

# O SCALE MODEL RAILROADING STEM LESSON PLAN SERIES

*Four Complete Lesson Plans Aligned to the  
Next Generation Science Standards (NGSS)*

Grades 6 – 10

<b>Series Title</b>	Tracks to Tomorrow: STEM Through O Scale Model Railroading
<b>Target Grades</b>	Grades 6 – 10 (adaptable for 4–5 and 11–12)
<b>Total Lessons</b>	4 Lessons   Approx. 55 minutes each
<b>NGSS Domains</b>	Physical Science · Engineering Design · Earth & Space Science
<b>Lesson 1</b>	Electricity & Circuits — Wiring a Layout
<b>Lesson 2</b>	Physics — Momentum, Friction & Grades
<b>Lesson 3</b>	Geometry — Track Planning & Scale Ratios
<b>Lesson 4</b>	Civil Engineering — Bridge Load Calculations
<b>Equipment Scale</b>	O Scale (1:48 ratio) — recommended for classroom use
<b>Contact / Source</b>	O Scale STEM Education Initiative

**Why O Scale?** O Scale (1:48) trains are the ideal classroom scale. Larger components are easier for young hands to handle, wiring connections are visible and touchable, scale relationships are straightforward to calculate (1 inch = 4 feet prototype), and the Lionel legacy means many families already have an emotional connection to the equipment.

## How to Use This Series

Each lesson is self-contained and can be taught independently or as a four-lesson arc. The lessons progress from foundational electrical concepts through physics, spatial mathematics, and applied engineering — mirroring the actual process of designing and building a real model railroad layout.

Recommended sequence for a club, after-school program, or semester elective:

- Weeks 1–2: Lesson 1 — Electricity & Circuits
- Weeks 3–4: Lesson 2 — Physics in Motion
- Weeks 5–6: Lesson 3 — Geometry on the Rails
- Weeks 7–8: Lesson 4 — Civil Engineering & Bridge Design

- Weeks 9+: Capstone — students design, build, and operate a complete small layout incorporating all four concepts

## LESSON 1

# Electricity & Circuits

*Wiring an O Scale Layout — From Power Pack to Rail*

<b>Duration</b>	55 minutes (or two 30-min sessions)
<b>Grade Band</b>	6–8 (primary)   9–10 (extension)
<b>NGSS Core Ideas</b>	PS3: Energy   PS2: Motion and Stability
<b>Key Vocabulary</b>	Circuit, voltage (V), current (A), resistance ( $\Omega$ ), conductor, insulator, short circuit, block wiring
<b>Driving Question</b>	How do electrons know where to go — and how do we keep our train on the right track?

## Teacher Background

O Scale layouts use a simple two-rail electrical system. The power pack outputs DC voltage (typically 0–18V) through the two rails. The locomotive's wheels pick up current from one rail, pass it through the motor, and return it through the other rail — completing the circuit. Understanding this requires students to grasp series vs. parallel circuits, the role of resistance, and how insulated rail joiners divide a layout into independently controlled blocks.

**Safety Note:** O Scale power packs used in classroom settings output 14–18V DC at low amperage. Always use UL-listed power packs designed for model railroads. Students should never touch both rails simultaneously while power is on.

## NGSS Alignment

Standard Code	Practice / Concept	How O Scale Activity Addresses It
MS-PS2-3	Ask questions about data to determine factors affecting electric and magnetic forces	Students vary voltage and observe changes in locomotive speed; question what happens when resistance increases (adding cars, steeper grades)
MS-PS3-2	Develop a model to describe potential energy changes when objects interact at a distance	Students model the complete circuit: power pack → wire → rail → wheel → motor → wheel → rail → return
MS-ETS1-1	Define the criteria and constraints of a design problem	Students must wire a two-block layout so two trains can stop independently — defining electrical constraints before wiring
HS-PS3-5	Develop and use a model of two objects interacting through electric or magnetic fields	Extension: students model DCC (Digital Command Control) and explain how multiple control signals share the same rails
Science Practice	Developing and Using	Students draw a schematic diagram of their

