Philosophy of Science: From Learning to Doing

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Lecture Structure

A: The challenges of doing vs. learning science.

B: What actually is Science?

How can we use that to guide research?

C: What does it mean to do science?

How can that inform our assessment of our field?

Discussions

- 2 ways to participate:
  1. Volunteer to speak (raise your hand)
  2. Use the link to add a thought to the discussion board.
- Please do participate; it's good for my blood pressure.

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Non-researchers: What aspect of doing research seems the most intimidating?
Researchers: What aspect of doing research was actually the most difficult to learn?

ⓘ Start presenting to display the poll results on this slide.

Some of The Classic Stumbling Blocks

Lack of structure

There are fewer guardrails and less guidance.

Background

How do I start research in a topic when I don't understand all of the background?

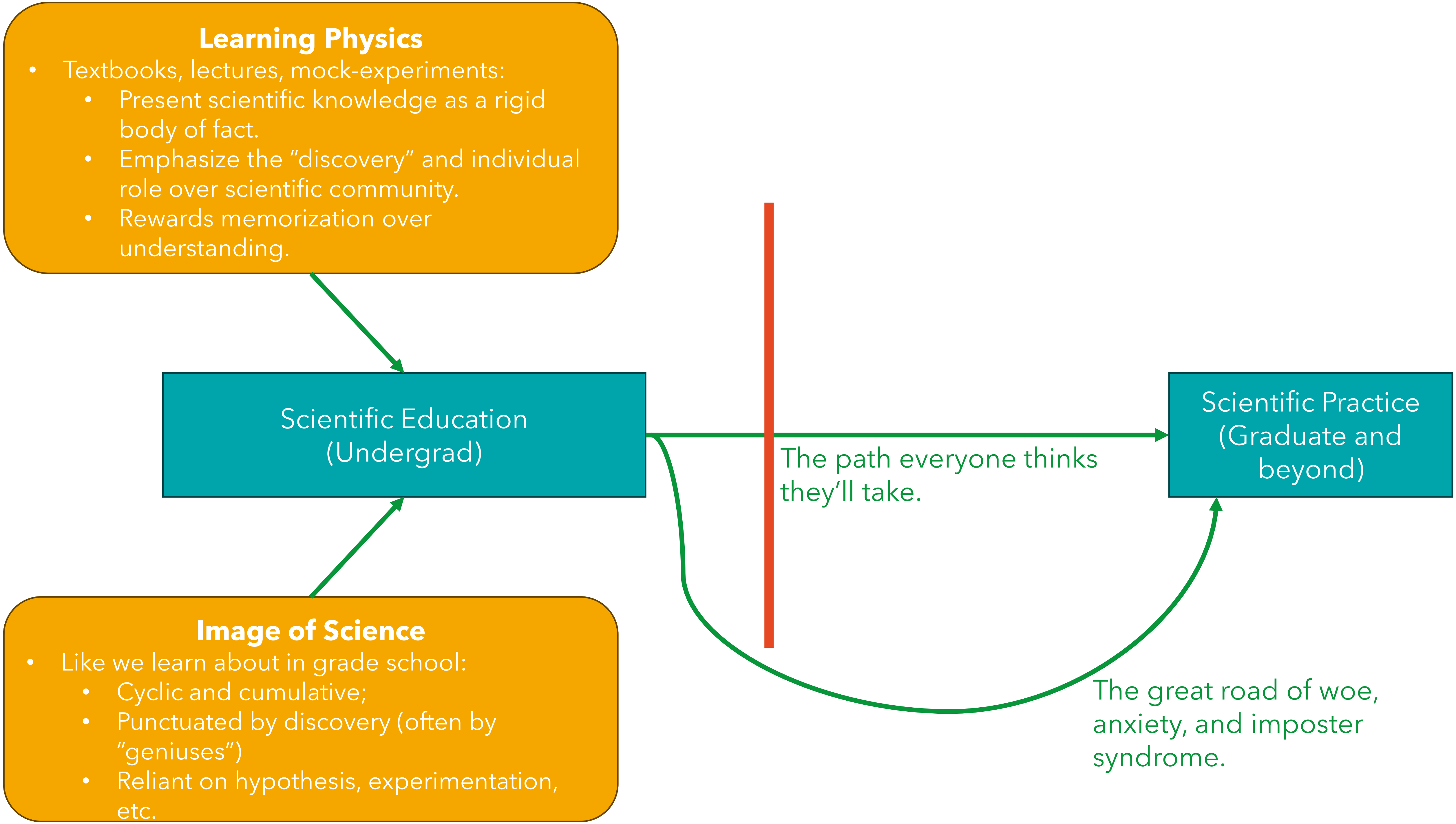
Finding Frontiers
What are the interesting questions to ask in my field?

