One-Day Mathematical Physics Audit Course

Calculus, physics, and equation-checking for evaluating AI-assisted theoretical work

Tailored to the mathematics and physics that appear in END Theory / Evans Node Dialect.

> **Purpose** By the end of one focused day, you should be able to read most equations in a theoretical-physics draft, check units and assumptions, follow basic derivatives and matrix operations, recognize when established physics has merely been inserted, and know exactly what must be derived before a claim is strong.

8 HOURS ● NOTEBOOK-BASED ● FAST TRACK

You do not need to memorize every formula. Your job is to become an intelligent auditor: translate symbols into meaning, reproduce short calculations, and detect hidden assumptions.

Hour	Topic	What you gain
1	Algebra, notation, scientific numbers & units	Read equations; catch unit errors
2	Calculus: derivatives, partial derivatives & integrals	Understand rates, fields, and accumulated quantities
3	Differential equations, oscillations, waves & dispersion	Read equations of motion and wave predictions
4	Vectors, matrices, eigenvalues & graph Laplacians	Audit node/graph models and normal modes
5	Mechanics, action, symmetry & special relativity	Understand how physical laws are built and constrained
6	Quantum mechanics essentials	Read wavefunctions, probabilities, operators, entanglement
7	QFT, gauge theory & general-relativity literacy	Recognize the language of modern unification attempts
8	Theory auditing: END-style derivation and validation	Separate definition, derivation, calibration, prediction, test

> **Reality check** Eight hours will not make anyone a professional theoretical physicist. It can, however, give you enough mathematical literacy to catch many consistency problems, ask the right questions, and understand where expert-level derivation is still required.

How to use the day

1. Keep your notebook open. Copy every boxed formula and every “audit rule.” Writing is part of the course.
2. Work the exercises before reading the answer key. If stuck for more than five minutes, mark it and continue.
3. For every equation, say aloud: What are the inputs? What is the output? What are the units? What was assumed?
4. Do not memorize decimal constants unless useful. Memorize relationships, dimensions, and what a symbol means in context.
5. At the end of each hour, make 3–5 flash cards from the checkpoint list.

Notebook setup

Page	Write this heading
1	Symbols and operations
2	Common physics variables
3	Units and dimensions
4	Derivatives and integrals
5	Waves and differential equations
6	Vectors / matrices / eigenmodes
7	Relativity and action
8	Quantum mechanics
9	QFT / gauge / GR
10	AI theory-audit checklist
Back pages	Questions I cannot yet answer

> **Best four-hour shortcut** If you only have half a day, complete Hours 1, 2, 4, and 8. Those four give the highest return for checking AI-generated theory mathematics.

Pre-course diagnostic (10 minutes)

6. What is the difference between = and ∝ ?
7. What does dx/dt mean in ordinary language?
8. If one side of an equation has units of joules and the other has units of seconds, can the equation be correct as written?
9. What does $\Sigma_i x_i$ mean?
10. What is the difference between fitting a parameter to data and predicting data with a parameter fixed beforehand?

Do not worry about the score. Repeat these five questions at the end of the day.

Algebra, notation, scientific numbers, and dimensional analysis

09:00–10:00 • Goal: Turn intimidating expressions into ordinary relationships.

1.1 Symbols are labels, not magic

A mathematical expression becomes meaningful only after its symbols are defined. The same Greek letter can mean different things in different papers.

$$y = f(x)$$

A function: give f an input x; it returns y.

$$\omega = 2\pi f \quad \text{and} \quad k = 2\pi/\lambda$$

Angular frequency and wave number.

> **Audit rule #1** Never accept a symbol because it "looks standard." Find its definition and make sure the definition does not silently change later.

1.2 Powers, roots, logs, and scientific notation

Expression	Meaning
x^2	$x \cdot x$
x^{-1}	$1/x$
x^{-2}	$1/x^2$
$x^{1/2}$	$\sqrt{x}$
10^6	1,000,000
10^{-6}	0.000001
ln x	natural logarithm; inverse of e^x

Scientific notation multiplication: multiply the front numbers and add exponents.

$$(3\times10^5)(2\times10^{-3}) = 6\times10^2 = 600$$

Division: divide the front numbers and subtract exponents.

$$(8\times10^{-8})/(2\times10^{-3}) = 4\times10^{-5}$$

1.3 Units and dimensions: your fastest error detector

Quantity	Symbol	SI unit	Dimension
Length	x, r	m	L
Time	t	s	T
Mass	m	kg	M

Velocity	v	m/s	$L\,T^{-1}$
Acceleration	a	m/s^2	$L\,T^{-2}$
Force	F	$N = kg{\cdot}m/s^2$	$M\,L\,T^{-2}$
Energy	E	$J = kg{\cdot}m^2/s^2$	$M\,L^2\,T^{-2}$
Momentum	p	kg·m/s	$M\,L\,T^{-1}$

Check Einstein's mass–energy relation dimensionally:

$$E = mc^2$$

$$[mc^2] = M(L/T)^2 = M\,L^2\,T^{-2} = [E]$$

> **Audit rule #2** Terms that are added or equated must have compatible dimensions. If A + B appears, A and B must have the same dimensions. This catches a large class of bad equations immediately.

