

THE UNIVERSE AND ITS OBSERVERS

IDE Youth Edition

Twenty-four evidence-led problems for readers aged 13 to 17

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How to read this volume

These chapters distinguish a claim from the evidence and reasoning used to support it. Each investigation asks what was measured, what assumptions connect the measurement to a conclusion and which stronger claim must be refused.

The language introduces technical ideas when they are needed, while keeping every conclusion tied to the approved IDE source article.

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IDE-001 | How does conservation depend on a system boundary?

Evidence source: IDE-001 · Energy: A Conserved Account, Not a Substance · v0.8

Working account. An energy balance begins by defining the system. What looks like a loss inside a narrow boundary may be a transfer into surroundings included by a wider one.

Evidence and reasoning. Mechanical motion can become microscopic motion, deformation and sound. Measurements of temperature, speed and emitted radiation allow the balance to be tested rather than assumed.

Investigation. Compare an energy ledger for a pendulum alone with one for the pendulum, support and air. Identify every term that changes sides when the boundary expands.

Claim boundary. Conservation and availability answer different questions. Global energy also requires care in general spacetimes, where a unique conserved total need not exist.

IDE-002 | What exactly does information measure?

Evidence source: IDE-002 · Information: Quantifying Alternatives and Dependence · v0.6

Working account. Information theory quantifies alternatives and statistical dependence. A value is defined only after specifying the possible outcomes, their probabilities and the question posed to sender or observer.

Evidence and reasoning. Shannon entropy measures expected uncertainty, while mutual information measures how much knowing one variable reduces uncertainty about another. Neither calculation identifies a causal mechanism.

Investigation. Construct two channels with the same alphabet but different error rates. Compare what a receiver can infer and state every probability used.

Claim boundary. Do not slide from a mathematical information measure to semantic content, truth or causal influence without an additional argument.

IDE-003 | Which counting makes entropy useful?

Evidence source: IDE-003 · Entropy: Counting, Constraint and Irreversibility · v0.8

Working account. Entropy connects a macroscopic description with the number or probability of microscopic states compatible with it. The definition depends on which variables and constraints define the ensemble.

Evidence and reasoning. When an isolated gas occupies a larger accessible volume, overwhelmingly more microstates correspond to the spread-out macrostate. Statistical mechanics explains the observed direction without claiming that reverse fluctuations are logically impossible.

Investigation. Enumerate the microstates of a small spin system under a fixed-energy rule. Then change the rule and observe how the entropy comparison changes.

Claim boundary. Disorder is only an analogy. A valid entropy statement names the state space, constraints and probability distribution, and it distinguishes thermodynamic direction from psychological time.

IDE-004 | What evidence separates cause from correlation?

Evidence source: IDE-004 · Causality: Intervention, Counterfactuals and Physical Influence · v0.7

Working account. Correlation describes a pattern in observations; causation adds a claim about how outcomes would differ under intervention. Confounders, selection effects and reverse direction can imitate a causal association.

Evidence and reasoning. Randomized experiments help by breaking systematic links between treatment and background variables. Where experiments are impossible, causal inference depends on explicit assumptions and diagnostic tests.

Investigation. Draw competing causal diagrams for exercise, health and income. For each arrow, state an intervention and a result that would count against it.

Claim boundary. Prediction may succeed without identifying the causal pathway. A causal conclusion is limited by the intervention, population and assumptions actually examined.

IDE-005 | How does invariance organize physical laws?

Evidence source: IDE-005 · Symmetry: Transformations, Invariants and Broken States · v0.5

Working account. A symmetry statement contains both an operation and an invariant. Without identifying what is transformed and what survives, the word supplies no testable physical content.

Evidence and reasoning. Rotational symmetry can be checked geometrically. In physical theories, continuous symmetries of an action can support conservation laws under the assumptions required by Noether's theorem, while representations classify possible states.

Investigation. Compare the rotational symmetry groups of a square and a circle. Then ask which additional assumptions would be needed before inferring a conserved quantity.

Claim boundary. Spontaneous symmetry breaking concerns asymmetric states governed by symmetric laws. It does not mean that the underlying equations have lost their symmetry.

IDE-006 | When does a change of scale require a new description?