Determining Research Ideas

How exactly does one come up with an idea?

Imposter Syndrome

Funding
How do I fit my science into the current trends of popularity?


Learning Physics
Textbooks, lectures, mock-experiments:
Present scientific knowledge as a rigid body of fact.
Emphasize the "discovery" and individual role over scientific community.
Rewards memorization over understanding.
Scientific Education (Undergrad)
Image of Science
Like we learn about in grade school:
Cyclic and cumulative;
Punctuated by discovery (often by "geniuses")
Reliant on hypothesis, experimentation, etc.
The path everyone thinks they'll take.
Scientific Practice (Graduate and beyond)
The great road of woe, anxiety, and imposter syndrome.

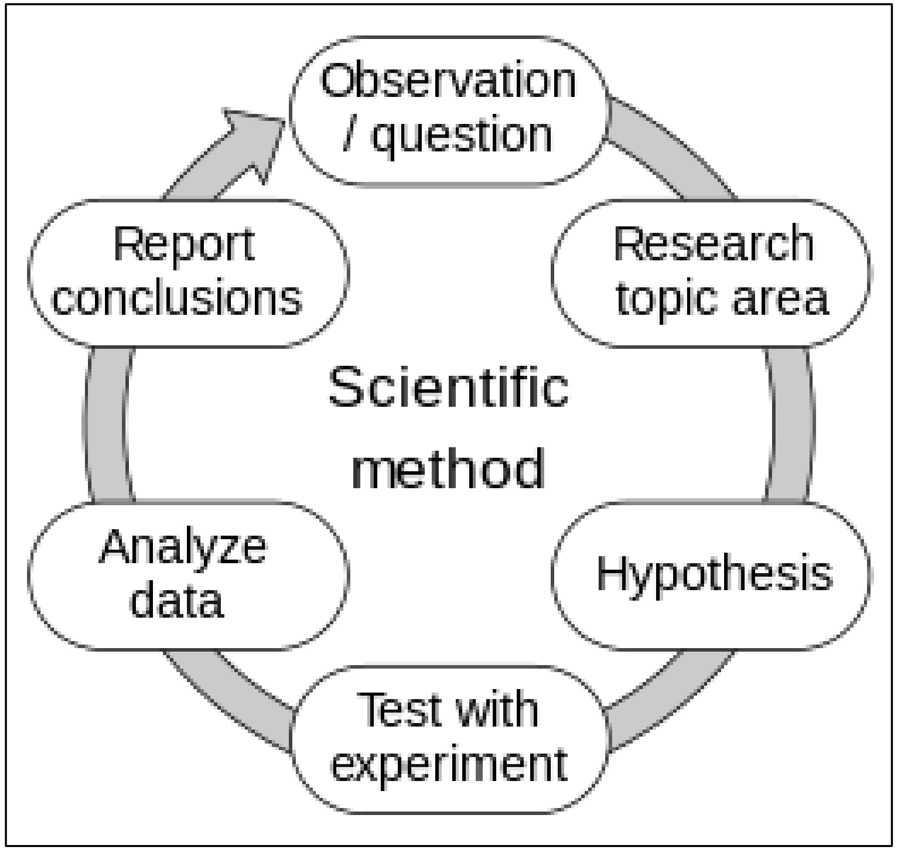
The Philosophy of Science

The **what** and the **why**.

The Scientific Method: **Inductive Empiricism**

Central Tenants

- Research questions are posed in terms of hypotheses.
- Hypotheses are tested by experiment.
- Repetitive experimentation verifies the universality of the hypothesis.
- New questions arise from existing hypotheses.



💡 **Key Points:**

- Scientific knowledge is cumulative.
- Observation must be independent of bias
- Theories (hypotheses) are verified by experiment.

