Scientific Critical Thinking

A missing ingredient in science education

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3 motivations

for a new angle

on science education

Good News

Science is advancing quickly, creating new topics/subfields every few years that have the potential to change our lives.

AI Deep (Machine) Learning
CRISPR Gene Editing
Quantum Cryptography

Bad News

Too many new topics to teach that could be as important to learn as physics, chemistry and biology.

Good News

Students (and public) have good access to online courses for most topics and fields, plus good access to facts and numbers.

Bad News

Despite this plethora of readily available intellectual riches, people are deeply confused.

How should this material be used?
What's important?
What can be believed?

Vulnerable to fads, conspiracy theories, or just plain lies.

This confusion leads to grid-lock polarization (in the U.S., though similar concerns are expressed almost everywhere).

Our polarized societies are struggling. It is urgent that we come together to make rational decisions, as we face increasing challenges.

- Pandemics & disease
- Poverty
- Injustice
- Climate change
- Biodiversity loss
- Nuclear weapons

This problem of collective critical thinking is perhaps the greatest challenge of our generation…

Good News

We have today the possibility to provide at least one piece to solve this puzzle:

Teach the intellectual methodologies of science that together have allowed us to make dramatic mental progress over centuries – and could now be applied to these larger group-thinking problems of an information-rich world.

This is perhaps the most underutilized offering of a scientific education.

What is Reality?

What is Reality?

Credibility on the Web ←→ *Credibility of our picture of scientific reality*

Both of these have a tendency to look for

- famous authorities
- indications of popularity

It's not that these are all wrong. They have their place, but…

You don't want Aristotle to be your last word on physics!

You don't want fashionable rumors to be your source of medical treatment!

…or the equivalent on the Web

Science dealt with this problem of "practical epistemology" by...

developing a methodology

particularly in the centuries since the Enlightenment,
but also over recent decades, and even over recent years.

which is much better described as

a set of methodological approaches and tricks-of-the-trade,
rather than, "THE SCIENTIFIC METHOD"

Scientific approaches and tricks-of-the-trade loosely held together by some common themes:

We are extremely good at fooling ourselves

unless we use tools and techniques.

We have mental/physical strengths and weaknesses

(often the flipside of each other)

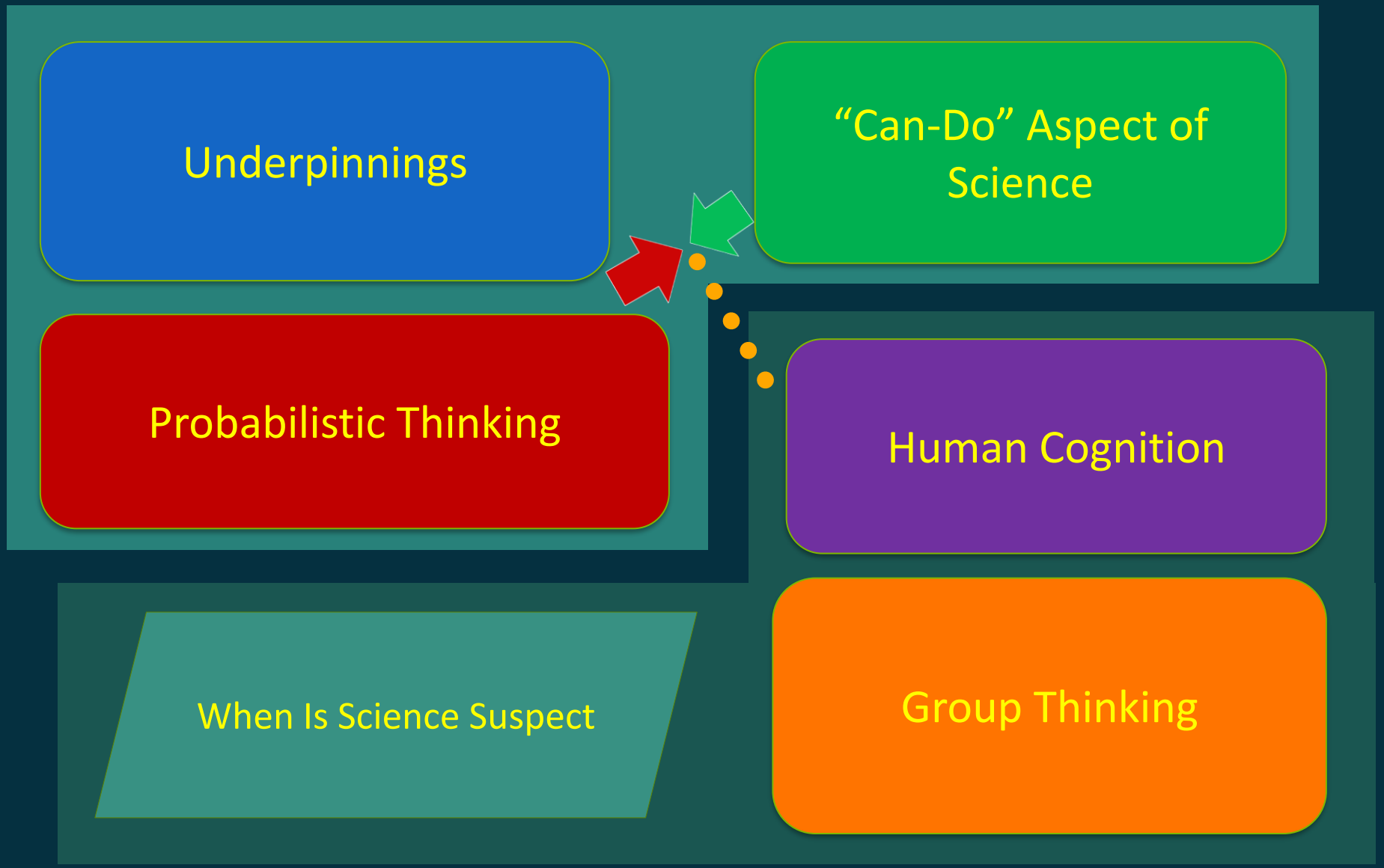
Need tools and scaffolding.