Evidence source: IDE-006 · Scale: Which Details Matter at Which Level? · v0.7

Working account. A change of scale alters which variables can be measured and which regularities remain useful. Effective descriptions deliberately average over fine detail while preserving predictions in a defined regime.

Evidence and reasoning. Thermodynamic pressure can be stable even though individual molecular trajectories vary rapidly. Recovering the macroscopic law does not require treating molecules as absent; it requires showing why their omitted details do not control the chosen observable.

Investigation. Compare a molecular simulation with a fluid model for the same gas. List the quantities each predicts and identify a condition where their agreement should fail.

Claim boundary. Coarse graining is controlled omission, not permission to ignore mechanisms. Every effective model needs a resolution, domain and breakdown test.

IDE-007 | When does collective behaviour earn an explanation?

Evidence source: IDE-007 · Emergence: When Collective Patterns Become Explanatory · v0.8

Working account. Collective behavior becomes explanatory when a small set of higher-level variables captures stable regularities that are cumbersome to express particle by particle. Those variables remain constrained by the underlying interactions.

Evidence and reasoning. Waves, vortices and ordered phases provide test cases: none belongs to an isolated constituent, yet each can be measured, predicted and connected to microscopic dynamics.

Investigation. Choose a crowd, fluid or magnetic system. Propose one collective variable and state how data could show whether it remains stable under changes in microscopic detail.

Claim boundary. A surprising pattern is not enough. Emergence requires a defined scale, reproducible organization and an accountable relation to the component system.

IDE-008 | Which interpretation belongs to a probability?

Evidence source: IDE-008 · Probability: A Calculus for Uncertain Alternatives · v0.5

Working account. Probability theory supplies coherent rules for uncertain alternatives, but the same number can play different roles. It may describe repeated frequencies, quantified belief, model parameters or quantum predictions.

Evidence and reasoning. Calibration and long-run behavior test some interpretations, while Bayesian updating tests whether stated priors and likelihoods are used consistently. Quantum probabilities require the experimental arrangement and observable to be specified.

Investigation. Write two claims assigning 0.7 to an event under different interpretations. For each, state what observation would count as poor calibration or model failure.

Claim boundary. A probability value does not identify a mechanism and does not ensure one outcome. The reference class and interpretation belong to the claim.

IDE-009 | What must be specified before something counts as a field?

Evidence source: IDE-009 · Field: Quantities Spread Over a Domain · v0.5

Working account. A field assigns one or more quantities to each point of a specified domain. Its mathematical type, transformation law and dynamics determine what kind of field it is.

Evidence and reasoning. Temperature fields summarize matter, whereas electromagnetic fields are physical degrees of freedom that carry energy and momentum and interact with charge. Shared mathematics does not erase this distinction.

Investigation. Construct a scalar temperature map and a vector wind map for the same region. State what each assigns to a point and how coordinates may change its components.

Claim boundary. Calling a distributed quantity a field does not establish its ontology or equations. Those require separate physical evidence and definitions.

IDE-010 | Which features decide whether feedback stabilizes?

Evidence source: IDE-010 · Feedback: When Output Returns as Input · v0.6

Working account. A feedback loop returns an output-dependent signal to the system's input. Its sign describes a local tendency, while gain, delay, saturation and system dynamics determine the actual trajectory.

Evidence and reasoning. Negative feedback can reduce deviations when corrections are timely and proportionate. The same loop may oscillate or destabilize when phase lag and amplification move the response out of step.

Investigation. Write a simple update rule for room temperature or vehicle steering. Vary one delay and one gain, then predict convergence, overshoot or oscillation.

Claim boundary. The feedback label is not a verdict. Stability belongs to the complete dynamical model and its operating range.

IDE-011 | What conditions allow selection to accumulate structure?

Evidence source: IDE-011 · Selection: How Differential Persistence Accumulates Structure · v0.7

Working account. Selection changes population composition when variants differ in a relevant trait, achieve different reproductive or persistence outcomes, and transmit the trait or its basis.

Evidence and reasoning. Repeated differential success can accumulate adaptation without foresight. Fitness is relational: the same variant may prosper in one environment and fail in another.

Investigation. Design a multigeneration simulation with mutation, inheritance and two environments. Track trait frequencies and state which condition produces each change.

Claim boundary. A change in frequency alone does not identify selection. Drift, migration and biased measurement are alternatives that must be separated.

IDE-012 | What makes a representation work for a task?