Practice — Hour 1

11. Compute $(4\times10^3)(5\times10^{-7})$.
12. Rewrite r^{-2} without a negative exponent.
13. If v = 12 m/s and t = 3 s, check whether x = vt has units of length.
14. Can E = mv be an energy equation? Show the units.
15. An AI writes A + B where [A] = joules and [B] = kilograms. What is your verdict?

Checkpoint

- ☐ I can read powers and scientific notation.
- ☐ I can distinguish equality from proportionality.
- ☐ I can perform a basic dimensional check.
- ☐ I know that symbols require explicit definitions.

Your notes / flash cards

HOUR 2

Calculus: functions, derivatives, partial derivatives, and integrals

10:00–11:00 • Goal: Understand change, slopes, fields, and accumulation.

2.1 Derivative = rate of change

$$v = dx/dt$$

Velocity is the rate at which position changes with time.

$$a = dv/dt = d^2x/dt^2$$

Acceleration is the rate at which velocity changes.

If $x(t) = t^2$, then $dx/dt = 2t$. At $t = 3$ s, the slope is 6 in the corresponding velocity units.

Derivative rules worth memorizing

Function	Derivative
constant C	0
x	1
x^2	$2x$
x^3	$3x^2$
x^n	$n\,x^{n-1}$
e^x	e^x
sin x	cos x
cos x	−sin x

> **Interpret before calculating** When you see $d^2x/dt^2 = -\omega^2x$, first read it in words: acceleration points opposite displacement, with strength proportional to displacement. That already tells you it describes restoring motion.

$$d^2x/dt^2 = -\omega^2 x$$

Simple harmonic oscillator.

2.2 Partial derivatives: one variable at a time

A field can depend on several variables, for example $\varphi(x,t)$. The symbol ∂ means "differentiate with respect to one variable while holding the others fixed."

$$\partial\varphi/\partial t \quad \text{and} \quad \partial\varphi/\partial x$$

These appear constantly in wave equations, quantum mechanics, field theory, and relativity.

2.3 Integral = accumulated contribution

$$\Delta x = \int v(t)\,dt$$

Accumulating velocity over time gives displacement.

$$W = \int F \cdot dx$$

Accumulating force along a displacement gives work.

A derivative asks “how fast is it changing here?” An integral asks “what total do all these tiny contributions make?”

Practice — Hour 2

16. If $x(t)=5t^2$, find dx/dt.
17. If $v(t)=3t^2$, find $a(t)=dv/dt$.
18. For $d^2x/dt^2=-\omega^2x$: when $x>0$, what sign is the acceleration? When $x<0$?
19. If a constant velocity is 4 m/s for 5 s, compute $\int v\,dt$.
20. In $\varphi(x,t)$, explain the difference between $\partial\varphi/\partial x$ and $\partial\varphi/\partial t$ in words.

Checkpoint

- ☐ I can translate first and second derivatives into physical language.
- ☐ I understand why partial derivatives appear in fields.
- ☐ I understand an integral as accumulation.

Your notes / flash cards

HOUR 3

Differential equations, oscillations, waves, and dispersion

11:00–12:00 • Goal: Read an equation of motion and extract its physical consequences.

3.1 An equation of motion is a rule for evolution

Algebraic equations relate quantities at one instant. Differential equations relate a quantity to its rates of change and therefore describe evolution.

$$m\, d^2x/dt^2 = F(x,t)$$

Once initial conditions are given, the equation tells you how the system develops.

3.2 Oscillations

$$d^2x/dt^2 + \omega_0{}^2 x = 0$$

$$x(t) = A \cos(\omega_0 t + \varphi)$$

A is amplitude; ω_0 is angular frequency; φ is phase. Verify a claimed solution by differentiating twice and substituting it back into the original equation.

> **Audit rule #3** Substitution is underrated. If AI claims "this solves the equation," differentiate or calculate the required pieces and substitute them back. A surprising number of errors die here.