What do these tools look like?

Sense and Sensibility and Science

A UC Berkeley "Big Ideas Course"

Two dozen or so concepts, roughly grouped into…



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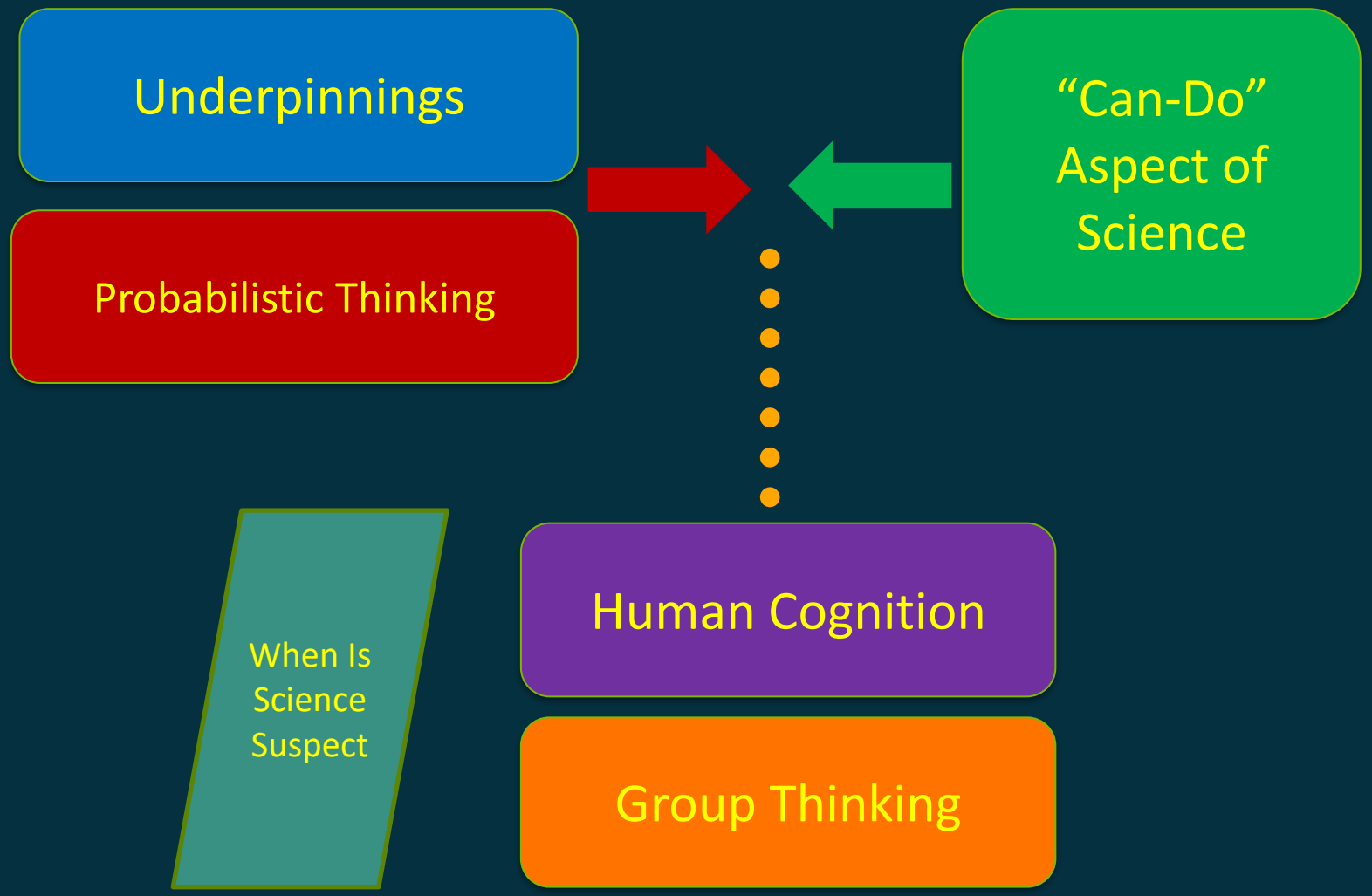