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Do you think the scientific method provides a good structure for science? Why or why not?

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Beyond the Scientific Method

Sooooo the scientific method sucks? Now what!?

Karl Popper: *The Logic of Scientific Discovery.*

What makes something scientific?

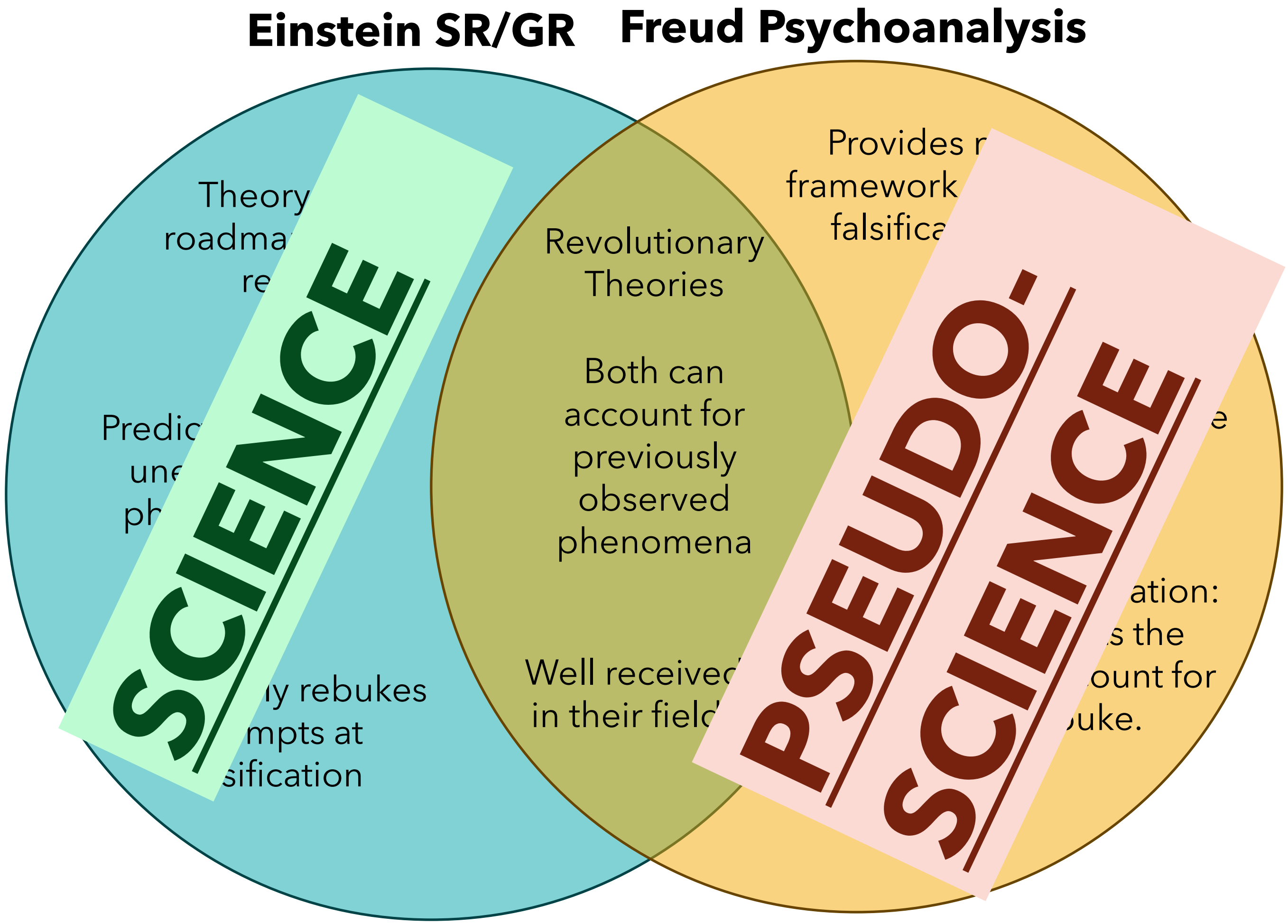
Thomas Kuhn: *The Structure of Scientific Revolution.*

Philosophy is dumb, how does science work in practice?