Evidence source: IDE-012 · Representation: When One Thing Stands For Another · v0.9

Working account. A representation works through a mapping between a vehicle and a target for a particular use. Accuracy therefore concerns which relations are preserved, not simple visual resemblance.

Evidence and reasoning. A circuit diagram omits physical layout while retaining connectivity; a scale model may retain geometry while omitting material behavior. Their adequacy must be judged against the intended inference.

Investigation. Compare a transit map, satellite image and verbal route. For each, list what is encoded, what is omitted and one task at which it could mislead.

Claim boundary. No object represents everything by itself. Users, conventions and inferential practices help establish the mapping without making accuracy arbitrary.

IDE-013 | Why is elapsed time tied to a path?

Evidence source: IDE-013 · Time: Clocks, Order and the Arrow · v0.10

Working account. Relativity assigns elapsed proper time to a worldline rather than to a universal clock shared by all observers. Motion and gravitational potential can therefore separate initially synchronized readings.

Evidence and reasoning. Precision-clock comparisons at different heights confirm the predicted gravitational rate difference. The result follows from comparing complete paths and specified spacetime conditions.

Investigation. Analyze two clocks that separate, remain at different heights and reunite. Mark which intervals and synchronization conventions enter the comparison.

Claim boundary. Relativistic clock differences do not establish the thermodynamic arrow of time. Irreversibility and temporal orientation require additional conditions.

IDE-014 | How does an instrument reading acquire meaning?

Evidence source: IDE-014 · Measurement: From Indication to Value · v0.6

Working account. Measurement assigns a value and uncertainty to a defined measurand through a model of the instrument, procedure and environment. Traceability connects that assignment to reference standards through documented comparisons.

Evidence and reasoning. Calibration can reveal offset or scale error, while repeated readings characterize some random variation. Neither step automatically captures model inadequacy or every systematic influence.

Investigation. Build an uncertainty budget for a length or temperature measurement. Separate resolution, repeatability, calibration and environmental contributions.

Claim boundary. The indication on a display is evidence, not the whole measurement result. Meaning depends on the measurand and measurement model.

IDE-015 | How do models support limited inferences?

Evidence source: IDE-015 · Model: An Inference Machine With a Domain · v0.8

Working account. A model links assumptions to predictions within a stated domain. Its value depends on the question, variables and precision required.

Evidence and reasoning. Evidence can support a model for one range while exposing failure elsewhere. Comparing alternatives requires tests that could distinguish their predictions.

Investigation. Take a familiar model, list what it represents and omits, then design one observation that would reveal the edge of its useful domain.

Claim boundary. Agreement with selected data does not prove that a model is unique, literally true or universally adequate.

IDE-016 | Which question is a complexity measure answering?

Evidence source: IDE-016 · Complexity: Several Questions Wearing One Word · v0.5

Working account. Complexity is a family of measures rather than one universal scale. Description length, computational cost and organized dependence answer different questions.

Evidence and reasoning. Random data can be incompressible yet lack the structured organization associated with living or engineered systems. A measure must state its object, encoding and task.

Investigation. Test three strings or networks with two measures. Explain why their rankings change and which scientific question each ranking serves.

Claim boundary. No single score licenses the claim that one system is simply more complex in every respect.

IDE-017 | How should different sources of uncertainty be treated?

Evidence source: IDE-017 · Uncertainty: Naming the Sources Before Adding Them · v0.5

Working account. Uncertainty can arise from sampling variation, measurement error, unknown parameters, incomplete data or model choice. These sources should not be collapsed into one vague doubt.

Evidence and reasoning. Replication estimates some random variation; calibration addresses instrument response; sensitivity analysis tests assumptions. Systematic bias may persist through unlimited repetition.

Investigation. For one reported quantity, draw an uncertainty map linking every source to a diagnostic and a possible remedy.

Claim boundary. A narrower interval is not necessarily a more trustworthy conclusion when shared bias or model inadequacy has been ignored.

IDE-018 | How do definitions shape a network's conclusions?

Evidence source: IDE-018 · Connection: What an Edge Claims · v0.6

Working account. Network analysis depends on operational definitions of nodes and edges. Directed, weighted, temporal and multilayer links encode different claims about a system.

Evidence and reasoning. Centrality and community measures summarize topology under those choices. A node prominent by one measure may be ordinary by another.