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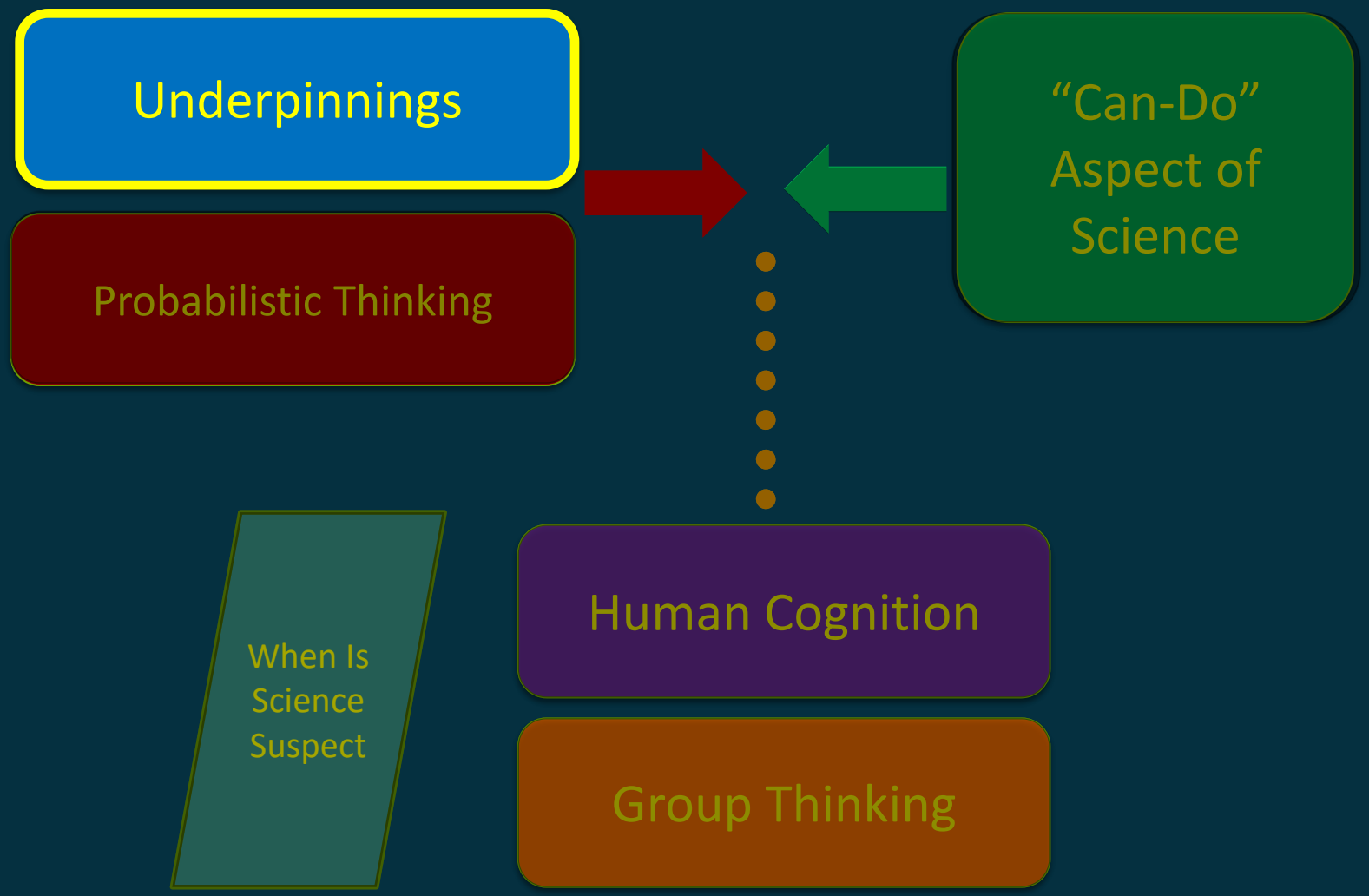


Underpinnings

Belief in a common, shared objective reality.

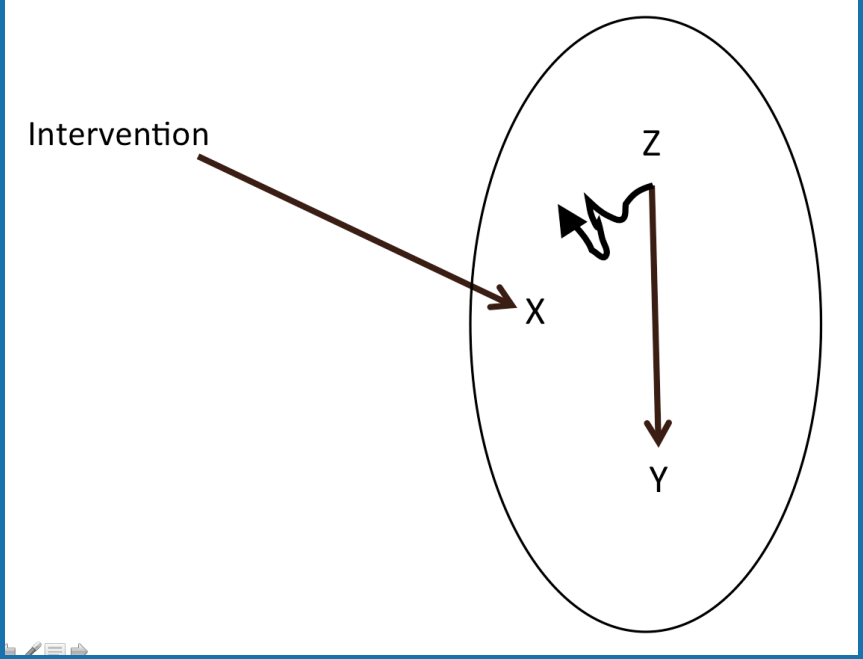
Versus: reality as a social construction

Pyramid vs raft metaphor for knowledge

Underpinnings

② Causal reasoning: correlation vs causation.