Imre Lakatos: *Criticism and the Methodology of Scientific Research Programmes*

How do we decide what science is right in practice?

Popper: **Critical Rationalism**



Insight: There will always be more than one way to explain any observation. Therefore, no experiment can verify a theory.

What do these critical differences teach us?

Popper: **Critical Rationalism**

Central Tenants

- The purpose of science is **falsification**.
- Theories are only scientific **if they are falsifiable**.
- Questions lead to conjecture. Conjecture leads to theory, which must then **withstand attempts at refutation**.

💡 **Key Point:** Observations are **never** explained. Science is an exercise in model building.

💡 **Key Point:** Experiments should **always** be testing a theory. Experiments never support theory.

💡 **Key Point:** Competing theories may be judged by their ability to withstand rigorous attempts at refutation.

IS IT SCIENCE?

- Mathematics
- String Theory
- Astronomy
- Ethics

Kuhn: **Scientific Sociology**

Paradigm: The standard set of beliefs, methods, norms, instruments, and techniques which are shared within a scientific community.
[The rules of the game]

Insight: Popper has a point about the nature of science, but scientists don't spend all their time trying to falsify things…

Central Tenants

- Science occurs within a paradigm.
- All results are interpreted within the paradigm. Deviation from the paradigm is punished.
- Crisis occurs when a paradigm can no longer "cover the cracks" of observed phenomena.

"What man sees depends both upon what he looks at and also upon what his previous visual-conception experience has taught him to see."

"In science novelty emerges only with difficulty, manifested by resistance, against a background provided by expectation."

Lakatos: **Sophisticated Falsificationism**

- **Popper**: Theories are nullified when experimental falsification is successful.
- **Kuhn**: Much of science in the real world relies on adherence to the paradigm; including ignoring faults.

💡 **Lakatos:** The atomic element of science is not theory; it is **research programmes.** Experimentation allows us to compare and progress research programmes; revolution in science occurs when a dominant research program is no longer "progressive."

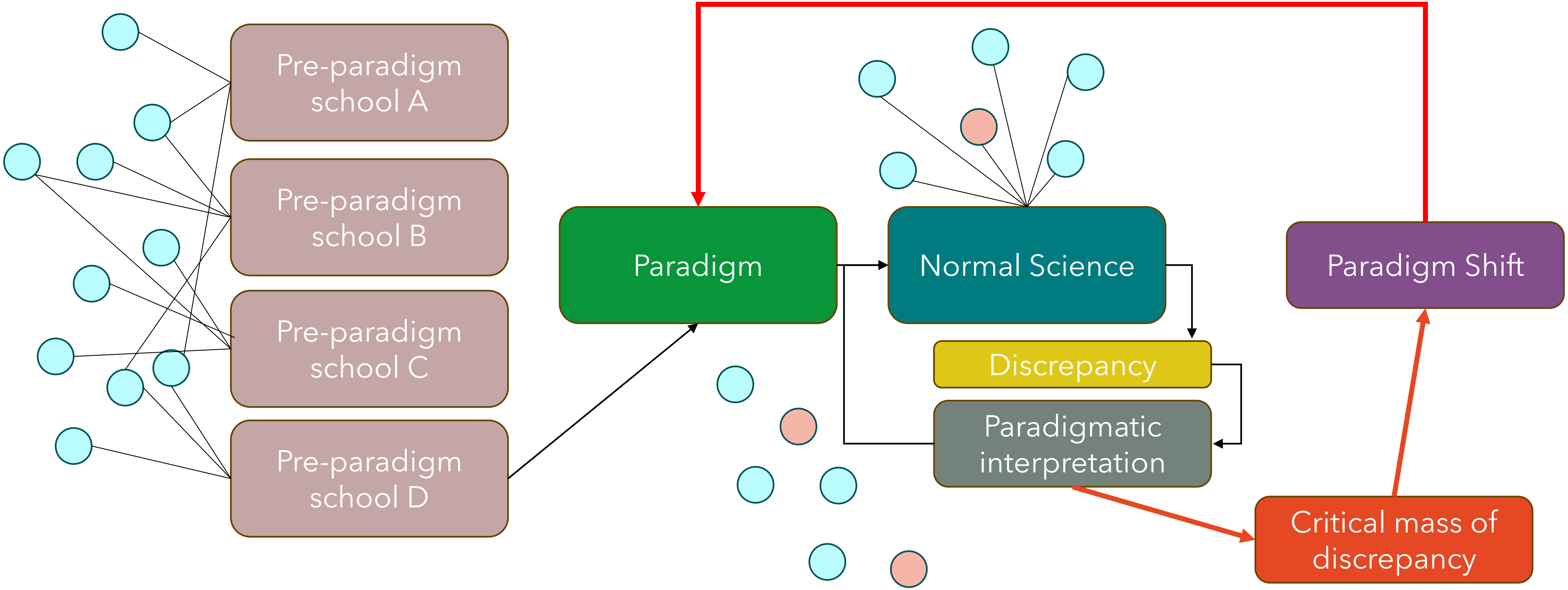
- Falsification is not as important as a theory's ability to **adapt to falsifying instances**.
  - Programmes are progressive when they are still able to adapt to contradictory evidence.
- The sequence of theories generated by iterative falsification and adaptation is a research program.
- The progressivity of research programmes a measure of their scientific-ness.
- Programmes get replaced **only when a better option appears**.

