

Investigating Inelastic Collisions

From Bounce to Coefficient of Restitution

Scientific Inquiry with AI

Student Guide

Detailed Instructions & Course Material

Why This Lesson

Drop a ball and it bounces back a little lower each time. It feels obvious, but hidden inside that fading bounce is a clean, measurable physics story: gravity, the conversion between potential and kinetic energy, and a fraction of mechanical energy converted to heat and sound at every impact. This investigation is about measuring that loss precisely enough to test a model, using nothing but the sound of the bounces and a high-sampling-rate microphone.

The point is not just to get a number. It is to practice a real research workflow with AI as a collaborator: you will collect messy experimental data, use AI to graph and process it, and, most importantly, verify every result against the raw signal before you trust it. AI makes the slow parts (plotting, smoothing, peak-finding, fitting) fast. The skill that matters is judgment: knowing when a detected bounce is real, when an algorithm has drifted, and when your model has stopped describing reality.

Learning Goals

Upon completion of this investigation, you should be able to:

Phenomena:

- Use a model of a ball colliding with a surface to describe elastic and inelastic collisions.
- Evaluate how material properties affect energy transfer during a collision, and characterize collisions using the coefficient of restitution.
- Discuss the conservation of mechanical energy and the conversion between kinetic and potential energy for an object in free fall.

Experimental Practices:

- Use indirect measurement techniques (recording sound with a high-sampling-rate microphone) to infer the timing of physical events (collisions between a ball and a surface).
- Identify and evaluate the precision of different digital signal processing methods, including strategies that involve rapid initial analysis followed by more computationally intensive refinement.
- Apply equations of motion for constant acceleration to calculate the position and velocity of an object in free fall given its initial conditions and the elapsed time.

Habits of Mind:

- Use a series of graphs to describe quantitatively how measured and calculated quantities vary with time, bounce number, and velocity.
- Describe how the high precision that results from careful experimental design and computational analysis enables more detailed testing of models and provides a deeper understanding of the phenomena.
- Use simulations to extend your understanding and predict how material properties affect energy transfer during collisions.

What You Will Need

- **Three balls** — two rubber balls made of different materials, and a ping-pong ball.
- **A device that records audio** at a high sampling rate (your phone voice recorder is usually fine), and a hard, flat surface.
- **Your AI model** with data-analysis and code-execution enabled, so it can plot and process your audio file.
- **Your prelab materials** — the technical data sheet on rubber balls and the Collision Analysis Guide. You will complete the short Collision Analysis self-check between Sessions A and B.

The Core Idea

- When a ball bounces, the ratio of its speed leaving the surface to its speed arriving is the coefficient of restitution (COR). A perfectly elastic bounce has $COR = 1$; a dead bounce has $COR = 0$.
- Because the ball is in free fall between impacts, the time between successive bounces shrinks in a predictable way. The ratio of a bounce interval to the preceding interval is the COR, so you can extract the physics from timing alone, without ever measuring height directly.
- You can hear each impact. A microphone recording turns the experiment into a long sound file where every bounce is a spike, so the whole investigation becomes: find the precise time of each spike, then look at how those times change.
- AI can graph, smooth, and detect peaks far faster than you could by hand, but it can also confidently mislabel noise as a bounce or miss faint late bounces. Treat every AI-detected bounce time as a claim to verify against the raw waveform, not a fact.
- The driving question is real research: does the percentage of energy lost per collision stay constant across velocities, or does it change? You are looking for consensus across the whole group's measurements.

Session A — From Recording to Bounce Times

This investigation runs across two class sessions. In Session A you will record your bounce sequence, explore the waveform, build and verify a first set of bounce times, and refine those times

against the raw signal (Stages 1–7). In Session B you will defend your analysis method and turn the verified times into the full set of physics graphs (Stages 8–10).

Part 1 — Pre-Class Preparation

~1.5 hours

A. Exposure to the Phenomena (~5 minutes)

Explore the properties of the two solid balls. You will be asked about your observations during the Socratic tutoring session.

B. Socratic AI Tutoring Session (~30 minutes)

Upload the prelab tutor document into a chatbot and thoughtfully engage with the AI. The discussion will help you build the knowledge needed for the in-class investigation.

C. Happy and Sad Balls Reading (~10 minutes)

Read the short document describing the materials used to make the two balls and explaining their observed behavior. This will reinforce the discussion from the Socratic tutor.

D. Collision Analysis Guide: Read (~20 minutes)

Read the Collision Analysis Guide, which provides a summary of the equations and analysis methods you will use to analyze the experimental data during Session B. You will review this guide again and complete a short self-check worksheet between Sessions A and B.