- "Interventions," holding other "variables" fixed.



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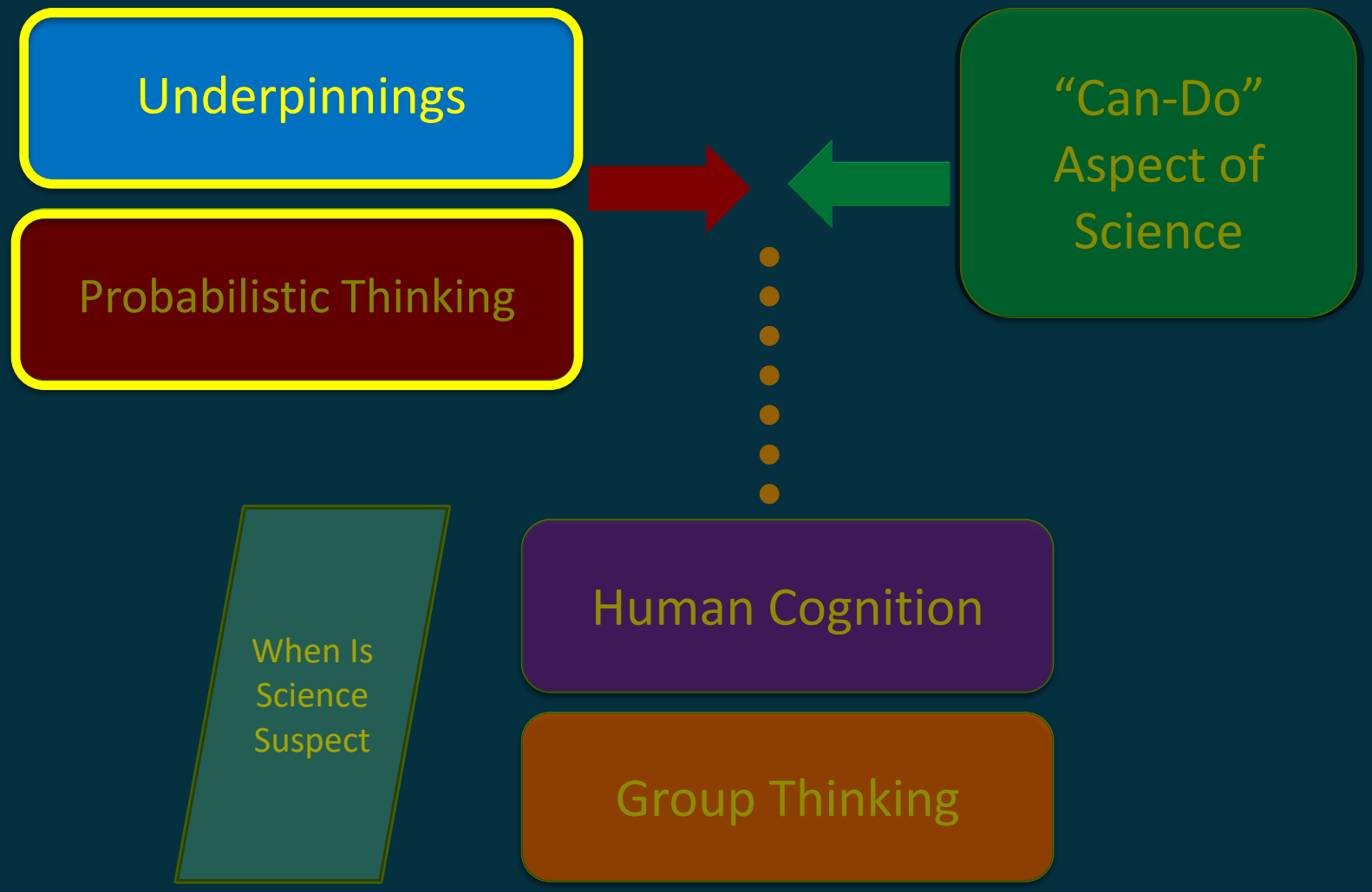
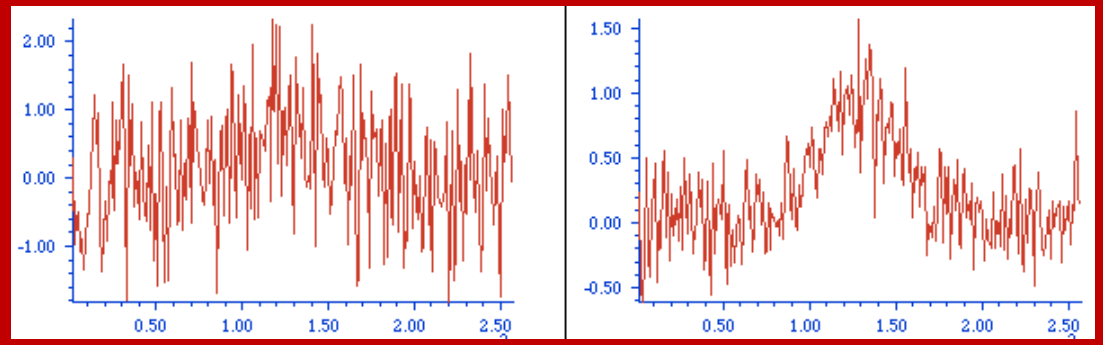


Probabilistic / statistical thinking

Why we use statistics:

- Finding *signal* in *noise*.