3.3 Waves

$$\partial^2\varphi/\partial t^2 = c^2\, \partial^2\varphi/\partial x^2$$

One-dimensional wave equation.

$$\varphi(x,t) = A \cos(kx - \omega t)$$

$$\omega = c\, k$$

For an ideal nondispersive massless wave.

Phase velocity is $v_p = \omega/k$. Group velocity is v_g = dω/dk. If ω(k) is not a straight line, different wavelengths travel differently: that is dispersion.

3.4 Why dispersion matters for END-style validation

A discrete node or lattice model commonly predicts small short-wavelength corrections to the continuum relation. Those corrections are potentially testable, but only after the lattice quantities are mapped to physical units and detector observables.

$$\omega^2 \approx c^2k^2 + m^2c^4/\hbar^2 + \text{higher-order corrections}$$

> **Prediction test** A curve is not a prediction until every coefficient needed to draw it is fixed independently of the data used to test it.

Practice — Hour 3

21. For x=A cos(ωt), show qualitatively why the second derivative is proportional to −x.
22. If ω=ck, what is ω/k?
23. If doubling k exactly doubles ω, is the relation dispersive or nondispersive?
24. Why would a frequency-dependent propagation speed be interesting in gravitational-wave data?
25. What must be supplied before a dimensionless lattice dispersion curve can be compared with a detector timing measurement?

Checkpoint

☐ I can identify an equation of motion.

- ☐ I can verify a proposed solution by substitution.
- ☐ I understand phase, frequency, wavelength, and dispersion.
- ☐ I know why a detector bridge is required before data validation.

Your notes / flash cards

10-minute notebook drill

→ Sketch a sine wave. Label amplitude A and wavelength λ.

→ Draw a straight ω-versus-k line and a curved one. Mark which is dispersive.

→ Write one sentence explaining why a measured detector lag cannot determine a theory coefficient unless a source/propagation map connects them.

Vectors, matrices, eigenvalues, and graph Laplacians

13:00–14:00 • Goal: Understand the mathematical core of node and network models.

4.1 Vectors and matrices

$$x = (x_1, x_2, x_3)^T$$

A vector: an ordered collection of numbers.

$$y = A\,x$$

A matrix A transforms vector x into vector y.

For a 2×2 matrix, each output component is a weighted sum of the inputs.

$$[a\ \ b;\ c\ \ d]\ [x;\ y] = [ax+by;\ cx+dy]$$

4.2 Eigenvectors: patterns that keep their shape

$$A\,v = \lambda\,v$$

v is an eigenvector if applying A changes only its scale, not its direction. λ is the eigenvalue. In physics, eigenvectors often represent natural modes and eigenvalues encode frequencies, energies, or response strengths.

4.3 Graphs and the Laplacian

For a graph, the adjacency matrix A says which nodes are connected. The degree matrix D counts how many links touch each node. The graph Laplacian is:

$$L = D - A$$

For a three-node chain 1—2—3:

$$A = [0\ 1\ 0;\ 1\ 0\ 1;\ 0\ 1\ 0]$$

$$D = \mathrm{diag}(1,2,1)$$

$$L = [1\ -1\ 0;\ -1\ 2\ -1;\ 0\ -1\ 1]$$

For node values $q=(q_1,q_2,q_3)$, the Laplacian measures differences between a node and its neighbors. That makes it the natural discrete analogue of spatial curvature/second derivatives in many network field models.

4.4 Normal modes

$$L\,v_n = \lambda_n\,v_n$$

If an END benchmark equation contains Lq, diagonalizing L separates a complicated network motion into independent normal modes. This is why eigenvalues are central to stability and dispersion calculations.

> **Audit rule #4** When AI introduces a matrix or tensor, ask its dimensions, symmetry, domain, and transformation law. “It is a matrix” is not enough.

Practice — Hour 4

26. Multiply [2 0; 0 3] by vector $(4,5)^T$.
27. For A=diag(2,3), identify two obvious eigenvectors and eigenvalues.
28. For the 3-node chain above, verify that $L(1,1,1)^T=0$.
29. Explain physically why a constant value on every node should have zero graph-Laplacian response.
30. If an AI claims L is positive but produces a negative eigenvalue for an ordinary undirected Laplacian, what should you investigate?

Checkpoint

- ☐ I can multiply a simple matrix by a vector.
- ☐ I understand eigenvectors as natural patterns.
- ☐ I can construct A, D, and L for a small graph.
- ☐ I understand why graph eigenvalues affect waves and stability.

Your notes / flash cards

10-minute graph drill

→ Draw a four-node square. Write its adjacency matrix.
→ Count each node degree and build D.
→ Form $L=D-A$ and verify that every row sums to zero.
→ Explain why the all-ones vector should be a zero mode for a connected ordinary Laplacian.