The Practice of Science

The **how**.

A TLDR summary of Thomas Kuhn's *The Structure of Scientific Revolution*.

A Timeline of Scientific Development



Phase 1: Pre-paradigm

No single school of research is sufficiently successful to generate a paradigm.

When a school can account for the key phenomena of competing schools with greater "progressivity," it may begin to drive the formation of a paradigm.

Characteristics

- **Many** schools of thought; each explaining some (but never all) of the available physical facts.
- Schools carry **different beliefs about methodology and theory**: cannot agree on what's important and what's a valid experiment.
- Lack of uniform background leads practitioners to **reformulate the basics repeatedly**.

💡 **Example:** The study of optics before Newton:

- Some believed light emanated from the eye.
- Some believed light modified the medium between the eye and the object.
- Some believed light emanated from the object.

Phase 2: Emergent Paradigm

Paradigm: The standard set of beliefs, methods, norms, instruments, and techniques which are shared within a scientific community.
[The rules of the game]

- Paradigms emerge from schools which are **successful in incorporating the facts of other schools** into their theoretical and methodological structure.

- Established paradigms set the playing field for the science to come.
  - Determine what **questions are worth asking**.
  - Determine what **techniques are acceptable**.
  - Determines what **assumptions one can make**.

💡 **Example:** The study of optics before Newton:

- Newton's corpuscular theory of optics.
  - Predicted radiation pressure, dispersion, refraction, etc.

Phase 3: Normal Science

Normal Science: The "regular" work of scientists in which an existing paradigm is relied upon for esoteric puzzle solving.

Goals of Normal Science:

- **Re-articulation:**
  - e.g. Hamiltonian / Lagrangian mechanics.
- **Improving Precision:**
  - Measurements of Hubble's Constant.
- **Paradigm Evaluation**
  - Eddington's test of GR; Clauser / Freedman tests of Bell's inequalities.

Phase 4: Crisis

💡 **Key Point:** Sometimes paradigmatic explanations of an anomaly fail; leading to crisis of confidence in the paradigm.

- Occurs when **normal science** reveals anomalies (typically many) which cannot be explained from within the paradigm.
- When this occurs, the paradigm allows for competing paradigms to emerge in contest.
  - Dark matter and modified gravity are competing paradigms to explain the missing mass anomaly.
    - Dark matter has a much stronger paradigmatic backing.

- From **Lakatos'** view, the paradigm has a **negative heuristic** and is no longer progressive if it cannot account for the anomaly.
- A competing research program / paradigm may now emerge.

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What parts of physics are NOT in the normal science phase right now?