2	Models	circuit before physically wiring it
Science Practice 3	Planning and Carrying Out Investigations	Students test hypotheses about open circuits (rail gap) and short circuits (touching wires)

## Materials

Item	Qty (per group)	Notes
O Scale oval track set (minimum 12 sections)	1 set	Lionel FasTrack or similar
O Scale power pack (0–18V DC)	1	Lionel PowerMaster or equivalent
O Scale locomotive (any)	1	Diesel starter loco recommended
22-gauge hookup wire, two colors (red/black)	4 ft each	Pre-cut in 6-inch lengths
Insulated rail joiners	6	To create electrical blocks
Small screwdrivers (flathead and Phillips)	2	For terminal connections
Multimeter (basic)	1 per group	For measuring voltage across rails
Breadboard + LED + resistors (for circuit modeling)	1 kit per group	Optional but highly recommended
Student Circuit Diagram Worksheet	1 per student	Students draw schematics
Conductors/Insulators sorting cards	1 set per group	Laminated, reusable

## Lesson Sequence

### Phase 1: Engage (10 min)

Write the Driving Question on the board: "How do electrons know where to go?" Hold up an unconnected locomotive.

1. Ask: "What does this need before it can move?" Accept all responses.
2. Conduct a rapid Conductors vs. Insulators card sort — students classify materials: copper wire, rubber band, aluminum foil, plastic rail joiner, steel rail. Discuss.
3. Introduce the analogy: "The power pack is the pump. The wires and rails are the pipes. The locomotive motor is the water wheel. Electricity needs a complete loop — just like water in a plumbing system."

### Phase 2: Explore (20 min)

Groups of 3–4 students assemble a simple oval of O Scale track and connect to the power pack.

4. Before connecting power, students draw a schematic on their worksheet, labeling: power pack, positive terminal, negative terminal, rail 1, rail 2, locomotive motor, return path.
5. Connect power and run the locomotive. Record: What is the voltage across the rails? What happens when you adjust the throttle?
6. Insert an insulated rail joiner in one rail. The locomotive stops in one section. Question: "What does the gap do to the circuit? Draw the change on your schematic."
7. Add a feeder wire to the isolated block with a separate on/off switch. Students can now stop one train while another continues — this is block wiring.

### Phase 3: Explain (10 min)

Whole-class debrief using student observations:

- Voltage: "The push that moves electrons"
- Current: "The flow rate of electrons — measured in amperes"
- Resistance: "Anything that slows the flow — dirty rails, long wire runs, motor windings"
- Two wire colors: Convention and safety — red = positive, black = negative

Introduce Ohm's Law:  $V = I \times R$ . Students calculate: if the motor has 10 ohms resistance and we supply 12V, how much current flows? (1.2 amps) Is that within the power pack's rated output?

### Phase 4: Elaborate (10 min)

Extension challenges (assign by readiness):

- "Add a third block and wire it so switch 2 cuts power to blocks 1 and 2 simultaneously." (Series wiring of switches)
- "What happens if we wire the locomotive's two pickup rails to the SAME rail? Why?" (Short circuit — demonstrate safely with LED indicator)
- DCC Extension: Show a DCC decoder and explain it reads a digital address signal from the rails — the rails carry data, not just power.

### Phase 5: Evaluate (5 min)

Exit ticket — students answer three questions on their worksheet:

8. Draw and label a complete circuit for a one-block O Scale layout.
9. What is ONE thing that would break the circuit, and what would you observe?
10. If you wanted to run two trains independently, what electrical component would you add and where?