HOUR 5

Mechanics, action, symmetry, and special relativity

14:00–15:00 • Goal: See how modern physics builds laws from principles rather than fitted formulas.

5.1 Energy and momentum

$$p = mv$$

Nonrelativistic momentum.

$$K = \tfrac{1}{2}mv^2$$

Nonrelativistic kinetic energy.

$$E^2 = p^2c^2 + m^2c^4$$

Relativistic energy–momentum relation.

At rest, $p=0$, so $E=mc^2$. For a massless excitation, $m=0$, so $E=pc$.

5.2 The Lagrangian and action

$$L = T - V$$

Simple mechanical Lagrangian: kinetic minus potential energy.

$$S = \int L\, dt$$

Action.

The physical trajectory makes the action stationary. Varying S produces the Euler–Lagrange equation:

$$d/dt(\partial L/\partial \dot{q}) - \partial L/\partial q = 0$$

This framework generalizes beautifully to fields and is why actions appear throughout QFT and GR.

5.3 Symmetry and conservation

Noether's theorem is one of the deepest audit tools in physics: continuous symmetries of the action imply conserved quantities.

Symmetry	Typical conserved quantity
Time translation	Energy
Space translation	Momentum
Rotation	Angular momentum
Internal phase symmetry	Charge / current

5.4 Special relativity essentials

$$\gamma = 1/\sqrt{(1 - v^2/c^2)}$$

$$\Delta\tau = \Delta t/\gamma$$

Proper time for uniform relative motion in the simplest setting.

The important conceptual requirement for an emergent model is not merely "there is a maximum speed." The long-wavelength theory must recover Lorentz symmetry accurately enough that all relevant matter and signal sectors share the same causal structure.

> **Audit rule #5** If a theory claims relativity emerges, ask for the transformation law and the low-energy Lorentz-invariant limit—not just a speed parameter named c.

Practice — Hour 5

31. What does $E^2=p^2c^2+m^2c^4$ reduce to when $p=0$?
32. What does it reduce to when $m=0$?
33. For $L=T-V$, which part contains motion and which part contains interaction/potential?
34. What conserved quantity is associated with time-translation symmetry?
35. Why is “my lattice has a fastest signal” not by itself a derivation of special relativity?

Checkpoint

- ☐ I can read the relativistic energy relation.
- ☐ I know what an action is and why varying it matters.
- ☐ I understand the symmetry → conservation connection.
- ☐ I know what an emergent-relativity claim must actually recover.

Your notes / flash cards

10-minute derivation drill

→ Starting with $L=½m\dot{q}^2-½kq^2$, identify T and V.
→ Without doing the full variation, predict the sign of the restoring force.
→ Write the sentence: “A limiting speed is not the same as Lorentz symmetry.” Under it, list two extra requirements.

HOUR 6

Quantum mechanics essentials

15:00–16:00 • Goal: Read wavefunctions, probabilities, operators, and entanglement without confusing interpretation with derivation.

6.1 Complex numbers

$$i^2 = -1$$

$$z = a + ib$$

$$|z|^2 = z^*z = a^2 + b^2$$

Complex phases are central to interference. Multiplying a quantum state by a global phase e^{iθ} does not change ordinary probabilities.

6.2 State and probability

$$|\psi\rangle = \text{quantum state}$$

$$P(a) = |\langle a|\psi\rangle|^2$$

Born rule for outcome a in an ideal projective measurement.

Normalization requires total probability to be one:

$$\langle\psi|\psi\rangle = 1$$

> **Crucial distinction** A deterministic microscopic model does not automatically derive quantum probabilities. If END proposes deeper deterministic updates, the Born rule, Bell correlations, and no-signalling behavior must emerge from a complete preparation/measurement map.

6.3 Operators and eigenvalues

$$\hat{A}\,|a\rangle = a\,|a\rangle$$

An observable is represented by an operator. Its eigenvalues are possible ideal measurement outcomes in standard quantum mechanics.

$$[\hat{A}, \hat{B}] = \hat{A}\hat{B} - \hat{B}\hat{A}$$

Commutator.

Noncommuting observables cannot generally have simultaneously sharp values.

6.4 Schrödinger evolution

$$i\hbar\, \partial|\psi\rangle/\partial t = \hat{H}|\psi\rangle$$

H is the Hamiltonian (energy operator). If H is Hermitian, the evolution is unitary and preserves total probability.