- Seeing patterns in random noise.
  - False positive / false negative trade-off.
  - “Look elsewhere” effect.

Probabilistic / statistical thinking

- Perhaps most important:

  "The Calculus of Tentative Propositions."

  - Assigning credence levels, and using them.

An important element of the culture of science is the use of "tentative" propositions, often quantified. These can be as confident as 99.99999% -- you would bet your life on it – but it would still be understood to be held as a proposition which could be wrong.

This makes it psychologically easier for a scientist to be open to being wrong – and to look for the ways they might be wrong.

A class exercise/game:

Has the increased use of standardized testing in U.S. elementary schools improved the quality of education or made it worse?

During the discussion, state the likelihood (0-100) after each proposition that you state – and then raise your hand to remind each other if someone forgets to do so.

"Most teachers have now begun to teach what they think will be on the tests, rather than what they think is the most important material to teach – 82."

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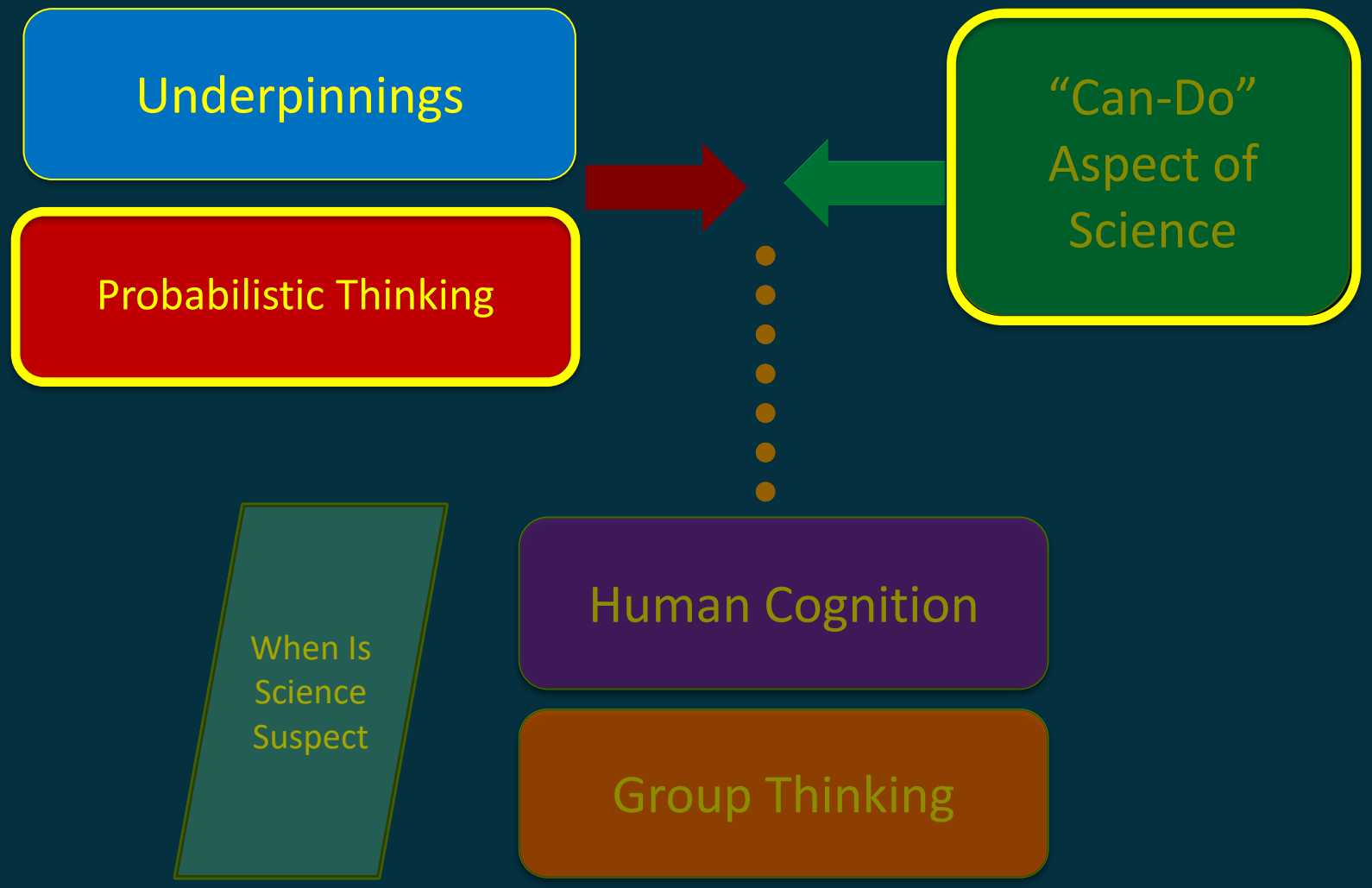

“Can-do” aspect of science

“Scientific Optimism”

What is the *second* longest time you ever spent trying to solve a puzzle?