## Assessment Rubric — Lesson 1

Criterion	4 – Exceeds	3 – Meets	2 – Approaching	1 – Beginning
Circuit Schematic	Complete, accurate, labeled;	Mostly complete; minor labeling	Partially complete; missing one	Incomplete or does not show a closed loop

	correctly shows current path through both rails and motor	error; current path is correct	component or incorrect direction	
<b>Block Wiring</b>	Correctly explains and demonstrates two-block wiring with independent switches	Demonstrates block wiring with minor prompting	Understands concept but cannot implement without significant help	Cannot explain what an insulated rail joiner does
<b>Ohm's Law</b>	Correctly calculates V, I, or R for 3+ scenarios and explains units	Correctly calculates for 2 scenarios	Sets up formula correctly but makes arithmetic errors	Cannot apply $V = I \times R$ without direct instruction
<b>Safety Awareness</b>	Proactively identifies 2+ safety considerations and explains the reasoning	Correctly states key safety rule when asked	Aware of safety rule but cannot explain why	Does not demonstrate awareness of electrical safety

## Differentiation

Support: Provide pre-labeled circuit diagram with blanks; use breadboard/LED before track; pair with peer tutor.

Extension: Research how DCC encodes digital signals; calculate voltage drop along 10 feet of rail at  $0.01\Omega/\text{ft}$ ; design a reverse loop and explain the electrical challenge.

## LESSON 2

# Physics in Motion

*Momentum, Friction & Grades on an O Scale Layout*

<b>Duration</b>	55 minutes
<b>Grade Band</b>	6–8 (primary)   9–10 (extension with calculus concepts)
<b>NGSS Core Ideas</b>	PS2: Motion and Stability — Forces and Interactions
<b>Key Vocabulary</b>	Momentum, inertia, friction, grade (%), tractive effort, rolling resistance, terminal velocity
<b>Driving Question</b>	Why does a heavy freight train need a mile to stop — and what does your layout have to do with that?

## Teacher Background

Model railroads offer a uniquely controllable environment for physics experiments. The grade (slope) of track can be adjusted precisely, the weight of rolling stock can be measured and varied, and the locomotive's tractive effort can be compared against the load. O Scale equipment is heavy enough that momentum and friction effects are clearly observable, yet safe to handle. Real railroads limit grades to 1–2% on mainlines; model railroads commonly use 2–4%.

**Real-World Connection:** Railroad engineers use detailed momentum calculations to determine safe braking distances. A loaded freight train at 60 mph may require more than a mile to stop. Students will model this at 1:48 scale and then scale their numbers up to prototype dimensions.

## NGSS Alignment

Standard Code	Practice / Concept	How O Scale Activity Addresses It
MS-PS2-1	Apply Newton's Third Law to design a solution involving the motion of two colliding objects	Students collide a rolling locomotive into stationary cars and measure the transfer of momentum
MS-PS2-2	Plan an investigation showing that change in motion depends on net force and mass	Students vary grade and mass while measuring acceleration and stopping distance
MS-PS2-4	Construct arguments that gravitational interactions depend on masses of interacting objects	Students explain why the locomotive stalls on a steep grade in terms of the gravitational force component along the incline
HS-PS2-1	Analyze data to support Newton's second law relating force, mass, and acceleration	Extension: $F=ma$ applied to calculate tractive force needed to move a given tonnage up a given grade

Science Practice 4	Analyzing and Interpreting Data	Students graph speed vs. grade percentage and momentum vs. car count
Science Practice 6	Constructing Explanations	Students write a lab report explaining observations in terms of Newton's Laws

## Materials

Item	Qty (per group)	Notes
O Scale oval track with 4 grade-adjustable sections	1 set	Use foam blocks to create 1%, 2%, 3%, 4% grades
O Scale locomotive with known weight	1	Weigh on kitchen scale before class
O Scale freight cars (loaded with washers for consistent weight)	8	Each car same weight; add washers to vary
Kitchen/postal scale (capacity 2 kg)	1	For weighing locomotive and cars
Metric ruler and tape measure	1 each	For measuring grade rise/run and stopping distances
Stopwatch or phone timer	1 per group	For timing runs
Masking tape	1 roll	Mark start/stop positions on track
Graph paper or graphing software	1 per student	For plotting results
Lab Worksheet — Physics of Trains	1 per student	Data table + reflection questions
Bubble level (small)	1	For verifying grade accuracy

## Lesson Sequence

### Phase 1: Engage (8 min)

11. Show a 30-second video clip of a loaded freight train struggling on a grade. Ask: "What forces are working against that train? What forces are helping it?" Collect responses in two columns: HELPING and HINDERING.
12. Introduce grade percentage: "A 1% grade means the track rises 1 foot for every 100 feet of horizontal distance. In O Scale (1:48), what does that look like on our layout?" Students calculate.

