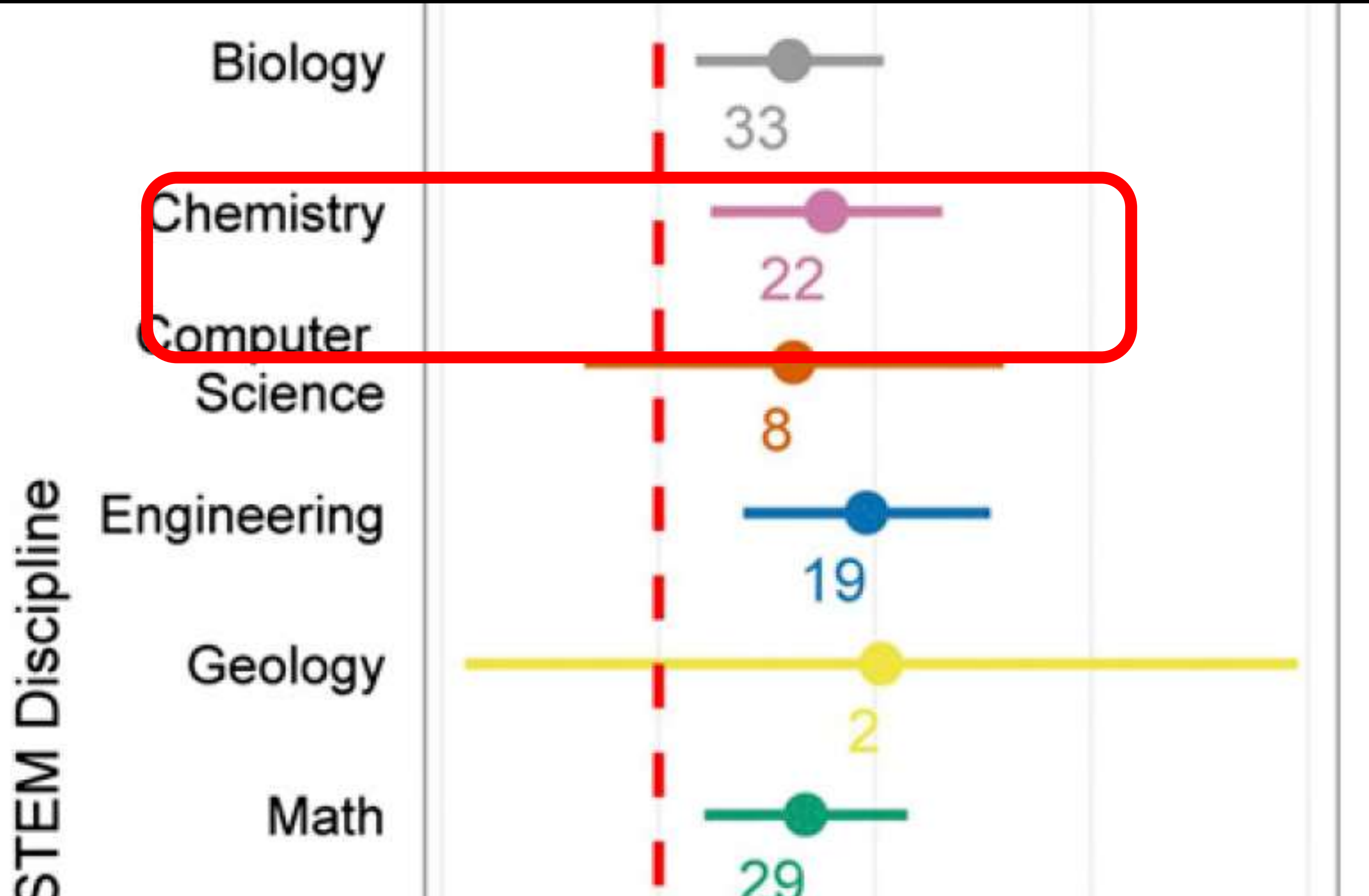
What do you infer?