E. Review of In-Class Investigation (~10 minutes)

Review the Session A stages (Stages 1–7) in Part 2 below to prepare for the in-class investigation.

Part 2 — In-Class Investigation

110 minutes

The Investigation, Stage by Stage

The full investigation is condensed into ten stages spread across the two sessions: Stages 1–7 in Session A take you from a raw recording to verified, refined bounce times, and Stages 8–10 in Session B take you from those times to the physics. Your instructor will lead the group through these together, so this guide gives you the purpose and what to look for at each stage rather than every keystroke.

Stage 1 — Record and visualize your data

Drop your ping-pong ball a couple of centimeters (gap between ball and surface) onto a hard surface and let it bounce until it stops, recording the audio on your smartphone. The phone should be about 10-20 cm from the impact location and the bounce location should stay within about a 5 cm radius of the initial bounce location (ask yourself why this might be important).

Upload the audio file to your AI along with a short description of the experiment (ball type, surface, approximate measured drop height) and ask it to plot the full waveform — amplitude versus time.

Look for: a series of “spikes” that get closer together and shrink over time. That overall shape is the entire experiment in one picture. Compare it with a peer’s waveform — where are they similar, where do they differ?

Why this ball and surface: the ping-pong ball on a hard surface is intentional. This combination has a large coefficient of restitution, which gives an extended series of bounces and allows more detailed investigation of the low-velocity physics.

Stage 2 — Check your sampling rate and trim the file

Determine the sampling rate by inspecting the time-series data. One practical way is to ask the AI for a table of the time and amplitude for the first 10 data points, then calculate the sampling rate from the spacing.

If your recording includes excess time before or after the bouncing sequence, trim it to retain the full sequence with approximately 0.5 s on either side. This keeps subsequent graphs and analysis focused on the bouncing motion.

Why it matters: the sampling rate limits the best timing precision you can achieve. This becomes more and more important as the time between bounces becomes smaller.

Stage 3 — Zoom in on a single bounce

Pick one clear bounce and have the AI zoom in on it. You will probably not see a single clean spike — you will see a complicated, messy waveform.

Ask the AI: why does one bounce produce such a complex sound-wave pattern? This is exactly why picking the exact bounce time is harder than it looks. Since we care about the time intervals between bounces, do we need to know the exact time of the bounce, or can we identify a repeatable feature?

Stage 4 — Graphically compare early, middle, and late bounces

Have the AI graphically compare bounces from the beginning, middle, and end of the recording. Does the shape of the waveform change significantly as the bounces get weaker? Does the amplitude alone look like a reliable measure of energy?

Decide: you are testing whether amplitude or timing is the more useful measurement for this investigation. Spoiler from the workflow: timing wins — but see the reasoning for yourself before you accept it.

Stage 5 — Smooth the signal with RMS

A raw waveform swings rapidly above and below zero, which makes peak-finding fragile. Ask the AI to compute a running root-mean-square (RMS) of the signal, which turns each messy burst into a single smooth hump. Graph the RMS for the whole file and for early, middle, and late bounces.

Judgment call: how wide should the RMS window be? Too wide and two late bounces blur together; too narrow and the hump stays jagged. Try a couple of widths and reason about the shortest time between bounces you need to resolve.

Stage 6 — Find a first estimate of each bounce time

Using the smoothed RMS data, have the AI detect the maximum of each hump and mark the bounce times. Ask it to make a graph with the detected times marked on the first ~50 bounces, and a second, expanded graph near the end where bounces crowd together.

Verify, do not trust: this is the most important habit in the lab. Look at every marked peak. Did it catch a real bounce, mistake background noise for one, or miss a faint late one? A panel of small graphs with each peak labeled is the best way to check. Adjust the algorithm until the marks match what your eyes see.

Stage 7 — Refine the bounce times using the raw signal

RMS gives you good approximate times, but it smears the exact moment of impact. Now create overlay graphs of the original raw data for every 10th bounce, using a window of about 10 ms centered on each RMS bounce time.

Ask the AI if it has suggestions for refining the bounce times using the raw data, which has much better time resolution. Pick one suggestion, or design your own approach, and use a sharp, repeatable feature as a consistent timing marker.

Key insight: you do not need the true instant of impact — you only need the time between bounces measured consistently. Measuring changes precisely is often more important than knowing the absolute time of a physical event.

Verification graphic: create expanded graphs around every 10th bounce with the refined bounce times indicated. These graphs are your evidence that the bounce-time list is reliable.