### Phase 2: Explore — Experiment A: Grade vs. Stall Point (15 min)

Set up track at 1% grade. Run the locomotive pulling 0, 2, 4, 6, and 8 cars. Record maximum number of cars the locomotive can pull without stalling. Increase grade to 2%, 3%, 4%.

Grade (%)	Cars Pulled	Total Weight (g)	Stall? Y/N	Observations
1%				
2%				
3%				
4%				

### Phase 3: Explore — Experiment B: Momentum & Stopping Distance (12 min)

On level track, accelerate locomotive + 4 cars to full speed. Mark position when power is cut. Measure coast distance before stopping. Repeat with 8 cars at same throttle setting.

- Question: "Which stopped sooner — 4 cars or 8? Why? What does this tell you about momentum?"
- Extension: Calculate momentum ( $p = mv$ ) using measured mass and estimated speed from timing over a known distance.

### Phase 4: Explain (10 min)

- Newton's First Law: "The train keeps moving because it wants to keep moving. The heavier the train, the harder it is to stop."
- Grade Force Component: On a grade of  $g\%$ , the force opposing motion =  $m \times 9.8 \times (g/100)$ . Students calculate for their 4% grade.
- Rolling Resistance: Real railroad steel-on-steel rolling resistance is approximately 2–5 lbs per ton.
- Tractive Effort: The locomotive's maximum pull force. If tractive effort < gravity component + rolling resistance, the locomotive stalls.

### Phase 5: Evaluate (10 min)

Students write a "Dear Engineer" letter (one paragraph) explaining to a fictional junior railroad engineer why the mainline through the mountains cannot exceed a 1.5% grade, using at least three physics terms from the lesson.

## Assessment Rubric — Lesson 2

Criterion	4 – Exceeds	3 – Meets	2 – Approaching	1 – Beginning
<b>Data Collection</b>	All data recorded accurately with units; table complete for all trials	Data mostly complete; one or two missing values; units present	Significant gaps in data; some units missing	Data table largely incomplete or inaccurate

<b>Graph / Analysis</b>	Graph correctly plotted with labeled axes, trend line, and written interpretation	Graph plotted correctly; interpretation partially complete	Graph constructed but axis labels missing or trend misidentified	No graph produced or graph is irrelevant to data
<b>Newton's Laws</b>	All three laws correctly identified and applied to experimental observations with specific examples	Two of three laws correctly applied	One law correctly applied; others confused or incorrectly stated	Cannot connect Newton's Laws to train motion
<b>"Dear Engineer" Letter</b>	Uses 4+ vocabulary terms correctly; reasoning is clear and accurate; grade limit justified with math	Uses 3 terms correctly; reasoning is mostly sound	Uses 1–2 terms; reasoning is partially correct	Does not reflect understanding of grade/force relationship

## LESSON 3

# Geometry on the Rails

Track Planning, Scale Ratios & Spatial Mathematics

<b>Duration</b>	55 minutes
<b>Grade Band</b>	6–8 (primary)   adaptable to Grade 4 with modifications
<b>NGSS Core Ideas</b>	ETS1: Engineering Design (with CCSS-Math integration)
<b>CCSS-Math Links</b>	7.G.A.1 (Scale drawings)   7.RP.A.2 (Proportional relationships)   8.G.B.7 (Pythagorean theorem)
<b>Key Vocabulary</b>	Scale ratio, prototype, model, radius, gauge, right-of-way, clearance, track plan
<b>Driving Question</b>	If 1 inch on our model equals 4 real feet, how do we fit a whole railroad into one room?