A. Less than an hour
B. Less than a day
C. Less than a month
D. Less than a year
E. More than a year

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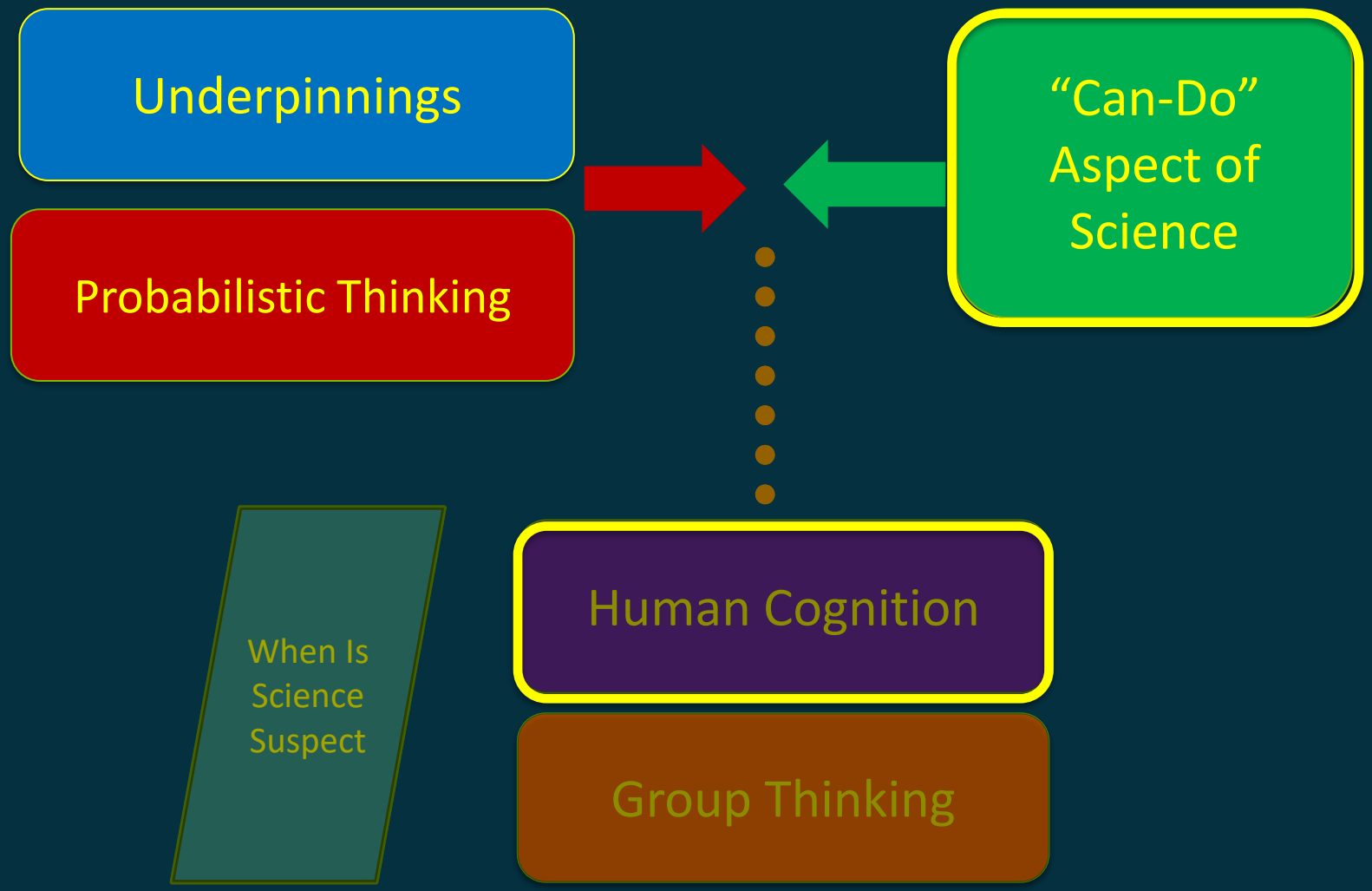

Human cognition

Availability, representativeness, anchoring heuristics and biases

Confirmation bias

Human cognition

Availability, representativeness, anchoring heuristics and biases

Confirmation bias

Blind analysis

A recently introduced science tool.

Group thinking

"Wisdom of Crowds" vs. herd thinking.

Optimal/non-optimal approaches to group decisions.

How should/shouldn't values, emotions, goals, and conflicts of interest be woven into decision making.

