Computational Neuroscience: Neural Dynamics

Cognition in the wild…

- attention/gaze
- active perception/working memory
- action plans/decisions/sequences
- goal orientation
- motor control
- background knowledge
- learning from experience

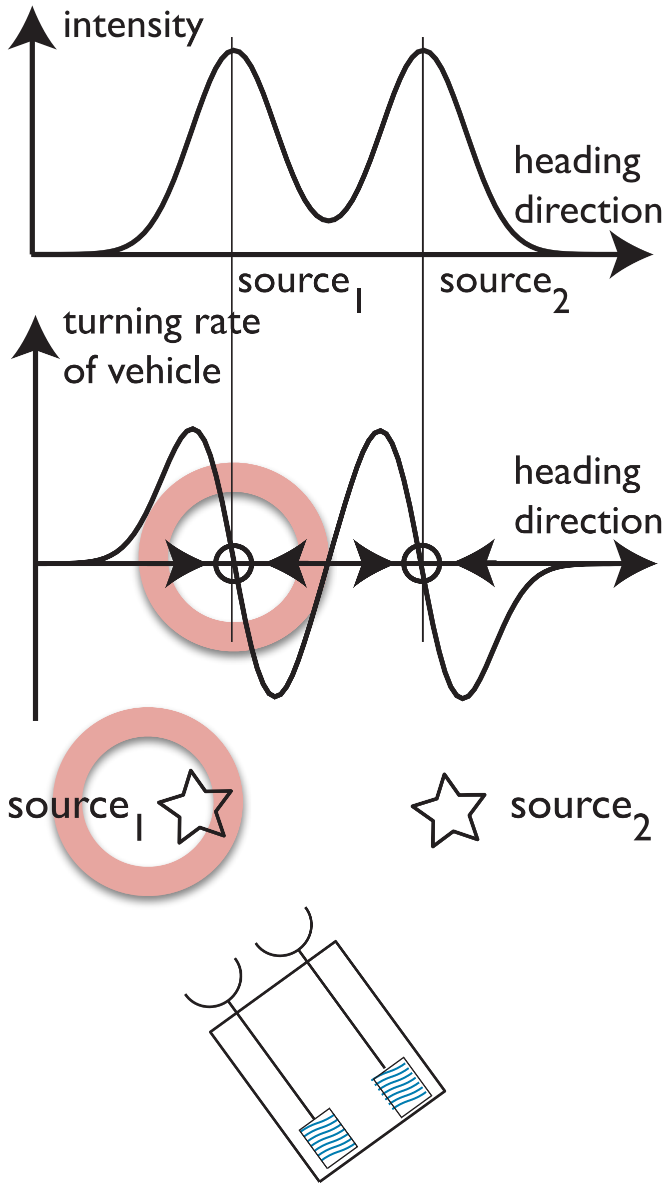
=> implied properties of the underlying neural processes

- graded state
- continuous time
- continuous/intermittent link to the sensory and motor surfaces
- from which discrete events and categorical behavior emerge
- in closed loop
- => states must be stable