## Teacher Background

O Scale uses a ratio of 1:48, meaning every dimension on the model is 1/48th of the real (prototype) dimension. This makes O Scale mathematically elegant for classroom use: 1 inch = exactly 4 feet prototype. O Scale track gauge (distance between rails) is 1.25 inches, representing the standard gauge of 4 feet, 8.5 inches — a measurement dating to Roman chariot wheel spacing and still the world standard today.

**Mathematical Magic of O Scale:** Because 1 inch = 4 feet in O Scale, unit conversions are straightforward: a 4×8 foot layout table represents a railroad corridor 192 feet wide by 384 feet long in prototype space. Students can directly feel the real-world scale of what they're building.

## NGSS / Math Alignment

Standard Code	Practice / Concept	How O Scale Activity Addresses It
ETS1-1	Define the criteria and constraints of a design problem	Students define the space constraints of their layout and work within them
ETS1-2	Evaluate competing design solutions using a systematic process	Students compare two alternative track plans and justify their choice with measurable criteria
7.G.A.1 (CCSS)	Solve problems involving scale drawings	Students convert between model measurements and prototype in both directions
7.RP.A.2 (CCSS)	Recognize and represent proportional relationships	Students verify that all O Scale dimensions maintain the 1:48 ratio
8.G.B.7 (CCSS)	Apply Pythagorean theorem to real-world problems	Students calculate diagonal distances and determine if equipment will clear corners

Science Practice 5	Using Mathematics and Computational Thinking	Students use scale ratios to solve design problems and verify solutions computationally
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## Materials

Item	Qty (per group)	Notes
O Scale track planning template (1:48 scale grid paper)	1 per student	1/4-inch grid = 1 prototype foot in O Scale
O Scale track sections for hands-on measurement	Assorted	Straight, O36/O54/O72 curves, switches
Metric and imperial rulers	1 each per student	Both units for conversion practice
Protractors	1 per group	For measuring curve angles
Colored pencils or markers	1 set per group	For track plan coloring
O Scale equipment dimension reference card	1 per group	Loco length, car length, clearance requirements
Calculator	1 per student	For scale calculations
Tape measure	1 per group	For measuring layout space
String (for measuring curve lengths)	2 ft per group	Lay along curve to measure arc length
Track Planning Worksheet	1 per student	Guided calculation + freehand design section

## Lesson Sequence

### Phase 1: Engage — The Scale Challenge (8 min)

Hold up an O Scale locomotive. Ask: "This is 10 inches long. It represents a real locomotive. How long is the real one?" After guesses, reveal:  $10 \times 48 = 480$  inches = 40 feet. Show an image of an actual EMD GP38 (59 feet long) for comparison and discuss prototype research.

Quick conversion drill (oral, whole class):

- A real boxcar is 60 feet long. How long is our O Scale model? ( $60 \div 4 = 15$  inches)
- Our layout table is 8 feet wide. How wide is that in prototype feet? ( $8 \times 4 = 32$  feet)
- A real signal bridge is 20 feet tall. How tall should our model be? ( $20 \div 4 = 5$  inches)

## Phase 2: Explore — Measuring Real Track (12 min)

Students measure actual O Scale track sections and convert to prototype:

Track Section	Model Measurement	Prototype Equivalent	Calculation Shown
O36 curved section arc length			
O36 curve radius			
Straight section length			
Rail gauge (between rails)	1.25 in	5 ft 0 in	$1.25 \times 4 = 5 \text{ ft}$
Rail height			
Tie (sleeper) spacing			

Discuss: "Standard gauge — 4 feet 8.5 inches — has been used since the early 1800s and is still the world standard. Why do you think railroads standardized this measurement? What would happen if every railroad used a different gauge?"

## Phase 3: Explore — Track Planning Design Challenge (20 min)

**Design Challenge:** You have been hired to design a switching yard for the Pocono Mountain Mining Company. Your layout space is 6 feet × 4 feet. You must include: (1) a main oval, (2) at least one siding that holds 3 freight cars, (3) a runaround track so the locomotive can reach either end of the cars, and (4) all curves must have a minimum radius of O36 (to allow your longest car to pass). Use 1:48 scale grid paper. Label all features in both model inches and prototype feet.