Active Learning Reduces Failures

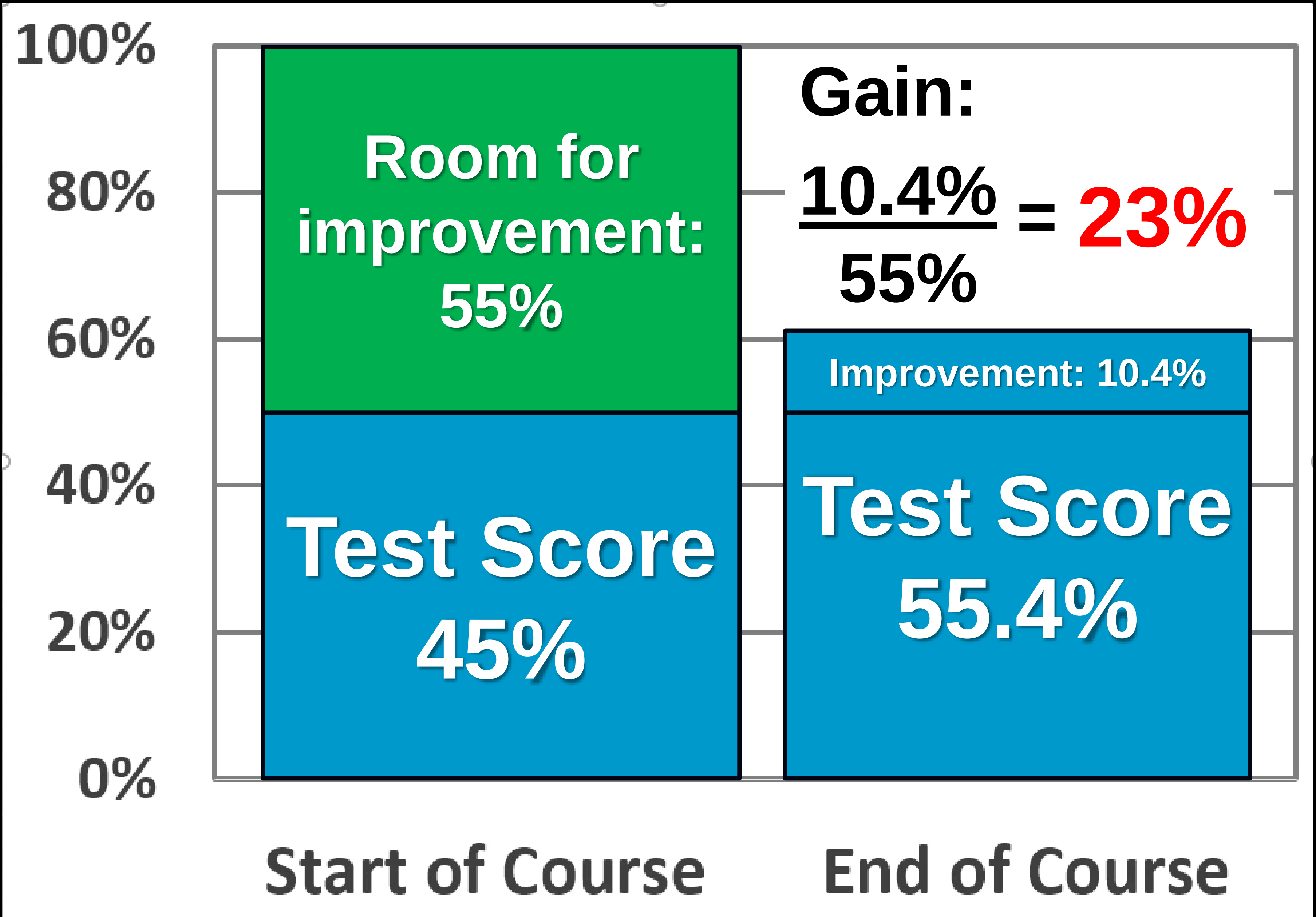


Freeman, Scott, et al. "Active learning increases student performance in science, engineering, and mathematics." ***Proceedings of the National Academy of Sciences*** **(2014): 201319030.**

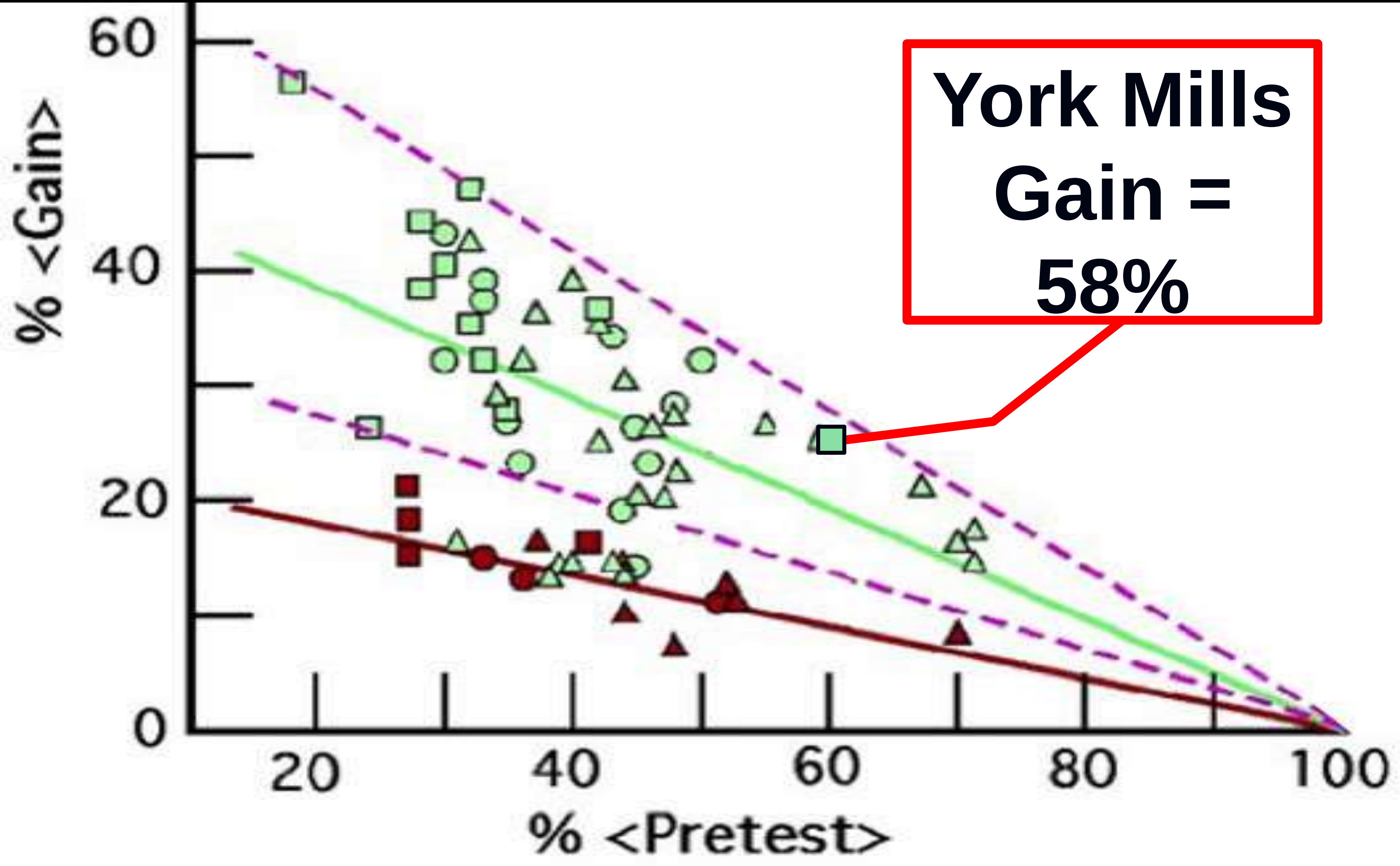
Improves Course Performance



Force Concept Inventory Scores



Active Learning Works!