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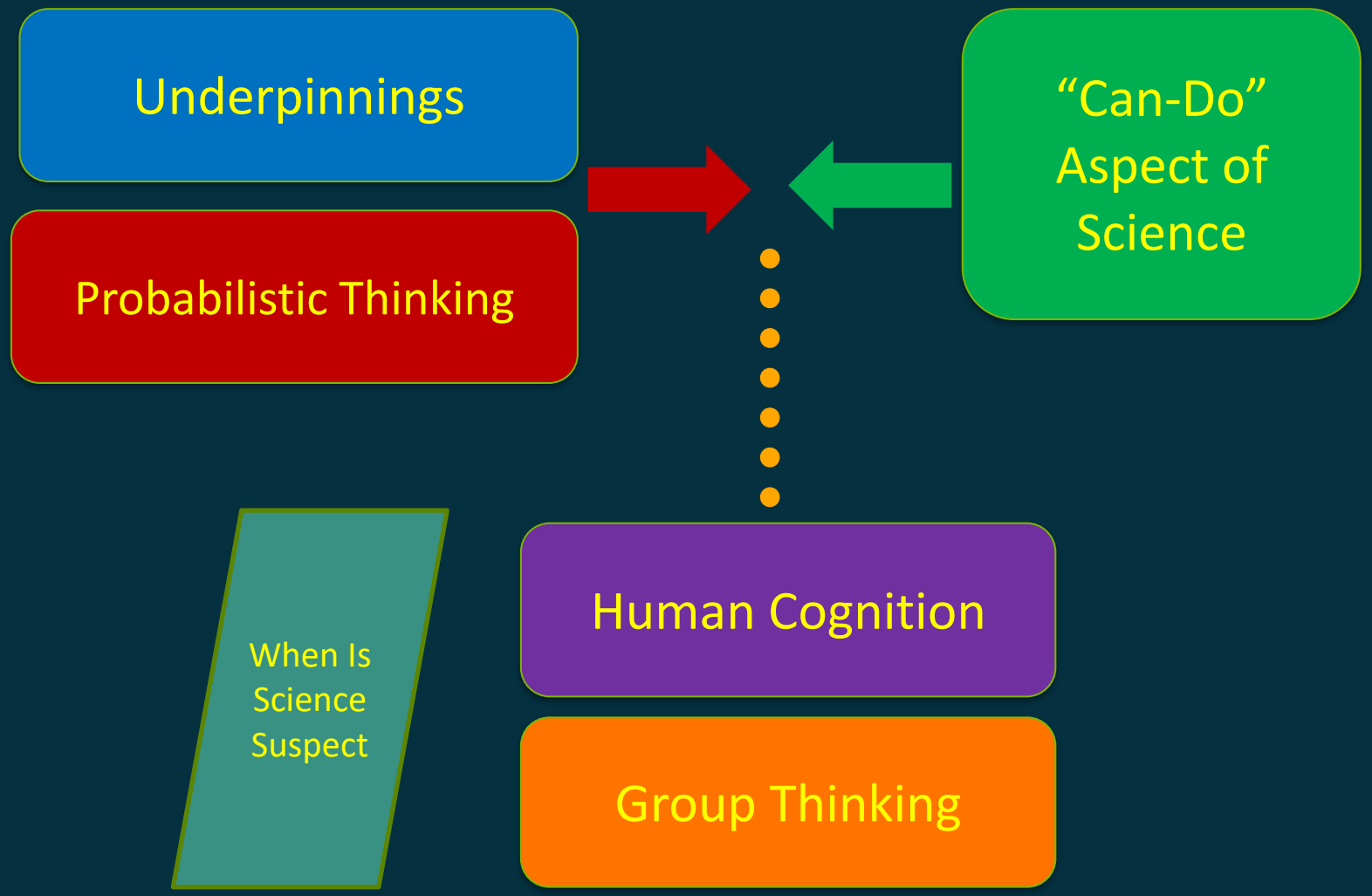


We hope a next-generation of citizens will understand:

- how important it is to be trying to establish **a shared realistic picture of the world** we live in.
- how to use **probabilistic thinking** to navigate amid the uncertainties, and to be comfortable updating our realistic picture of the world -- changing our minds as new data becomes available.
- how **easy it is to fool ourselves and be mistaken** about this realistic picture.
- how this understanding of our tentative and fallible understanding of the world is our greatest strength, but also it's a strong motivation to join in group decision-making in the spirit of **listening to what others can tell us** to help us see how we are going wrong.

We hope a next-generation of citizens will understand:

- how to **recognize an expert you should trust**:

  They are the ones who approach problems with humble, self-questioning probabilistic thinking, openness to others' contributions, but also with a can-do enlarge-the-pie spirit of confidence that we can solve the big problems.

Can this “vocabulary” of science’s thinking tools make a difference?

In the end, these must be the shared skills of the citizens in a society,
so we can work together constructively.

There are many conduits for such *Science-Based Critical Thinking* to be taught

schools,

universities,

professional schools,

online education,

and science museums.

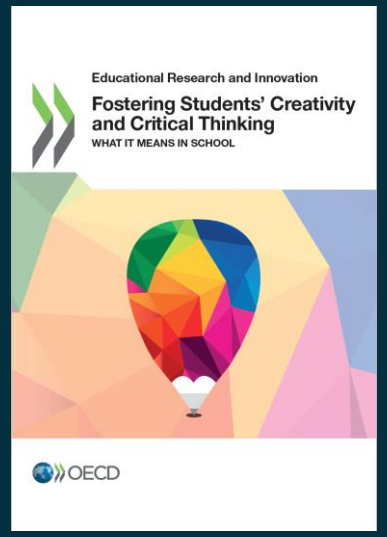
We are working with the Nobel Prize Foundation Outreach to create teaching material for a full high-school-level curriculum.