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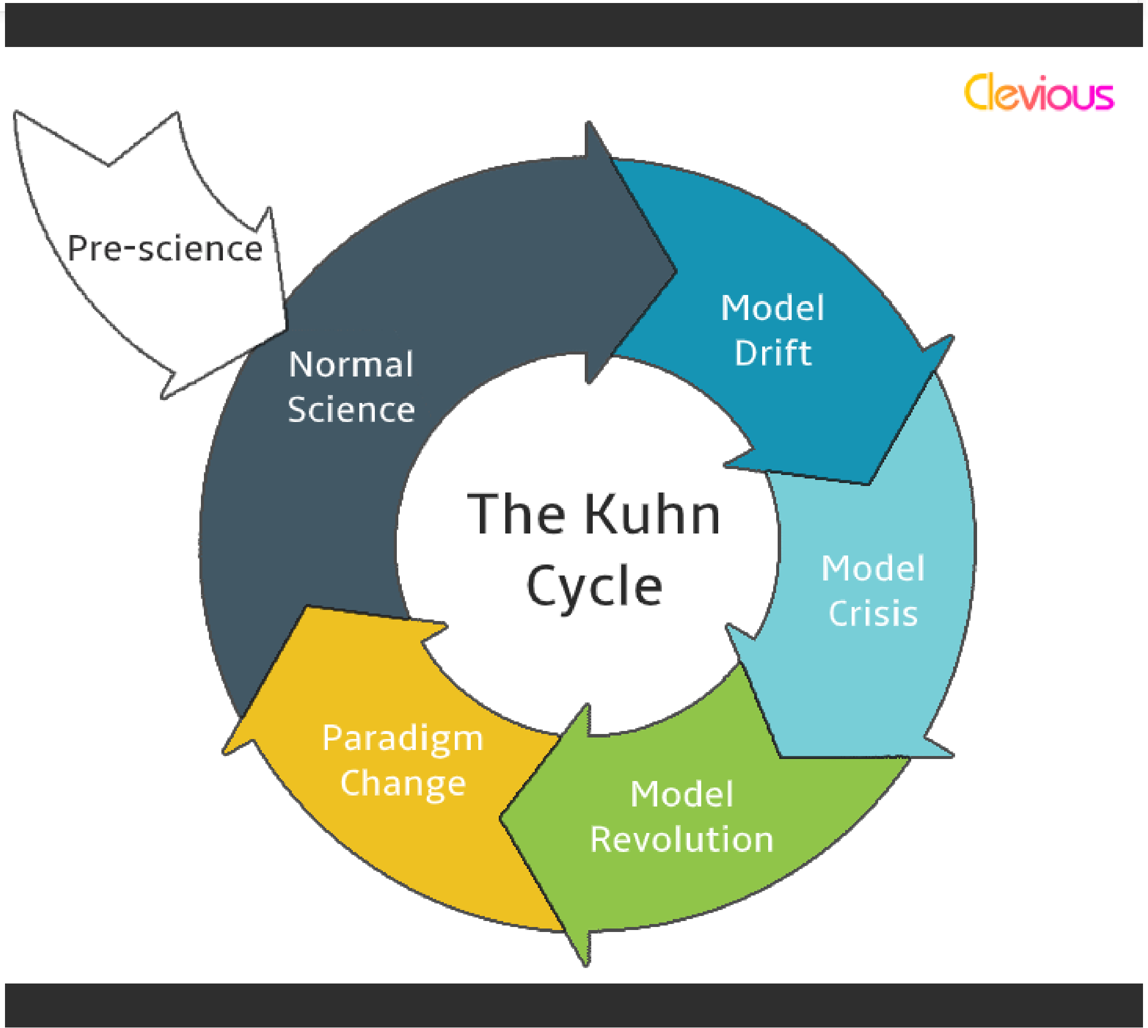
Phase 5: Paradigm Shift

💡 **Key Point:** A new, more progressive, paradigm emerges which can account for the anomaly. Normal science then resumes to characterize the paradigm.

People also tend to get famous / rich / win Nobel prizes during this period.



Take Aways

- Science is a <u>sociological undertaking</u>
  - Identifying the relevant paradigms, anomalies, and normal scientific practices of a field can be instructive for doing good science.

- Normal science is the typical state of science:
  - Normal scientific practices are valuable science: <u>paradigm articulation, precision, and application.</u>

- Identifying the progressivity of a paradigm / research programme can be a guiding factor in identifying new scientific questions.

P&A Student Lecture Series!

- **Sign up for a talk!**
  - There are three more available lecture dates for the spring semester.
  - Talks can be 25 or 50 minutes about almost anything!

More Information:
https://physics.utah.edu/events/student-lecture-series

Next Talk: March 12th

The Path Integral Formulation of Quantum Mechanics

Conrad Morris