Wrap Up Session A: What You Should Leave With

By the end of Session A you should have: a clean, trimmed recording with a known sampling rate; a full-waveform graph; a working RMS analysis procedure; raw-signal overlay/refinement graphs; and a set of bounce times you have personally verified against the raw waveform. Write a line or two on which detections you had to correct and how you caught them — when did the measurement technique begin to fail, and what surprised you about the difference between what the algorithm reported and what your eyes saw?

Part 3 — Post-Class Work

~1 hr

A. Finalize Your Bounce-Time Verification (~20 minutes)

Review your bounce-time data and graphs to verify that you trust your analysis and results. If your panel-graph or raw-signal checks revealed missed bounces, false detections, or shifted timing markers, correct them. Save your chat/analysis session so you can continue it in Session B.

B. Retrieval Practice / Course Review (~30 minutes)

Spend about 30 minutes with the AI-enhanced retrieval tool, which spaces and interleaves material across the whole course — an adaptive alternative to flashcards.

Session B — From Refined Times to the Physics

Session B: 1) finalizes the bounce times so you can defend your analysis and results; 2) investigates the physics through calculations and graphical analysis of time between bounces, coefficient of restitution, velocity, height, and percent energy lost; and 3) addresses the driving question and compares results across the group.

Part 1 — Pre-Class Preparation

~30–45 min

A. Review the Analysis Methods (~20 minutes)

Revisit the Collision Analysis Guide sections on converting bounce intervals to velocity, height, energy, and the coefficient of restitution, including the log-plot fit. These are the calculations the AI will perform on the full dataset in class, so you should be able to check them on a single bounce by hand. To prepare for class, complete the Collision Analysis self-check worksheet by hand. Upload a clear photo of your completed worksheet to an AI, along with the file “Collisions_SelfCheck_AI_Grading_Prompt.md” from the supplemental materials on the KnowledgeWithAI website. Ask the AI to follow the prompt to review your answers and provide feedback. Confirm that it has read your handwriting correctly, work through any corrections, and ask for explanations of concepts you still find unclear.

B. Prediction Exercise (~10 minutes)

Before running the analysis in class, commit to a written prediction for the driving question: will the percentage of energy lost per collision stay constant across velocities, or change with speed — and if so, in which direction?

Part 2 — In-Class Investigation

110 minutes

Bring your verified Session A bounce times, your saved analysis session, and your completed self-check. After a brief retrieval exercise connecting back to Session A, your class will first discuss bounce-time analysis and verification methods, then continue with Stage 8.

Discussion — Bounce-Time Analysis and Verification Methods

Before moving into the physics graphs, discuss and briefly present the method you used to identify and refine bounce times. Explain how you verified reliability: RMS peaks, raw-signal overlays, panel

graphs, corrections to missed bounces, false detections, or shifted timing markers, and any choices you made about window size or repeatable timing features.

This discussion is where you defend the data you will use for the physics analysis. The goal is not a perfect algorithm; the goal is evidence that your bounce-time list is trustworthy.

The Investigation, Stage by Stage (continued)

Stage 8 — Plot time-between-bounces and extract the COR

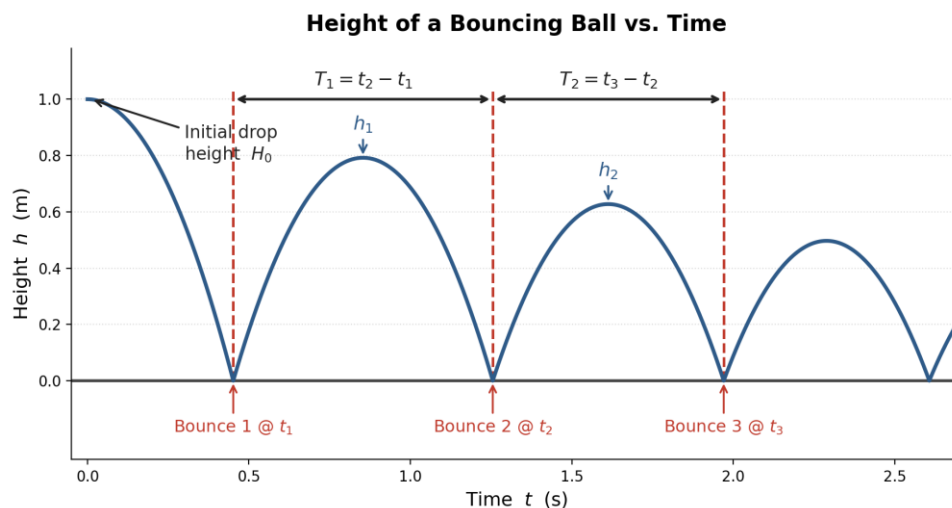
Have the AI plot the time between successive bounces against bounce number, then plot the natural log of that time against bounce number. If the coefficient of restitution is approximately constant over a range of bounces, those points should lie close to a straight line. Identify and fit a reasonably linear region. Explain your choice of fitting range and check whether modest changes to that range affect the result.