The university course is now spreading to other universities beyond UC Berkeley, including Harvard, University of Pennsylvania, UC Irvine, and (expected) Humboldt University of Berlin. It is available on a course website.

With the Moore Foundation, we are developing a short animation video series for online education.

With the Exploratorium science museum, we are testing approaches to scientific critical thinking education in museums.

Many reports and science standards call for developing “critical thinking”

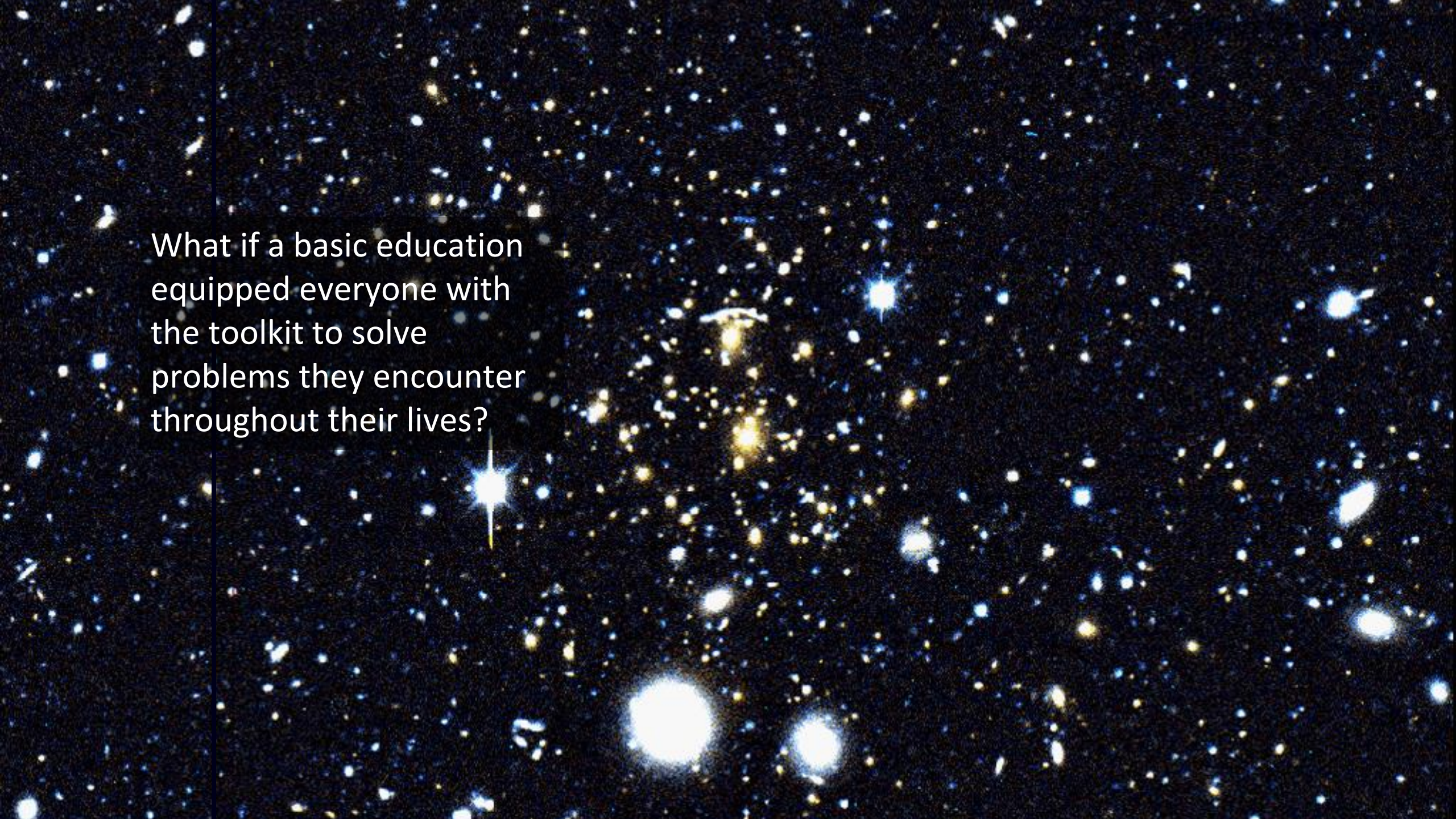


We here aim to equip students with explicit strategies to scaffold success in critical thinking aims and goals, such as those described in the OECD rubrics.
Such very specific elements of scientific (or non-scientific) reasoning and deliberation are generally missing.

For comparison, the same reports and standards are usually much more detailed in their description of what elements should be taught in chemistry or biology than they are for critical thinking.

Empowering, not building broad skepticism

When elements of scientific critical thinking are taught, it is important not to just teach the problem to look for, but also to teach the approaches that science offers to help us play to our mental strengths and mitigate our mental weaknesses.



What if a basic education equipped everyone with the toolkit to solve problems they encounter throughout their lives?