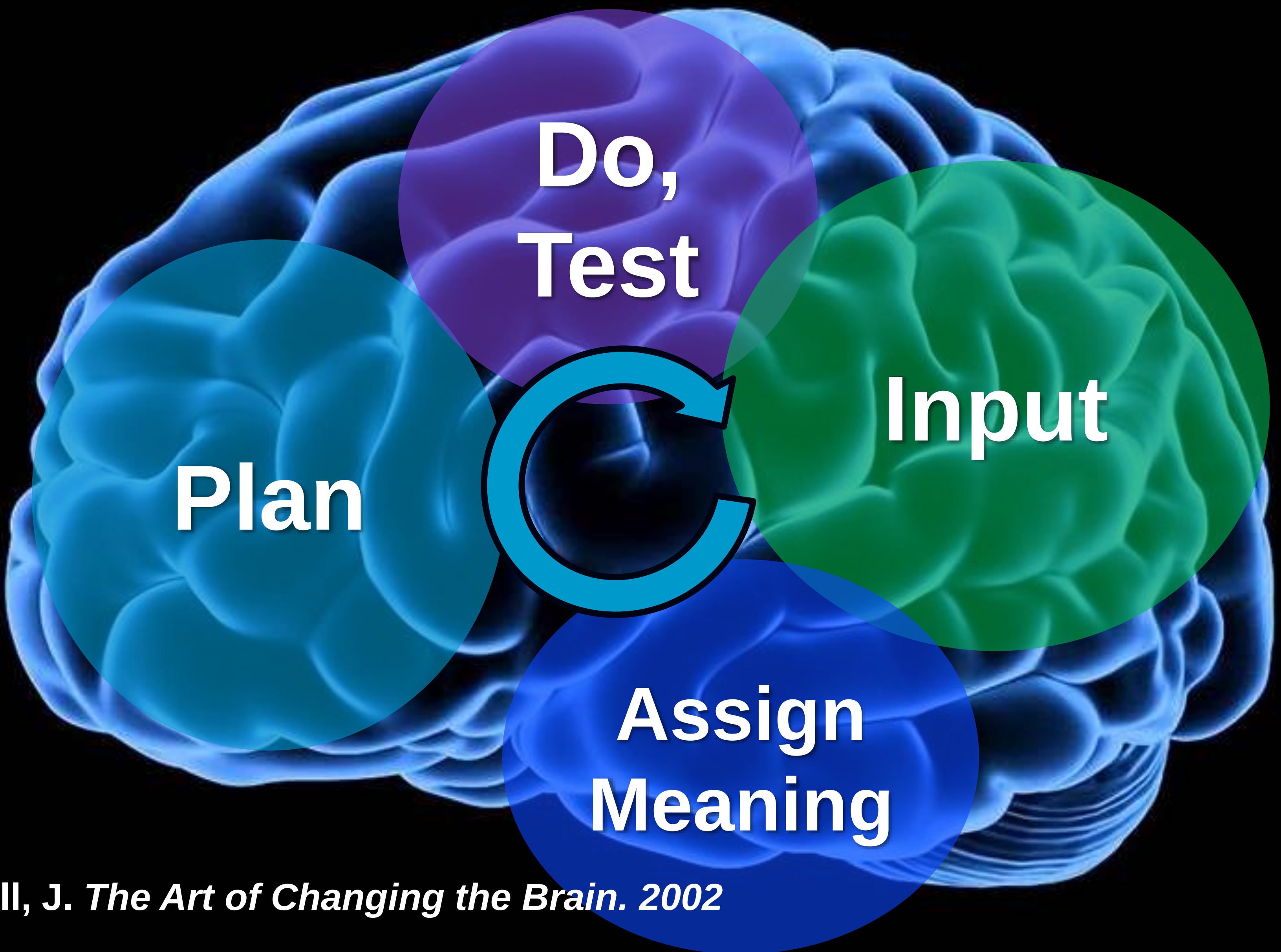


Implications for Teaching

Cognitive Learning Cycle

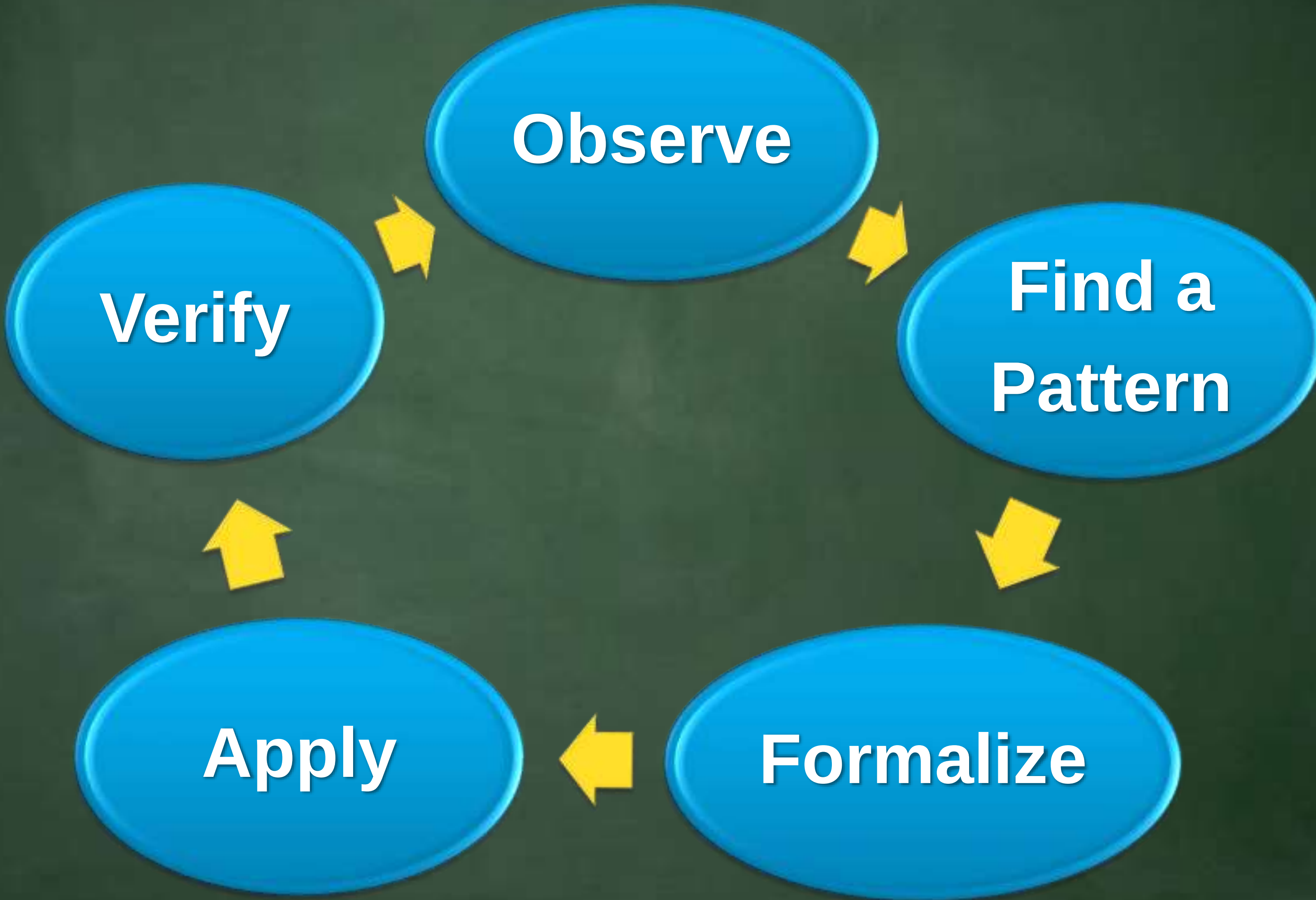
(how brains figure stuff out)