Calculate COR by exponentiating the fitted slope: $COR = \exp(\text{slope})$. This value summarizes the selected range; it does not establish that COR is constant throughout the recording. Systematic curvature may indicate changing COR or limitations of the measurement or model.

This is a central result of the analysis: a single number, COR, pulled from timing alone. Check the calculation by hand to confirm the AI analysis — do not accept the conversion blindly.

Stage 9 — Turn timing into velocity, energy, and COR vs. velocity

From the bounce intervals, have the AI calculate and graph the approach velocity at each bounce, the coefficient of restitution as a function of bounce number, and the percent of energy lost as a function of velocity. The figures below is a reminder of the index nomenclature for describing the process and the key equations.



From flight intervals to collision physics

Worked relationships for bounce 2

	$T_1 = t_2 - t_1$	$T_2 = t_3 - t_2$
Approach speed	$v_{in, 2} = \frac{gT_1}{2}$	
Rebound speed	$v_{out, 2} = \frac{gT_2}{2}$	
Coefficient of restitution	$e_2 = \frac{v_{out, 2}}{v_{in, 2}} = \frac{T_2}{T_1}$	
Percentage energy lost	$100(1 - e_2^2) \%$	

Plot percentage energy lost against approach speed.

Assumes vertical motion, a stationary surface, negligible air drag, and contact duration much shorter than the flight intervals. Speeds are positive magnitudes.

Return to the driving question: does the percentage of energy lost per collision remain constant or change with speed? This graph is your answer, and the one you will compare against the rest of the group.

Stage 10 — Check consistency and spread

Finally, look at reliability. Graph height versus bounce number for the full run and for the final 20 bounces. Then have AI create an overlay graph of amplitude vs time the first ~60 bounces around a ± 2.5 ms interval, and plot the mean and spread of your measurements.

Ask yourself: how tight are your measurements, and where does the scatter grow? The spread tells you how far to trust your COR, and sets up the reflection on where the technique starts to fail.

Reflect: Where Does It Break Down?

Close the investigation by stepping back. When does the measurement technique begin to fail — where do overlapping sound waves or background noise make bounces impossible to separate?

Are there conditions where our model might begin to fail — what happens if the initial drop is very high, or when the contact time becomes significant compared to the flight time? What surprised you, and where did you struggle most? You are not expected to have clean answers; recognizing the limits of your method is an important part of any investigation.

Part 3 — Post-Class Work

~2 hours

A. Extend Your Investigation using a Simulation (30 min)

Use the provided bouncing-ball simulation to explore how changing the collision properties, air resistance, and gravity affects the ball's motion. Begin with a baseline using the ping-pong ball preset with air drag turned off. Then investigate five different scenarios, changing one variable at a time where possible so you can identify its effect.

Before running each scenario, predict what will change and explain your reasoning. Compare the simulation results with your prediction, using the graphs to support your explanation. You might explore a higher or lower coefficient of restitution, a different drop height, air drag, or a different gravitational acceleration. To compare motion with and without air drag, turn air drag on and select the no-drag comparison.

For each scenario, briefly describe the settings, your prediction, the results, and what you learned. Include relevant graphs and discuss at least one connection to your experimental findings.

Remember that the simulation uses a constant coefficient of restitution within each run. It illustrates the consequences of that assumption; your experimental measurements test how well it describes a real ball-surface collision.

Include a summary of your findings for five different scenarios in your report (part B).

B. Generate Your Report (60 minutes)

Ask the AI to produce a report based on your analysis. You write the prompt: specify exactly which text and which graphs you want included. Add the summary of your findings from using the simulation in Part A. Then read the report critically and make sure it presents the graphs and analysis accurately.

C. Retrieval Practice / Course Review (~30 min)

Spend about 30 minutes with the AI-enhanced retrieval tool, which spaces and interleaves material across the whole course.

Deliverables

- Your AI-generated report including a summary of the experiment, the key graphs we built together in class, a summary of the 5 scenarios from the simulation, and a reflection on the key findings and limitations of our model and approach. Submit on the knowledgewithai.com website.