6.5 Tensor products and entanglement

$$|\psi\_AB\rangle \in H\_A \otimes H\_B$$

$$|\Phi^+\rangle = (|00\rangle + |11\rangle)/\sqrt{2}$$

An entangled state cannot be written as a simple product |ψ_A⟩⊗|ψ_B⟩. Correlation is not the same thing as faster-than-light signalling.

Practice — Hour 6

36. Compute |3+4i|.
37. Why must a normalized state satisfy total probability = 1?

38. What is the physical role of the Hamiltonian in Schrödinger's equation?
39. What property of the Hamiltonian is associated with unitary probability-preserving evolution?
40. Why does "nodes are instantly paired" not by itself reproduce quantum entanglement?

Checkpoint

◻ I can work with basic complex magnitude.

◻ I know the Born rule is an additional probabilistic structure, not just the existence of waves.

◻ I understand operators/eigenvalues at a basic level.

◻ I know entanglement must satisfy Bell/no-signalling constraints.

Your notes / flash cards

10-minute quantum drill

→ Write $z=3+4i$ and calculate $|z|^2$ before taking the square root.

→ For a two-outcome state with probabilities 0.3 and 0.7, verify normalization.

→ Write three separate things a deterministic node model must reproduce beyond "correlation": Born statistics, Bell correlations, and no-signalling.

HOUR 7

QFT, gauge theory, and general-relativity literacy

16:00–17:00 • Goal: Recognize the structures a serious unification attempt must recover.

7.1 From particles to fields

Quantum field theory treats fields as the fundamental dynamical objects in the continuum description. Particles appear as excitations and, more technically, as poles/states of the quantum field dynamics.

$$S = \int d^4x\, \mathscr{L}(\varphi, \partial\varphi, \ldots)$$

Field-theory action.

The Lagrangian density $\mathscr{L}$ must be a scalar under the relevant spacetime symmetries and contain terms allowed by the theory's fields and symmetries.

7.2 Gauge symmetry

$$\psi(x) \rightarrow e^{i\alpha(x)}\, \psi(x)$$

A position-dependent phase transformation requires a compensating connection/gauge field if derivatives are to transform covariantly.

$$D_\mu = \partial_\mu + i\, g\, A_\mu$$

$$F_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu \qquad \text{(Abelian case)}$$

> **Audit rule #6** Naming a link variable "gauge" is not enough. Check the exact transformation law and whether the action/observable is invariant under it.

7.3 Effective field theory

$$\mathscr{L}_{eff} = \mathscr{L}_{low} + \Sigma_i\, (C_i/\Lambda^{d_i-4})\, O_i$$

At low energy, unknown short-distance physics can appear as higher-dimension operators suppressed by a scale Λ. Coefficients C_i must be derived, matched, or constrained—not chosen after seeing the target result.

7.4 General relativity essentials

GR describes gravity through spacetime geometry. The metric $g_{\mu\nu}$ defines intervals; curvature is constructed from derivatives of the metric; matter/energy is summarized by the stress-energy tensor $T_{\mu\nu}$.

$$ds^2 = g_{\mu\nu}\, dx^\mu\, dx^\nu$$

$$G_{\mu\nu} + \Lambda\, g_{\mu\nu} = (8\pi G/c^4)\, T_{\mu\nu}$$

For an emergent geometry theory, the difficult step is deriving an operational metric and showing that its coarse dynamics approach Einstein's equation with the correct universal coupling and limits.

7.5 The "recovery hierarchy"

Layer	What a candidate theory must recover
Classical continuum	Stable propagation, locality/causal structure, conservation laws
Quantum	Hilbert/probability structure, Born statistics, interference, Bell correlations, no-signalling
Gauge/QFT	Correct symmetries, matter representations, unitarity, renormalized low-energy couplings
Gravity	Metric/connection, equivalence principle, Newtonian limit, post-

	Newtonian tests, gravitational waves
Standard Model	SU(3)×SU(2)×U(1), chiral fermions, anomaly cancellation, masses/mixing

Practice — Hour 7

41. What is the difference between a Lagrangian L and a Lagrangian density $\mathscr{L}$?
42. What is the purpose of a covariant derivative D_μ?
43. Why must an EFT coefficient C_i be frozen before using held-out data to test it?
44. What does the metric g_{μν} determine?
45. What two distinct recoveries are needed before saying a relational graph model has derived gravity rather than merely imitated an inverse-square force?

Checkpoint

◻ I recognize field-theory action notation.

◻ I understand gauge symmetry as a transformation/invariance statement.

◻ I understand EFT coefficients and matching.

◻ I know what the metric and Einstein equation represent.

Your notes / flash cards

10-minute closure drill

→ Write "symmetry → allowed terms → dynamics → observables" as a chain.