Prompting questions as groups work:

- "What is the total length of your main oval in model inches? In prototype feet?"
- "Your longest freight car is 15 inches. Will it clear that O36 curve? How do you know?"
- "If you want to add a tunnel, minimum clearance is 4.5 inches tall. What does that represent in prototype feet?"

## Phase 4: Share & Critique (10 min)

Two groups share their track plans. Class evaluates each:

13. Does it fit within the 6×4 foot constraint?
14. Does it include all required elements?
15. Are the scale labels correct?
16. What is one design decision that was smart, and one that could be improved?

## Phase 5: Exit Ticket (5 min)

17. A prototype water tower is 48 feet tall. How tall should the O Scale model be? \_\_\_ inches

18. An O Scale station building is 9 inches wide. How wide is the prototype? \_\_\_\_ feet

19. Your layout is 4 feet × 8 feet. What area of prototype territory does it represent? \_\_\_\_ square feet

### Assessment Rubric — Lesson 3

Criterion	4 – Exceeds	3 – Meets	2 – Approaching	1 – Beginning
<b>Scale Conversions</b>	All 6+ conversions correct; work shown; units consistent	4–5 conversions correct; minor arithmetic errors; units mostly correct	2–3 conversions correct; unit errors present	Fewer than 2 conversions correct; scale ratio not applied
<b>Track Plan — Design</b>	Plan fits constraints; all required elements present; curves drawn to minimum radius	Plan mostly correct; one element missing or one constraint not met	Significant constraint violations; several elements missing	Plan does not demonstrate understanding of space or design requirements
<b>Track Plan — Labels</b>	All features labeled in model and prototype units; calculations shown for 3+ features	Most features labeled in both units; 1–2 missing	Labels in one unit only; minimal calculation shown	Labels absent or incorrect; no conversion calculations
<b>Explanation / Justification</b>	Clearly explains 2+ design decisions using specific measurements	Explains 1 decision with specific measurements	Explains decisions verbally but without specific measurements	Cannot explain why design choices were made

## LESSON 4

# Civil Engineering

*Bridge Load Calculations — Designing for O Scale and Beyond*

<b>Duration</b>	55 minutes + optional 30-min build session
<b>Grade Band</b>	7–10 (primary)   6th grade with scaffolding
<b>NGSS Core Ideas</b>	ETS1: Engineering Design   PS2: Forces and Interactions
<b>Key Vocabulary</b>	Load, dead load, live load, compression, tension, truss, beam, arch, factor of safety, load distribution
<b>Driving Question</b>	Railroad bridges hold thousands of tons. How do engineers make sure they don't fall — and how do we build one for our layout?

## Teacher Background

Railroad bridges are among the most heavily loaded structures in the built environment. A fully loaded coal train can apply 286,000 lbs (143 tons) to a single axle. Bridge engineers design for both dead loads (weight of the bridge itself) and live loads (weight of trains passing over). They also apply a factor of safety — typically 2–4 for railroad bridges — meaning the bridge is designed to hold 2–4 times the maximum expected load before failure.

Three primary bridge types appear on model railroads and in real railroad history: the beam bridge (simple span), the truss bridge (triangulated structure), and the arch bridge. Trusses convert vertical loads into compression and tension along members; arches convert vertical loads into horizontal thrust; beams experience maximum bending stress at the center span.

**Engineering Design Loop:** This lesson directly addresses NGSS ETS1 performance expectations. Students define the problem, generate solutions, build a prototype, test it, and evaluate results — the complete engineering design cycle in one lesson.