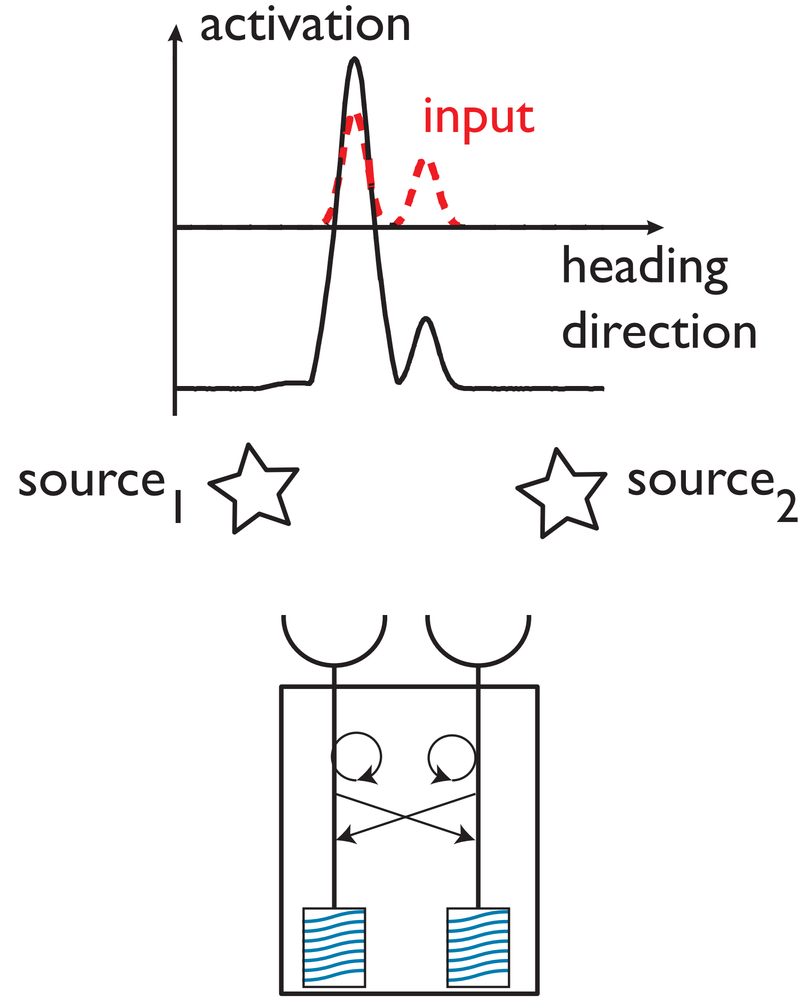
Embodiment hypothesis

- all cognition is like soccer playing = has the properties of embodied cognition
- => there is no particular boundary up to which cognition is embodied and beyond which it is computational/symbolic