Cognitive Learning Cycle



Zull, J. *The Art of Changing the Brain. 2002*

An Inquiry Cycle



Implications for Teaching

Cognitive Learning Cycle

(how brains figure stuff out)

↓

Inquiry Processes

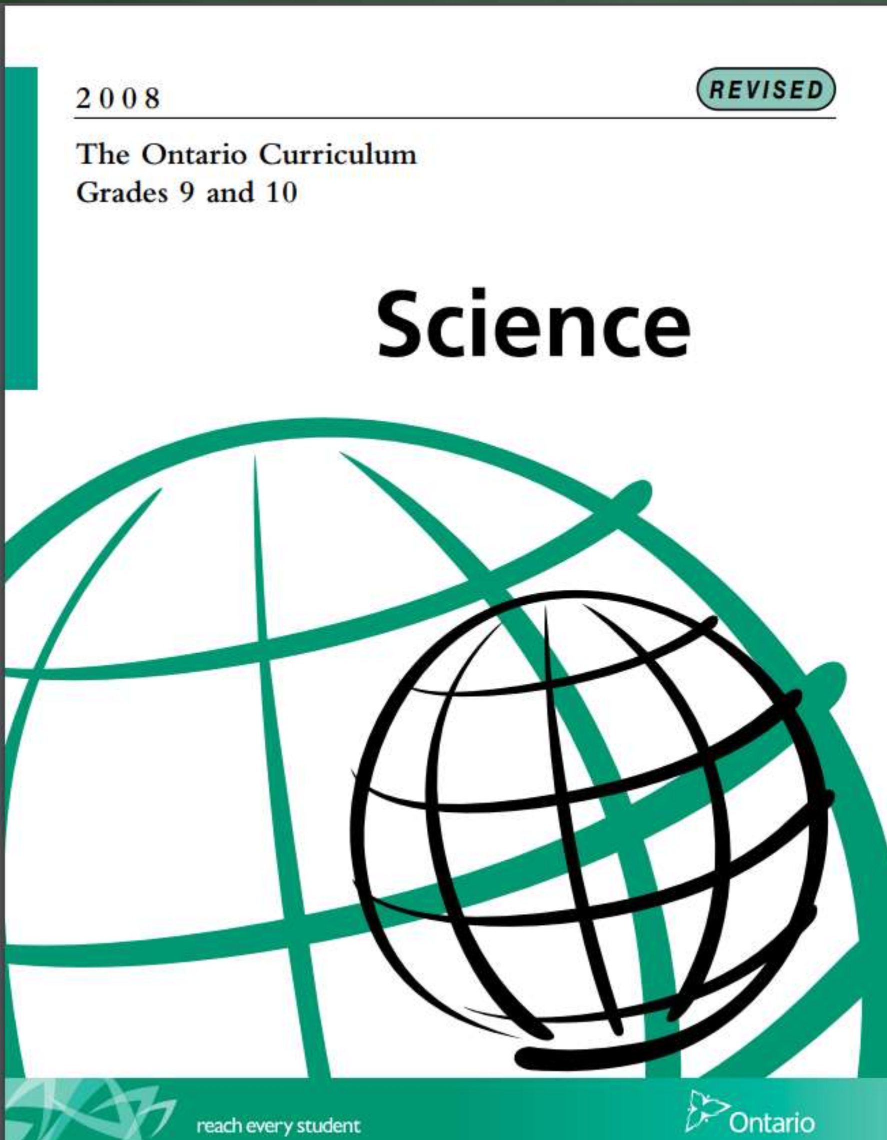
(how students figure stuff out)

↓

Process of Science

(how scientists figure stuff out)