## NGSS Alignment

Standard Code	Practice / Concept	How O Scale Activity Addresses It
MS-ETS1-1	Define the criteria and constraints of a design problem with sufficient precision	Students define: span length, minimum load capacity, material constraints (number of craft sticks), and clearance requirements
MS-ETS1-2	Evaluate competing design solutions using a systematic process	Students compare beam, truss, and arch approaches before selecting; justify selection with load analysis
MS-ETS1-3	Analyze data from tests to determine similarities and differences among design solutions	Groups test bridges from all three design types and compare failure loads, failure modes, and efficiency ratios

MS-ETS1-4	Develop a model to generate data to test ideas about designed systems	Students build scale-model bridges and load test them with calibrated weights
MS-PS2-2	Plan an investigation showing change in motion depends on net force and mass	Students calculate the distributed load of a locomotive crossing a bridge at various positions
Science Practice 1	Asking Questions / Defining Problems	Students define the engineering design problem in precise, measurable terms before beginning construction
Science Practice 8	Obtaining, Evaluating, and Communicating Information	Students present bridge design rationale and load test results to the class

## Materials

Item	Qty (per group)	Notes
Craft sticks (tongue depressors)	50 per group	Building material for model bridges
White glue or hot glue gun (teacher-operated)	1 per group	Hot glue for speed; white glue for stronger cured joints
Wax paper (work surface)	1 sheet per group	Prevents sticking to table during construction
Calibrated weights (50g increments, up to 1 kg)	1 set	For controlled load testing
Spring scale or digital kitchen scale	1	For measuring failure load
Ruler and pencil	1 each per student	For measuring and marking spans
Bridge Design Worksheet with load calculation template	1 per student	Includes calculation scaffolding
O Scale locomotive (for reference weight)	1	Students calculate its scale weight relationship
Images: Trestle, truss, and arch bridges (printed)	1 set per group	Reference for design types
Metric bathroom scale (for final load test if needed)	1	Or substitute calibrated weight stack

## Lesson Sequence

### Phase 1: Engage — Bridge Failure Analysis (8 min)

Show two images side by side: a collapsed railroad bridge and a famous surviving truss bridge. Ask:

- "What do you notice is structurally different about these two bridges?"
- "What forces caused the first one to fail? What resisted those forces in the second?"
- "What information would an engineer need BEFORE building a railroad bridge?"

Introduce the terms dead load, live load, and factor of safety. "Engineers don't just design for the exact weight they expect — they design for much more. Why is that wise?"

### Phase 2: Explore — Load Calculation (15 min)

**Calculation Scenario:** Your O Scale layout has an 18-inch gap over a modeled river gorge. Your heaviest locomotive weighs 3.5 lbs (model). The real locomotive weighs approximately 420,000 lbs. Apply a factor of safety of 3. What total load must your model bridge withstand?

Step-by-step calculation scaffold:

20. Prototype span: 18 inches  $\times$  48 = \_\_\_ inches  $\div$  12 = \_\_\_ feet
21. Weight scales as the CUBE of the ratio:  $(1/48)^3 = 1/110,592$ . If prototype = 420,000 lbs, model weight =  $420,000 \div 110,592 =$  \_\_\_ lbs. Compare to actual measured weight.
22. Live load = locomotive weight = 3.5 lbs
23. Dead load = bridge weight = 0.5 lbs (estimated; students weigh actual bridge after building)
24. Total load = live + dead = \_\_\_ lbs
25. Design load (factor of safety = 3): total load  $\times$  3 = \_\_\_ lbs
26. Convert to grams for testing: \_\_\_ lbs  $\times$  454 = \_\_\_ grams

### Phase 3: Design & Build (20 min)

Each group selects (or is assigned) one bridge type to ensure class sees all three approaches:

- Group A — Beam Bridge: Simple flat deck; quick to build but limited span-to-weight efficiency
- Group B — Truss Bridge: Triangulated framework above or below deck; strongest per unit of material
- Group C — Arch Bridge: Curved form converting load to horizontal thrust; aesthetically dramatic

Design constraints (all groups):

- Span: exactly 12 inches between supports — NO supports within the span
- Deck must be level and at least 1.5 inches wide (for O Scale track)
- Maximum 50 craft sticks total
- Minimum 2-inch clearance beneath the deck (for waterway)

Students sketch their design before building, labeling which members will be in COMPRESSION (being squeezed) and which will be in TENSION (being pulled). Build and allow at least 10 minutes to cure before load testing.