→ Write one reason a fitted EFT coefficient is not a fundamental derivation.

→ List the gravity ladder: operational intervals → metric → curvature → dynamics → Newtonian/post-Newtonian/wave limits.

HOUR 8

Theory auditing and the END derivation program

17:00–18:00 • Goal: Turn your conceptual idea into a falsifiable mathematical research program without letting AI smuggle in the answer.

8.1 The derivation chain

$$\text{Core postulates} \rightarrow \text{microscopic state} \rightarrow \text{update law} \rightarrow \text{stable patterns} \rightarrow \text{continuum limit} \rightarrow \text{QM/QFT + geometry} \rightarrow \text{observables} \rightarrow \text{held-out tests}$$

Every arrow is a mathematical obligation. A theory is only as strong as the weakest unproved arrow needed for its claimed conclusion.

8.2 Seven questions to ask every AI-generated equation

46. Definition: What exactly does every symbol mean?
47. Dimensions: Do all added/equated terms have compatible units?
48. Domain: Is this a scalar, vector, matrix, tensor, field, operator, probability, or graph object?
49. Derivation: Which previous equations imply this one? Can I reproduce the step?
50. Assumptions: What physical principle was inserted rather than derived?
51. Parameters: Which values were measured, calibrated, fitted, or predicted?
52. Test: What would the theory predict before seeing a held-out dataset, and what result would falsify it?

8.3 The anti-circularity ledger

Label	Meaning	Example
DEFINED	Chosen notation or structure	Define node state X_n
DERIVED	Follows mathematically from prior assumptions	Dispersion relation from a fixed update law
MEASURED INPUT	Imported from experiment/metrology	Use measured G or electron mass
CALIBRATED	Fit using a declared calibration dataset	Set one scale using a known clock
PREDICTED	Calculated without target data	Predict a new dispersion coefficient
TESTED	Compared to held-out observation	Likelihood on GW/CERN data
CLOSURE	Still missing	Derive Born rule or Einstein dynamics

> **The most important rule** Never count a quantity twice: if a measured constant or dataset selected a parameter, branch, scale, or formula, agreement with that same target is calibration—not a new prediction.

8.4 A compact END-style audit exercise

Suppose the microscopic theory proposes a graph field q and update law

$$\mu\,(q_i^{n+1} - 2q_i^{n} + q_i^{n-1})/\Delta\tau^2 = -(\kappa/a^2)(Lq^n)_i - V'(q_i^{n})$$

Your audit sequence:

53. List the dimensions assigned to μ, κ, a, $\Delta\tau$, q, and V.
54. Check that every term has the same dimensions.
55. Linearize V if needed and diagonalize L using $L v_r = \lambda_r v_r$.
56. Derive the normal-mode recurrence and stability condition.

57. Take the long-wavelength limit and identify the effective propagation speed and mass scale.
58. Only then define the physical-unit matching map. Record which measured quantity was used for calibration.
59. Derive a new coefficient or correction that was not used in the calibration.
60. Freeze it and compare with held-out data.

8.5 What "AI did the math" should mean

AI can perform algebra, derive variations, diagonalize matrices, search literature, write numerical solvers, propagate uncertainty, and test edge cases. Your job is to freeze the physical meaning and assumptions, require transparent intermediate steps, and refuse to promote a result until the derivation and audit pass.

> **Good division of labor** You choose the ontology and physical interpretation. AI proposes formalizations. Together, you test whether the formalization actually implies the claimed physics. If several mathematical implementations fit the same words, that ambiguity must be resolved before calling anything derived.

Final practical exam

61. An AI gives $R = (\hbar c)^2 E/(G\psi)$. Before calculating anything, list at least four questions you must answer about R and ψ.
62. An AI reproduces the fine-structure constant after tuning two dimensionless parameters against α. Is α a prediction? Why?
63. A graph model has waves with a maximum group velocity. Has it derived Lorentz invariance? What else is required?
64. A deterministic node model creates correlated pairs. Has it derived quantum mechanics? Name at least three additional requirements.
65. A continuum action reduces to Einstein–Hilbert form only after inserting measured G. What has been achieved, and what has not?

Checkpoint

- ☐ I can distinguish definitions, assumptions, derivations, calibrations, and predictions.
- ☐ I can identify circular validation.
- ☐ I can demand an explicit bridge from internal theory variables to detector observables.
- ☐ I know which major closure problems remain before a true GUT/TOE claim is justified.