Implications for Teaching



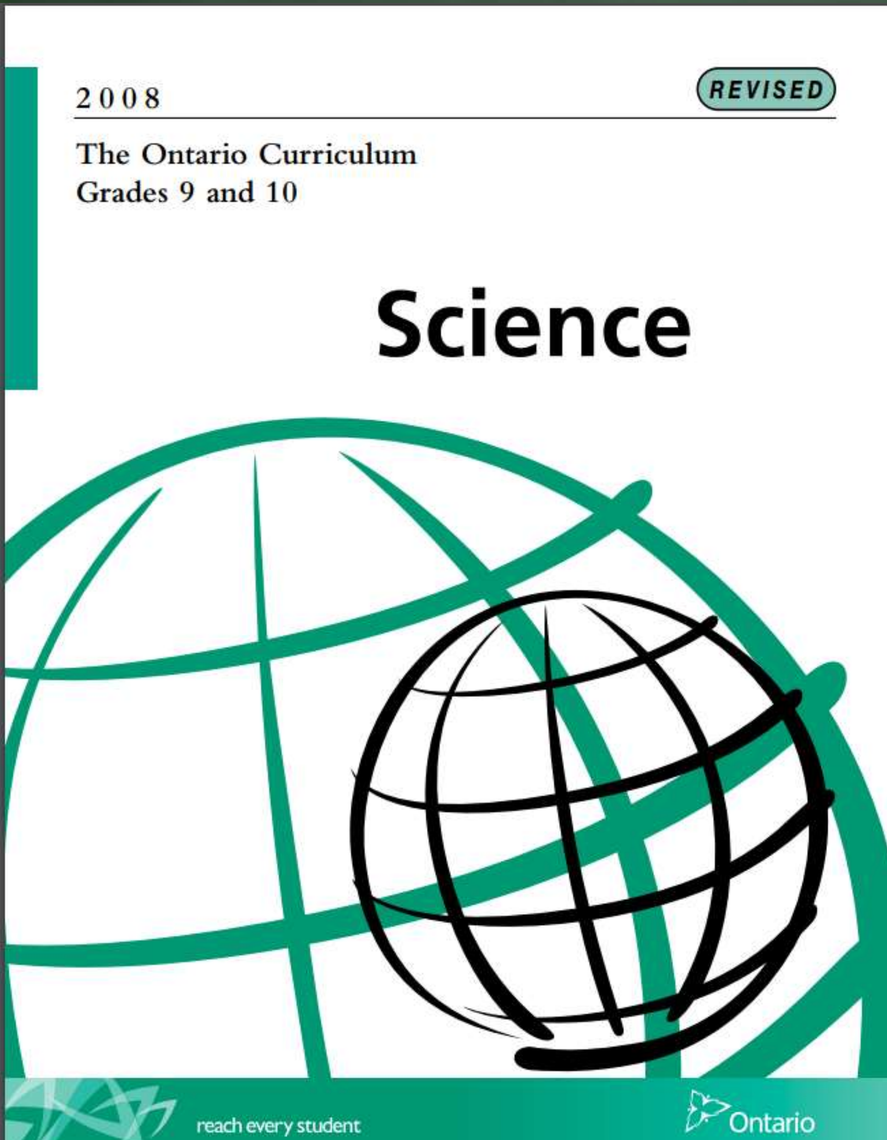
Goals of the Science Program

(1) to relate science to technology, society, and the environment

Context ✓

STEM Initiative

Implications for Teaching

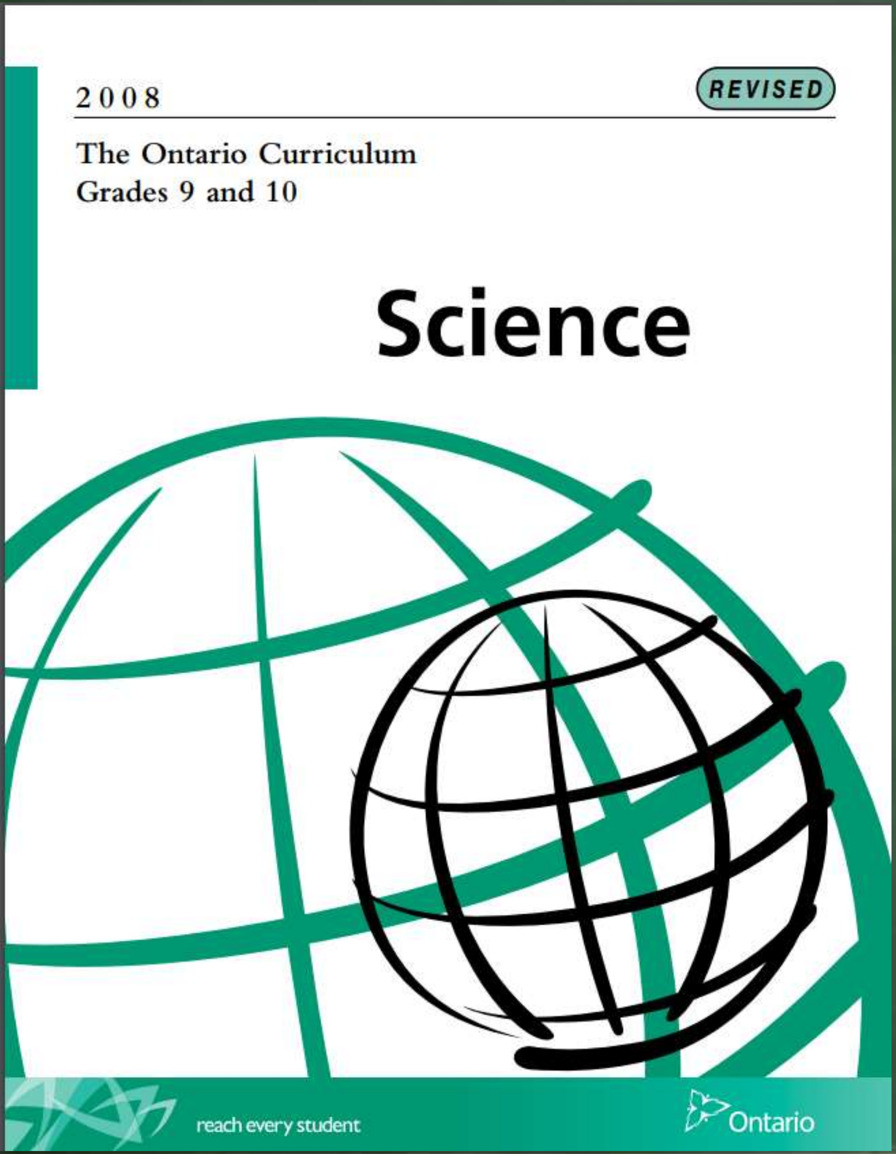


Goals of the Science Program

(2) to develop the skills, strategies, and habits of mind required for scientific inquiry