Closed loop => dynamics



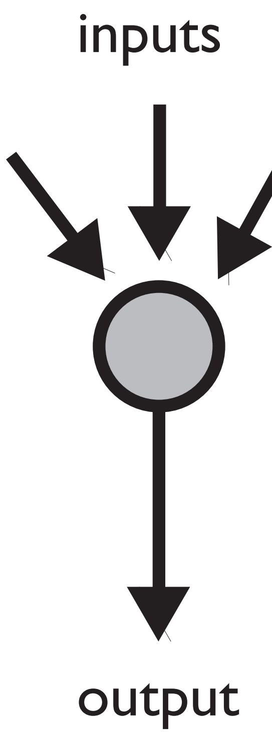
behavioral dynamics

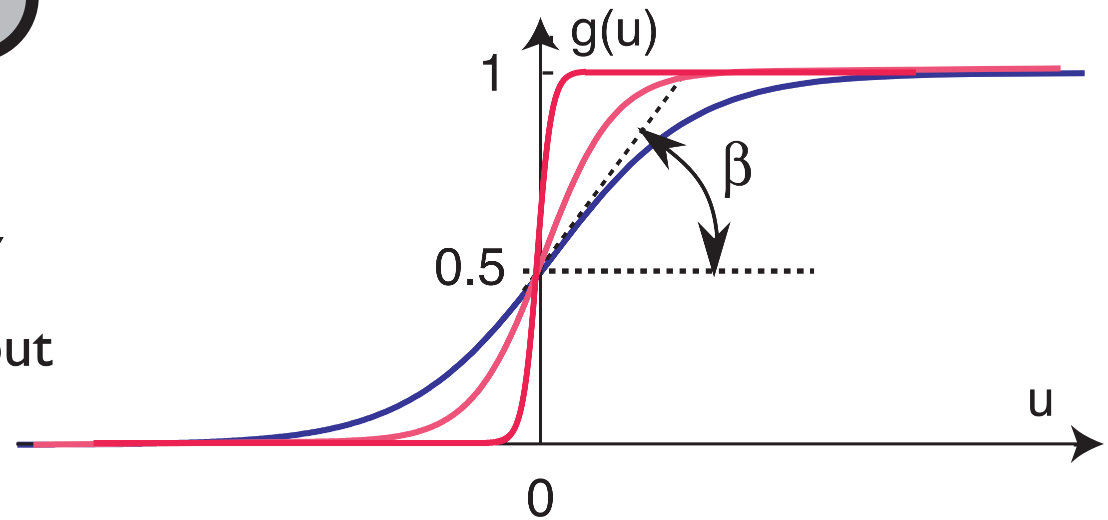


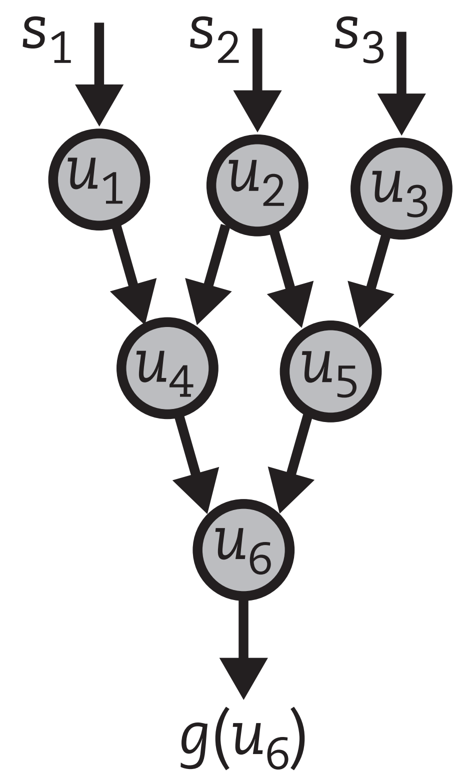
neural dynamics

What does “neural dynamics” mean?

- Neurons as input-output threshold elements that form feed-forward neural networks



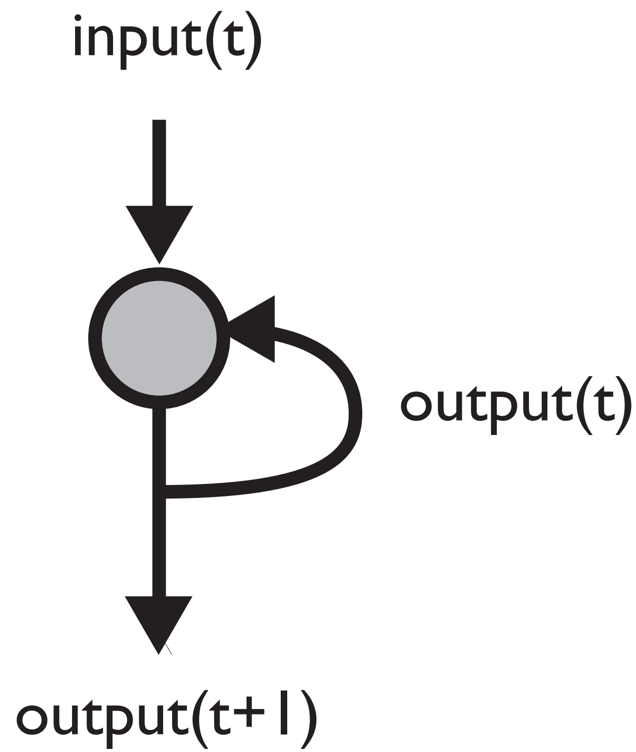




$$\text{output} = g\left(\sum(\text{inputs})\right)$$

Recurrent neural networks

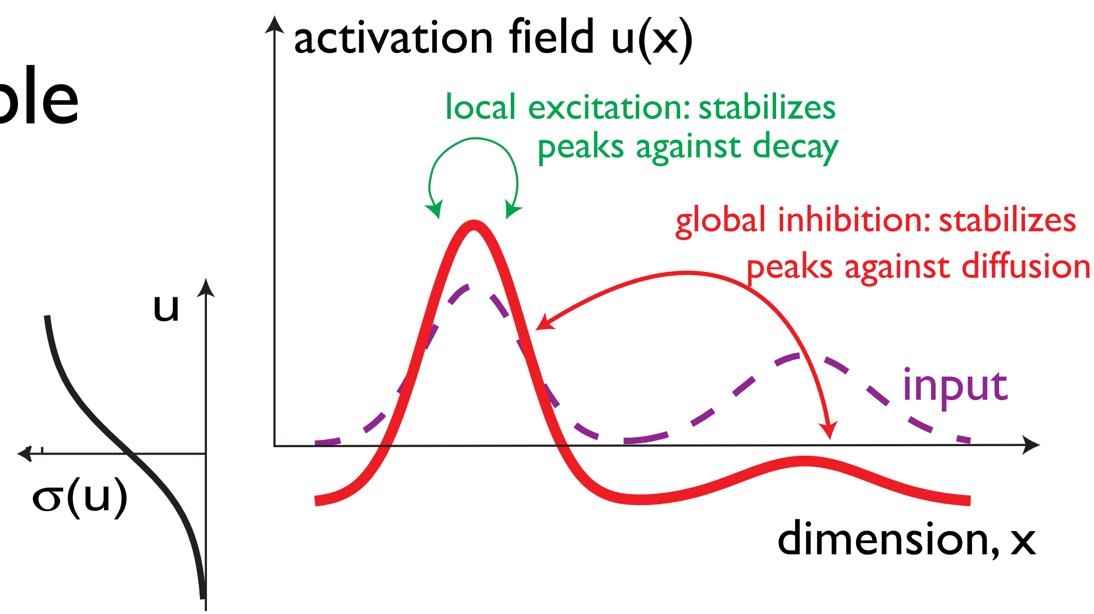
- require a concept of time
- time is not discrete (spiking is asynchronous) => neural dynamics…
- requires a concept of activation state, u (membrane potential, spiking rate)