Your notes / flash cards

Reference Sheet A — Symbols and formulas

Item	Formula / meaning
Derivative	$v=dx/dt$; $a=d^2x/dt^2$
Integral	Accumulation: $\Delta x=\int v\,dt$
Wave number	$k=2\pi/\lambda$
Angular frequency	$\omega=2\pi f$
Wave speed	$v_p=\omega/k$; $v_g=d\omega/dk$
Momentum	$p=mv$ (nonrelativistic)
Energy	$E=mc^2$ at rest; $E^2=p^2c^2+m^2c^4$ generally
Quantum energy	$E=hf=\hbar\omega$
de Broglie	$\lambda=h/p$
Graph Laplacian	$L=D-A$
Eigenvalue equation	$A\,v=\lambda v$
Action	$S=\int L\,dt$; fields: $S=\int d^4x\,\mathscr{L}$
Euler–Lagrange	$d/dt(\partial L/\partial\dot{q})-\partial L/\partial q=0$
Schrödinger	$i\hbar\partial\vert\psi\rangle/\partial t=H\vert\psi\rangle$
Born rule	$P(a)=\vert\langle a\vert\psi\rangle\vert^2$
Relativity factor	$\gamma=1/\sqrt{(1-v^2/c^2)}$
Metric interval	$ds^2=g_{\mu\nu}dx^\mu dx^\nu$
Einstein equation	$G_{\mu\nu}+\Lambda g_{\mu\nu}=(8\pi G/c^4)T_{\mu\nu}$

Reference Sheet B — Constants and unit reminders

Constant	Approximate value	Use
c	299,792,458 m/s (exact)	Relativistic causal conversion
h	6.62607015×10^{-34} J·s (exact)	Quantum action
$\hbar=h/2\pi$	$\approx1.05457\times10^{-34}$ J·s	Quantum action
e	$1.602176634\times10^{-19}$ C (exact)	Elementary charge
k_B	1.380649×10^{-23} J/K (exact)	Thermal energy scale

G	$\approx 6.6743\times10^{-11}$ m^3 kg^{-1} s^{-2}	Newtonian gravitational coupling
α	≈1/137.036	Electromagnetic fine-structure constant
1 eV	$1.602176634\times10^{-19}$ J	Particle-energy unit

> **Do not confuse calculation with derivation** Using c, G, and $\hbar$ to calculate the Planck length is correct mathematics. It does not mean a new theory has independently derived c, G, or $\hbar$.

Reference Sheet C — Flash cards worth making

Front	Back
What does dx/dt mean?	Rate of change of x with respect to t.
Difference between = and ∝?	= is a complete equality; ∝ specifies scaling until a coefficient is supplied.
Fastest equation sanity check?	Dimensions/units on both sides.
What is an eigenvector?	A pattern changed only by an overall factor under an operator/matrix.
What is L=D−A?	Graph Laplacian.
What does an action do?	Encodes dynamics; stationary variation gives equations of motion.
What is a symmetry good for?	It constrains allowed equations and often implies conservation laws.
Born rule?	$P(a)=\|\langle a\|\psi\rangle\|^2$.
What is calibration?	Using known data to select/fix model parameters or scales.
What is a prediction?	A quantity fixed before viewing the held-out target data.
What is circular validation?	Using the target to choose the model and then claiming agreement with the same target as evidence.
What must an emergent-gravity model derive?	Operational geometry plus dynamics/limits consistent with GR, not merely an inverse-square force.

Reference Sheet D — Prompt for auditing AI mathematics

> **Copy this prompt** "Audit the following derivation line by line. Make a symbol table with units and domains. For every equation, label it DEFINED, ASSUMED, DERIVED, MEASURED INPUT, CALIBRATED, or PREDICTED. Check dimensions, algebra, limiting cases, symmetry, conservation laws, parameter identifiability, and whether any target data leaked into parameter selection. Do not repair the derivation silently; list failures separately."

Then ask the AI to produce a minimal numerical test with frozen inputs and an explicit failure criterion.

Answer Key

Hour 1

1. $(4\times10^3)(5\times10^{-7})=20\times10^{-4}=2\times10^{-3}$.
2. $r^{-2}=1/r^2$.
3. vt has units (m/s)(s)=m, so yes.
4. No as written: mv has units kg·m/s, which is momentum, not energy $kg\cdot m^2/s^2$.
5. Invalid as an ordinary sum because joules and kilograms are different dimensions unless a conversion relation with additional factors has been explicitly defined.

Hour 2

1. dx/dt=10t.
2. a=dv/dt=6t.
3. When x>0, acceleration is negative; when x<0, acceleration is positive. It always points back toward x=0.
4. $\int v\,dt=4\times5=20$ m for constant v over 5 s.
5. $\partial\varphi/\partial x$ measures how the field changes across position at fixed time; $\partial\varphi/\partial t$ measures how it changes in time at fixed position.