Inquiry ✓

Implications for Teaching



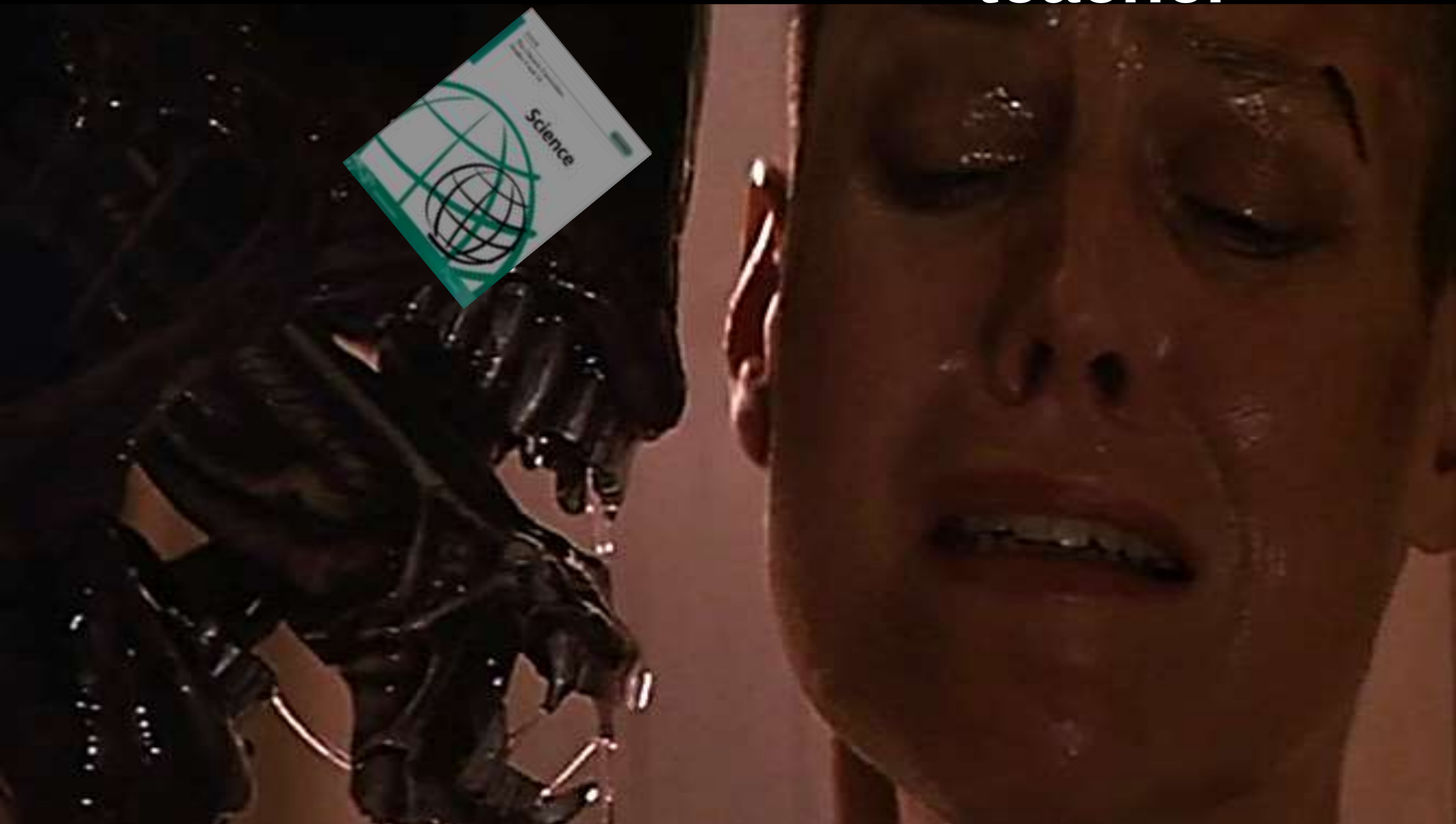
Goals of the Science Program

(3) to understand the basic concepts of science

Learning Cycle✓

Curriculum

Well-meaning teacher



Implications for Teaching

Inquiry takes time

Too many expectations

Skill fluency requires many contexts

Too many disjointed sets of skills

My Advice

Cover less material

Cover it **deeply**

Evaluation of Achievement of Overall Expectations

All curriculum expectations must be accounted for in instruction, but evaluation focuses on students' achievement of the overall expectations. A student's achievement of the overall expectations is evaluated on the basis of his or her achievement of related specific expectations. The overall expectations are broad in nature, and the specific expectations define the particular content or scope of the knowledge and skills referred to in the overall expectations. Teachers will use their professional judgement to determine which specific expectations should be used to evaluate achievement of the overall expectations, and which ones will be covered in instruction and assessment (e.g., through direct observation) but not necessarily evaluated.

Social Implications

Manufacturing Economy

Automation

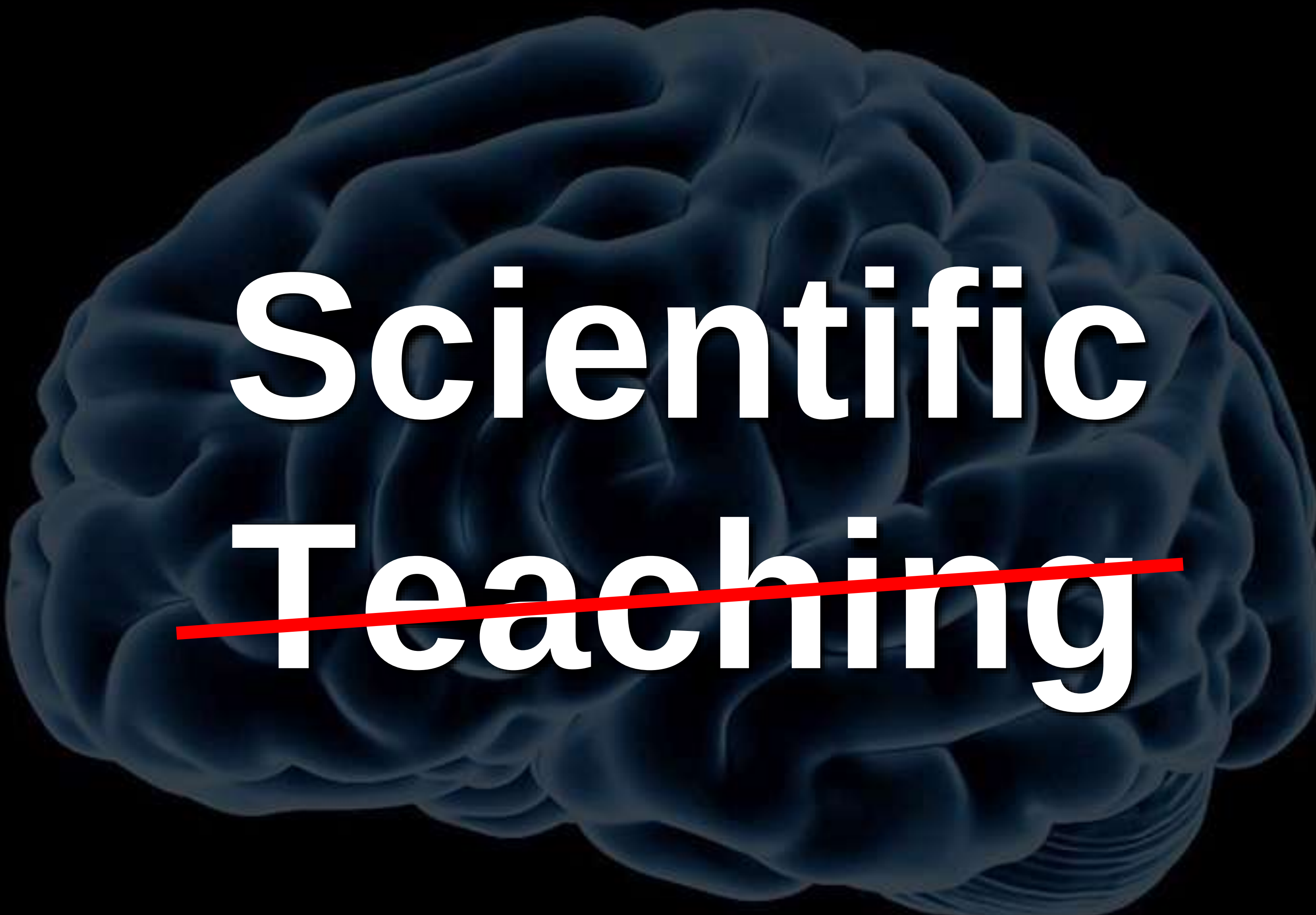
Knowledge Economy

Cognitive

Machines

Future Economy?