$$\dot{u}(t) = -u(t) + h + \text{input}(t) + g(u(t))$$

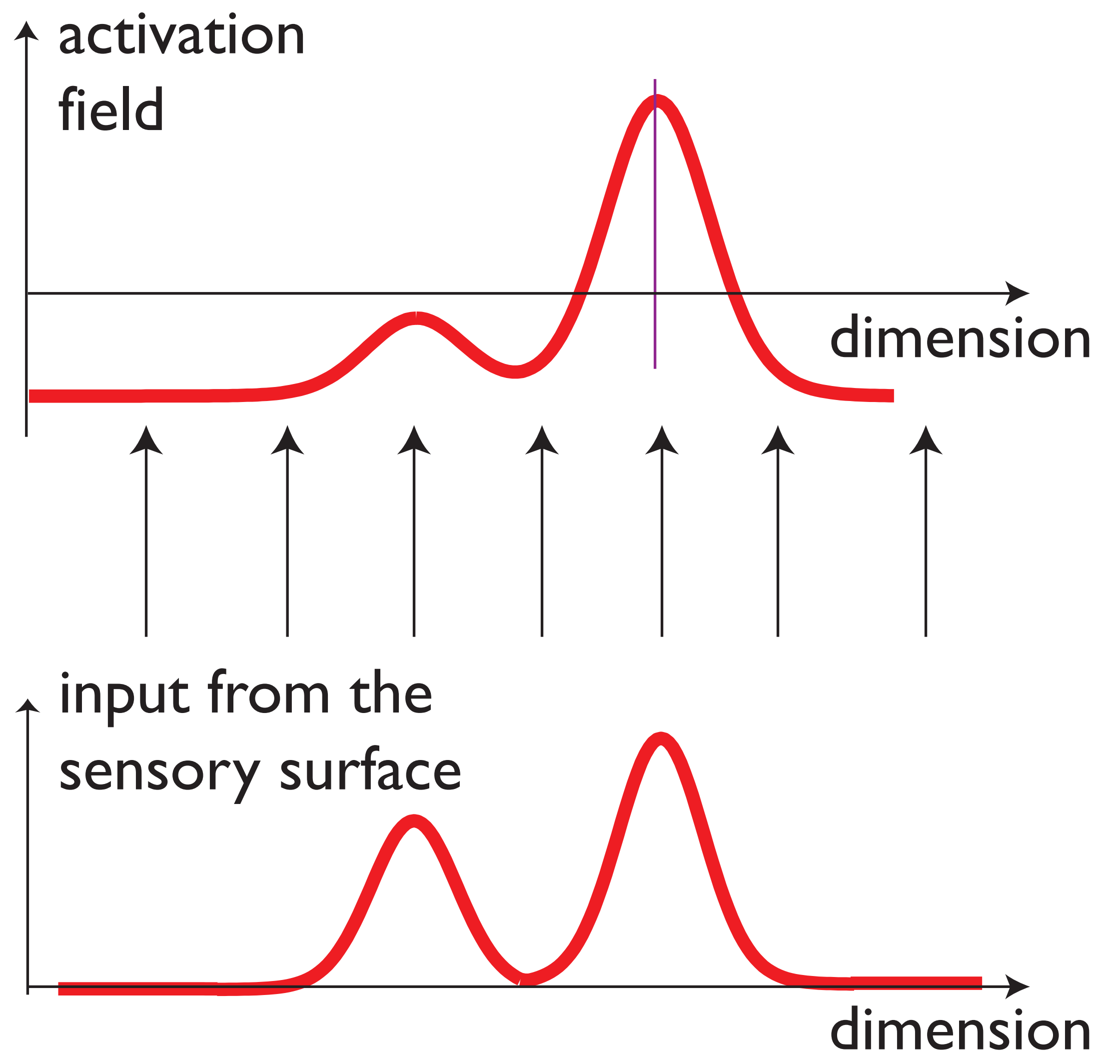
Neural dynamics

- localized activation patterns as attractor states:
  - stabilized by excitatory coupling against decay
  - stabilized by inhibitory coupling against diffusive spread
- => embedded in low-dimensional space to enable such regular patterns of connectivity/interaction