Investigation. Construct two networks from one dataset using different edge rules, then compare their central nodes and apparent groups.

Claim boundary. Topology can reveal patterns of association or possible pathways, but it does not by itself establish causal influence or mechanism.

IDE-019 | Why do wave and particle pictures both fall short?

Evidence source: IDE-019 · What Is Light? Wave, Quantum and Observer · v0.9

Working account. Quantum theory predicts localized detector clicks and the interference pattern formed by many events. That combination alone does not exclude a classical electromagnetic field coupled to quantized matter.

Evidence and reasoning. Evidence against every classical-wave account comes from photon statistics such as antibunching: a single emitter cannot produce two detections at once and violates a classical-field bound.

Investigation. Compare a two-path interference record with an antibunching measurement. Identify what each experiment establishes and why only the second tests the classical-field limit.

Claim boundary. Clicks and interference do not prove tiny classical particles; antibunching supports a quantized-field description without making either classical picture complete.

IDE-020 | What remains of the particle concept in quantum theory?

Evidence source: IDE-020 · What Is a Particle? · v0.12

Working account. In quantum theory, particle names classify excitations and detection events by invariant properties and interaction rules. They need not denote enduring miniature objects.

Evidence and reasoning. Localized outcomes are real records, but the theory may assign no definite trajectory between preparation and detection. Creation and annihilation also defeat fixed-particle-number pictures.

Investigation. For a scattering experiment, separate preparation, predicted probabilities and detector records from any added classical path narrative.

Claim boundary. Particle classification does not by itself warrant continuous identity, position or distinguishability throughout an unobserved interval.

IDE-021 | Why does quantum theory begin with fields?

Evidence source: IDE-021 · What Is a Field? · v0.8

Working account. Quantum field theory assigns operators and states to fields, with particle-like excitations emerging in suitable regimes. This framework accommodates relativity and changing particle number.

Evidence and reasoning. Shared field structure explains why electrons have identical defining properties. The vacuum is the lowest-energy state and can possess correlations without being an ordinary medium.

Investigation. Trace one interaction from an initial field state through predicted amplitudes to detector events, distinguishing formal elements from visual analogies.

Claim boundary. Fields organize this formulation without behaving like a classical substance, but whether fields, particles, local algebras or something else are fundamental remains an open interpretation.

IDE-022 | How is mass related to a system's energy?

Evidence source: IDE-022 · What Does Mass Mean? · v0.7

Working account. Invariant mass characterizes the total energy and momentum of a complete system in a frame-independent combination. Internal motion and binding energy therefore matter.

Evidence and reasoning. In protons and neutrons, quantum chromodynamic fields and quark-gluon dynamics account for most of the mass; the quarks' Higgs-related rest masses provide only a smaller share.

Investigation. Compare the invariant mass of a closed composite system before and after an internal energy change, tracking any energy that crosses its boundary.

Claim boundary. Mass is not a substance added by one mechanism, and the Higgs field is not the sole source of ordinary material mass.

IDE-023 | How does a physical record become an observation?

Evidence source: IDE-023 · What Is Observation? · v0.20

Working account. Scientific observation combines a physical record with an inferential link from instrument response to a claim. Provenance makes that link open to checking.

Evidence and reasoning. Calibration, controls and background models separate candidate signals from artifacts. Independent access concerns the procedure and record, not identical sensory experience.

Investigation. Audit one published observation by tracing preparation, detector output, processing, interpretation and the test that could expose a mistake.

Claim boundary. A recorded mark is evidence under a validated measurement model; it does not identify its own cause or interpretation.

IDE-024 | What must sender and receiver share for signalling?

Evidence source: IDE-024 · What Is a Signal? · v0.9

Working account. A signal selects among alternatives that the receiver treats as possible and carries a distinguishable effect through a noisy channel. Its source need not yet be known.

Evidence and reasoning. Coding can add redundancy and trade transmission rate for error protection. Shared conventions connect physical differences to messages without making meaning a substance in the channel.

Investigation. Model a binary channel with occasional flips, compare uncoded and repeated messages, and calculate which outputs remain distinguishable.

Claim boundary. Detecting a signal does not establish that an agent sent a message or that any intended content was recovered.

Use the canonical IDE articles when you need the complete argument and references.