### Phase 4: Load Testing & Comparative Analysis (10 min)

27. Place bridge on supports exactly 12 inches apart.
28. Place O Scale locomotive on bridge at center span (point of maximum bending stress).
29. Add calibrated weights in 50g increments to the center of the deck.
30. Record load at first cracking, and load at failure.
31. Record failure mode: Where did it fail? Compression member? Tension member? Joint? Deck?

Group / Type	Dead Load (g)	Live Load (g)	Failure Load (g)	Efficiency Ratio*	Failure Mode
A — Beam					
B — Truss					
C — Arch					

\*Efficiency Ratio = Failure Load ÷ Bridge Weight. A higher ratio means a stronger bridge per unit of material used.

Class discussion: Which bridge type had the highest efficiency ratio? Which failed most gradually (allowing warning) vs. suddenly? Which would you choose for a permanent layout installation, and why?

### Phase 5: Engineering Test Report (homework or extended session)

Students write a one-page Engineering Test Report including:

32. Problem statement and design criteria (span, load, material constraint, clearance)
33. Bridge type chosen and rationale — why this type for this span?
34. Load calculations from Phase 2 (with all work shown)
35. Test results compared to design load — did the bridge meet the factor of safety requirement?
36. Failure analysis: what failed, where, why, and what you would change in version 2
37. Connection to prototype engineering: name one real railroad bridge, identify its type, and explain why that type was chosen

### Assessment Rubric — Lesson 4

Criterion	4 – Exceeds	3 – Meets	2 – Approaching	1 – Beginning
Load Calculations	All 7 steps correct; units consistent; factor of safety correctly applied; work	5–6 steps correct; minor arithmetic errors; factor of safety understood	3–4 steps correct; factor of safety confused or omitted	Fewer than 3 steps correct; load calculation concept not demonstrated

	clearly shown			
<b>Design Sketch</b>	Complete bridge sketch with dimensions; compression/tension labeled; all constraints met	Mostly complete; compression/tension labeling has 1–2 errors	Present but missing labels or dimension information	No pre-construction sketch produced
<b>Build Quality</b>	Meets all 4 design constraints; joints are clean; deck is level and at correct width	Meets 3 of 4 constraints; minor quality issues	Meets 2 constraints; significant quality issues affect testing	Does not meet span or deck requirements; cannot be tested as designed
<b>Test Report</b>	All 6 sections complete; failure analysis correctly identifies member type using compression/tension vocabulary; real bridge example is accurate	4–5 sections complete; failure analysis mostly correct	2–3 sections; failure analysis is descriptive but lacks engineering vocabulary	Report largely incomplete; test results not connected to engineering concepts

## Differentiation — All Lessons

For Students Needing Support	For On-Level Students	For Advanced Students
Provide pre-filled data tables with one column complete as a model; offer sentence starters for written responses	Follow the standard lesson sequence; complete worksheets independently before comparing with group	Complete extension challenges; research prototype data; calculate and present findings to class
Use manipulatives throughout; pair with stronger peer during calculations; allow oral responses	Work in collaborative groups with rotating roles: recorder, builder, presenter, quality checker	Design improved experiment procedures; propose additional variables; connect findings to engineering careers

## Series Capstone Project (Optional, Weeks 9–12)

**Capstone — "The Pocono Pass Railroad":** Design and build a fully operational O Scale switching layout on a 4×3 foot baseboard that includes: (1) a two-block wired oval with independent control (Lesson 1); (2) one grade section of at least 2% with a working train (Lesson 2); (3) a complete,

dimensioned track plan drawn to 1:48 scale (Lesson 3); and (4) one scratch-built or kit-built bridge spanning at least 8 inches, with load calculations on file (Lesson 4). The layout must operate reliably for a 5-minute public demonstration.

Capstone is assessed with a portfolio including all four lesson worksheets, the final track plan drawing, load calculations, and a 3-minute presentation where students explain one STEM concept to a younger student or parent visitor.

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### **O Scale STEM Lesson Plan Series**

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