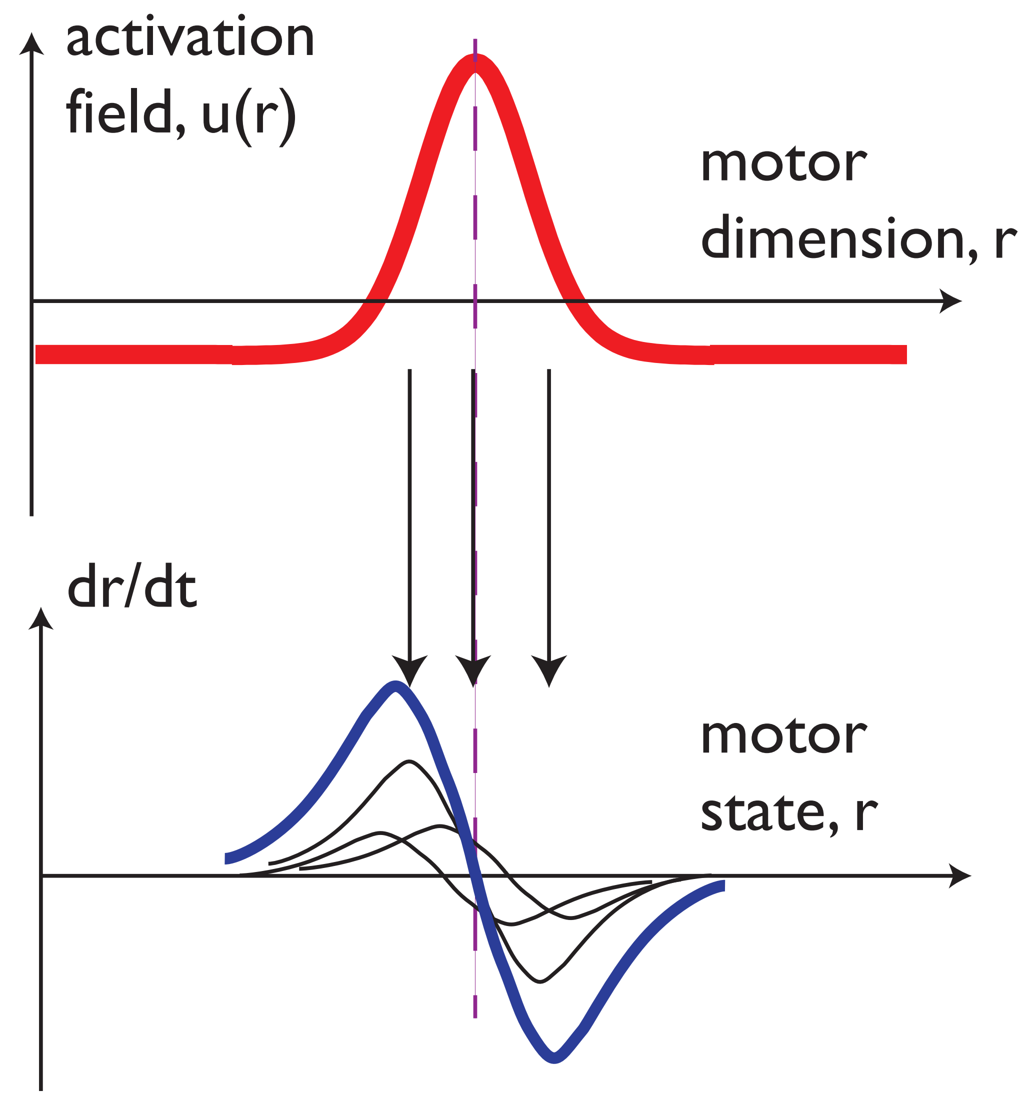
Interface with sensory surfaces

- dimensions reflect forward connectivity from sensory
- e.g., feature maps…



Interface with motor surfaces

- dimensions may reflect output to motor surfaces… => behavioral dynamics
- e.g., through peripheral reflex loops