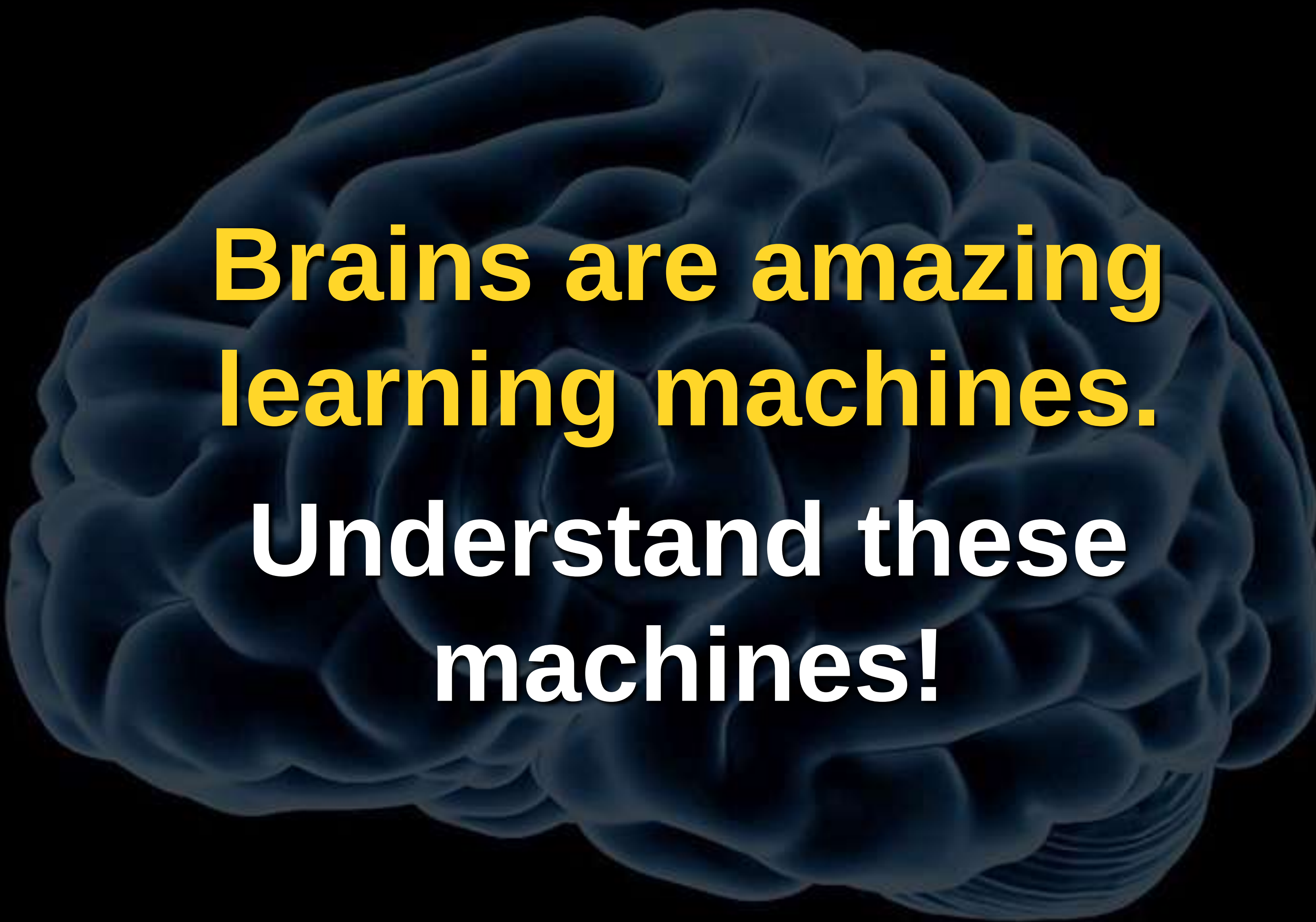
The Big Picture



Scientific ~~Teaching~~

The Big Picture

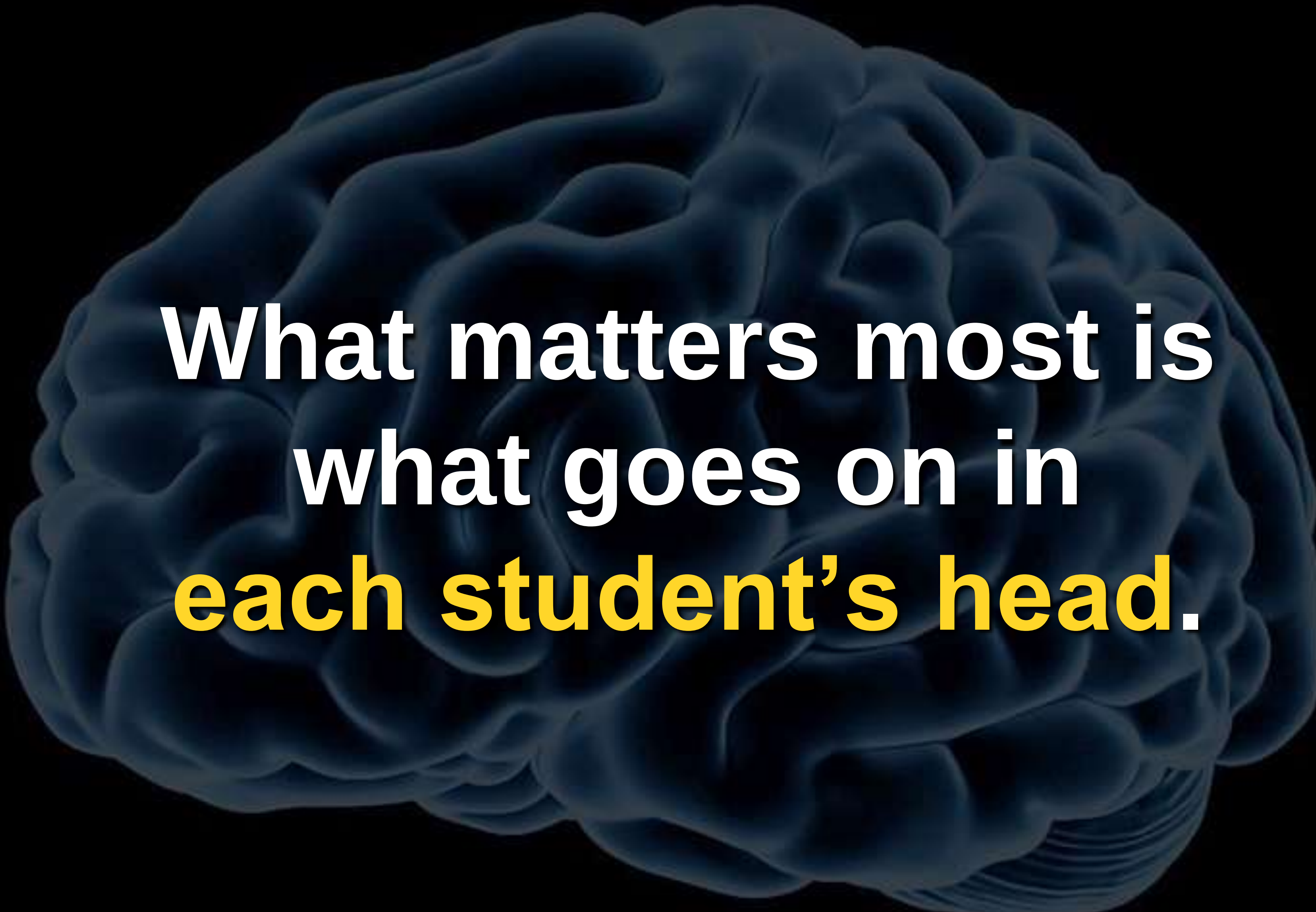
Scientific Learning



Brains are amazing learning machines.

Understand these machines!

Scientific Learning



Scientific Learning

Brain Workings

Help students understand how their brains work

Design learning environment to maximize connection building

Scientific Learning

Emotion

Create a collaborative culture of success

Ground learning in engaging problems (STSE, STEM)

Scientific Learning

Prior Knowledge

No empty vessels

Study prior knowledge

Help students find connections to what they already know

Scientific Learning

Cognitive Learning Cycle

Understanding can’t be told, students must **build** it.

Ideas first (constructivism)

Need **many** opportunities to explore, test understanding

Don’t Start From Scratch!

Reformed Physics Teaching

An Inquiry-Based, Cooperative Group Approach to Teaching Physics by Chris Meyer

Stop Teaching!

and Help Your Students Learn

Hello and welcome to my website! For six years I have been running a reformed physics classroom that is designed around cooperative group work using guided–inquiry investigations. The traditional lecture has completely disappeared! This website is designed to help you learn about this method of teaching and to provide you with the materials that you might need to start teaching this way yourself.

CBC Interview: Nobel Prize and Physics Teaching

October 6, 2015

Today the Nobel Prize in physics was awarded to Canadian physicist Arthur McDonald for his work on neutrino oscillations. I heard a bit

Reformed Physics Teaching

An Inquiry-Based, Cooperative Group Approach to Teaching Physics by Chris Meyer

Making a dramatic change to your teaching can be challenging, but fear not! Here you will find the resources you need to learn how to teach the inquiry way, including the materials you will need for your students.

The **Student Workbook** contains the complete set of daily investigations. Included in the workbook is a syllabus listing each lesson, the topics covered, the materials used and homework.

Our textbook for Gr. 11 is the old Addison Wesley Physics 11 (2002). The text for Gr. 12 is the old Nelson Physics 12 (2003). I am unaware of any current texts in Ontario that would be a suitable compliment

Resources for the Science Classroom

New! Gr. 11 Chemistry (SNC3U)