Hour 3

1. Differentiating cos twice gives $-\omega^2$ times the original cosine, so $d^2x/dt^2=-\omega^2x$.
2. ω/k=c.
3. Nondispersive over that range because ω is linear in k.
4. It could reveal or constrain departures from standard propagation if a theory predicts a fixed frequency-dependent correction.
5. A physical mapping: units/scale, source and propagation model, detector response, and fixed numerical coefficients.

Hour 4

1. $(8,15)^T$.
2. $(1,0)^T$ has eigenvalue 2; $(0,1)^T$ has eigenvalue 3.
3. Each row sums to zero, so the product is $(0,0,0)^T$.
4. If every node has the same value, there is no neighbor difference to drive a discrete spatial response.
5. Check whether the graph is actually undirected with nonnegative weights, whether L was defined conventionally, and whether the eigenvalue calculation is wrong.

Hour 5

1. $E^2=m^2c^4$, so positive-energy branch $E=mc^2$.
2. $E^2=p^2c^2$, so E=pc for positive energy.
3. T contains kinetic/motion terms; V contains potential/interaction energy.
4. Energy.
5. A maximum speed is weaker than Lorentz invariance. You must recover the correct transformation symmetry, causal structure, and universal low-energy behavior across sectors.

Hour 6

1. |3+4i|=5.
2. Because probabilities of all mutually exclusive outcomes must sum to one.
3. It generates time evolution and represents energy.
4. Hermiticity/self-adjointness in the standard setting, leading to unitary evolution.

5. Because quantum entanglement also requires the correct state space, probability rule, Bell correlations, contextual structure, and no-signalling behavior.

Hour 7

1. L is the finite-dimensional mechanical Lagrangian integrated over time; $\mathscr{L}$ is a density integrated over spacetime.
2. It lets derivatives transform correctly under local gauge transformations by including the gauge connection.
3. Otherwise the same data choose and test the coefficient, producing circular evidence.
4. It determines spacetime intervals and therefore causal/metric geometry.
5. At minimum: derive an operational metric/geometry from the microscopic model and derive its dynamics/limits so they approach the tested content of GR, including the Newtonian limit.

Final practical exam

1. Examples: What are the dimensions of R? What is ψ and its units/normalization? Why is G present—is it input or derived? What domain does R live in? Is the expression invariant under required symmetries? Was E independently fixed?
2. No. If parameters were tuned against α, reproducing α is calibration. A prediction must be fixed independently and tested elsewhere.
3. No. It must also recover Lorentz transformations/invariance to required precision, a universal causal cone, correct energy–momentum structure, and experimental limits on symmetry breaking.
4. No. It must additionally reproduce a quantum state/probability map such as the Born rule, interference, Bell/CHSH correlations, contextuality constraints, and operational no-signalling.
5. The model may have shown that its continuum structure can be matched to Einstein–Hilbert form. It has not independently derived the numerical gravitational coupling G if G was inserted as measured input.

After the one-day course: a 30-day follow-on

If today goes well, do not immediately try to memorize graduate textbooks. Build depth in the exact order that improves your ability to audit END.

Week	Study focus	Outcome
1	Algebra, scientific notation, calculus drills, dimensional analysis	Fast symbolic reading and unit checks
2	Linear algebra, eigenvalues, differential equations, Fourier/waves	Comfort with graph/lattice calculations
3	Classical mechanics, action, special relativity, introductory QM	Understand standard derivation structures
4	QM operators, QFT/field-action basics, tensors/GR overview, statistics	Recognize closure requirements and data-analysis logic

Suggested daily pattern: 20 min reading + 20 min handwritten derivation + 20 min exercises + 15 min auditing one equation from your own project.

How this maps to your END project

The current END / Evans Node Dialect materials explicitly use or discuss ordered updates, graph Laplacians and eigenmodes, discrete variation, lattice dispersion and stability, gauge covariance, continuum/effective-action recovery, quantum probability and Bell constraints, operational geometry, Einstein/Newtonian limits, and detector-level validation. This course is deliberately organized around those mathematical skills rather than around a generic school syllabus.

Project sources used to tailor the syllabus: END Theory 2.0 — Technical Reference Edition (2026); Evans Node Dialect — Definitive Scientific Report (2026); END Theory — Site Edition (2026); and the earlier Node-Reality Matrix Theory draft.

> **Final standard** You do not need to do every advanced derivation mentally. You do need to know what kind of object an equation is, what assumptions created it, whether the algebra/units make sense, what was imported from known physics, and what would count as a genuinely new prediction.