Theoretical research program

- develop a set of theoretical concepts that are necessary … to fulfill constraints
- probe how the set is sufficient to account for behavior and cognition
- be conservative: only introduce new theoretical concepts when forced to …
- be mindful of neural constraints

Theoretical research program

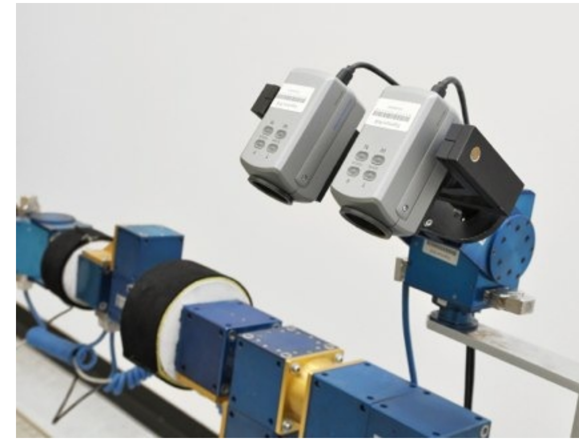
- when studying cognitive competences, keep the links to the sensorimotor domain in view, both experimentally and theoretically
- because tasks create context, study behavior and cognition in naturalistic tasks that connect to elementary behaviors
- keep conceptual commitments made in one domain when studying other domains: stability

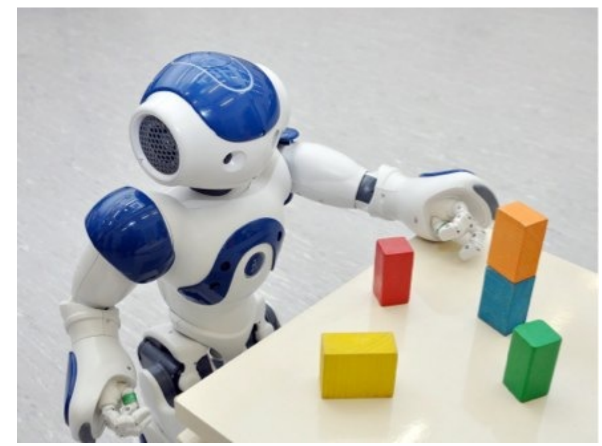
Experimental research program

- look for metric effects
- study role of time
- look for online updating

Robotic research program

- autonomous robots: actively generate behavior, initiating, selecting, terminating actions based on the system's own perceptual processes
- use autonomous robots as heuristic devices
- the demonstrate that a link to the sensorimotor domain is possible
- they may uncover overlooked processes and constraints
- they may review that certain processes are not necessary





What contents do you learn?

- elements of embodied cognition
    - detection decisions
    - selection decisions
    - working memory for metric information
    - memory trace

What contents do you learn?

- theoretical concepts
  - behavioral dynamics
  - neural dynamics
  - dynamic neural fields
  - Dynamic Field Theory

What contents do you learn?

- neural foundations
  - Braitenberg vehicles
  - rate code
  - population code

What contents do you learn?

- mathematic concepts
  - dynamical systems
  - stability, attractors, instabilities
  - numerical solution of differential equations

What contents do you learn?

- theory-experiment relationships
  - accounting for neural and behavioral data
  - accounting for behavior in process models

What contents do you learn?

- robotic and simulated behavior
  - as a heuristic tool
  - to demonstrate function from neural dynamics
  - to uncover overlooked problems

What skills do you learn?

- academic skills
  - read and understand scientific texts
  - write technical texts, using mathematical concepts and illustrations

What skills do you learn?

- mathematical skills
  - conceptual understanding of dynamical systems
  - capacity to read differential equations and illustrate them
  - perform “mental simulation” of differential equations
  - use numerical simulation to test ideas about an equation

What skills do you learn?

- interdisciplinary skills
  - handle concepts from a different discipline
  - handle things that you don’t understand
  - sharpen sense of what you understand and what not