Over the past few semesters, our chemistry teacher, Erik Lindala, has been creating an inquiry-based introductory chemistry course modeled after our grade 11 physics program. It has gone through a few iterations now and has a complete handbook with the lessons for the course. Many thanks to Erik for sharing this with us.

Gr. 11 Chemistry Student Workbook (Fall 2015)
A complete, day-by-day, set of lesson plans and activities for the Gr. 11 chemistry course by Erik Lindala from York Mills C. I. If you try it out, please let me know how it goes!

Gr. 10 Science (SNC2D)

Gr. 11 Physics (SPH3U)

Gr. 12 Physics (SPH4U)

How to Teach, Inquiry–Style

Workshops and Presentations

To download the presentation PowerPoint and handouts, click on the presentation title!

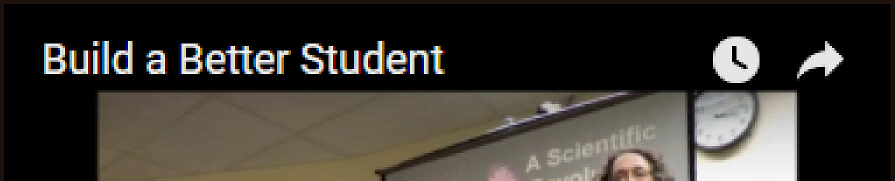
Scientific Teaching, Keynote Address (TDSB Eureka Science Teachers Conference, February 17, 2017)

In this workshop, Chris shares four principles of scientific teaching: (1) understanding how the brain physically works, (2) the role of emotion, (3) students' prior knowledge, and (4) the cognitive learning cycle. To help students learn as well as possible, teachers need to create learning environments that maximize the mental connections students make with scientific ideas.

How Learning Works (OISE, January 30, 2017)

In this workshop, Chris takes you on a tour of an emerging scientific model for learning. Educational research shows how three factors in humans: their emotional state, their prior knowledge, and their cognitive learning processes, all interact when we learn. Chris explores the implications of this model for teaching and provides examples from his classroom teaching.

Build a Better Student, Build a Better Teacher: Revolutions in Physics Education (University of Guelph Physics Department, January 24, 2017)



We live in an exciting time for teaching physics. Over 30 years of education research by physics professionals is transforming physics teaching from a mystical art into a

Open invitation

Visit my classes!

Get in touch!

OAPT

Join us at the physics teacher's conference!

All are welcome!

Conference 2017

YORK UNIVERSITÉ UNIVERSITY

Lassonde School of Engineering: May 11-13

Bergeron Centre for Engineering Excellence

Affective Physics:

Harnessing Emotion to Improve Learning

#OAPT2017

Scientific ~~Teaching~~ Learning

TDSB Eureka Conference 2017

christopher.meyer@tdsb.on.ca

York Mills C. I., Toronto

www.meyercreations.com/physics