O SCALE MODEL RAILROADING

APPLIED STEM CURRICULUM

Four College-Level Lesson Plans

Adapted for Community College Programs in Engineering Technology, Skilled Trades, Architecture & Physics

Series Title: Tracks to Tomorrow: Applied STEM Through O Scale Railroading

Level: Community College — Introductory to Intermediate (100–200 level courses)

Target Programs: Engineering Technology · Electrical/Electronic Technology · Architecture · Physics Survey · Skilled Trades

Total Lessons: 4 lessons · Approx. 75 minutes each (1.25-hour community college class period)

Equipment Scale: O Scale (1:48 ratio) — recommended for technical lab settings

Source / Contact: TrainWay STEM Education Initiative | allnationline.com

Series Introduction

Why O Scale for Community College?

Community college students in technical programs benefit from lab work that bridges theory and professional practice. O Scale (1:48) model railroading provides an unusually rich hands-on platform: circuits operate at accessible voltages, mechanical forces are directly measurable, scale conversions involve real unit analysis, and structural loading can be tested to failure safely in a single class period.

Unlike simulations, the hardware here is real — a locomotive stalls when tractive effort is exceeded, a bridge actually breaks at a calculable load, and wiring errors produce measurable consequences. This directness supports the applied learning philosophy central to community college technical programs.

The 1:48 ratio also makes O Scale mathematically transparent: 1 inch = exactly 4 prototype feet. Students can perform all scale conversions mentally, which keeps cognitive load on the engineering concepts rather than on arithmetic.

Alignment to Technical Programs

Lesson	Core Concept	Primary Program Fit	Transferable Skills
1 — Electrical Systems	Circuit theory, Ohm's Law, block control, DCC	Electrical/Electronic Technology · Instrumentation	Wiring, multimeter use, circuit troubleshooting, technical drawing
2 — Applied Mechanics	Newton's laws, momentum, rolling resistance, grade forces	Engineering Technology · Skilled Trades · Physics	Force analysis, data collection, technical report writing
3 — Technical Drawing & Scale	Scale ratios, unit conversion, 2D drafting, constraints	Architecture · CAD/Drafting · Engineering Graphics	Scale drawing, spatial reasoning, design constraints
4 — Structural Engineering	Load analysis, factor of safety, bridge types, failure modes	Civil/Construction Technology · Structural Mechanics	Load calculations, engineering design loop, test reports

How to Use This Series

Each lesson is self-contained and can be integrated into an existing course or taught as a four-session arc. The progression mirrors the professional workflow of civil and transportation infrastructure: power systems → mechanics → spatial planning → structural design.

Recommended deployment options:

- Single-course integration: use individual lessons as lab activities within a physics, circuits, or drafting course.
- Two-week intensive module: run all four lessons as a consecutive block within a first-year engineering technology survey course.
- Semester elective: pair each lesson with a related lecture module and conclude with the Capstone project (see final section).

- Makerspace workshop series: four standalone 75-minute evening or weekend workshops, open enrollment, no prerequisites beyond basic algebra.

Prerequisites assumed at the community college level:

- Lessons 1 & 2: Completion of a high school algebra course; basic familiarity with SI and Imperial units.
- Lesson 3: Ability to read and draw to scale; comfort with ratios and proportions.
- Lesson 4: Basic understanding of forces and vectors (concurrent with or following introductory physics).

LESSON 1

Electrical Systems — Wiring an O Scale Layout

Duration: 75 minutes (can be split into two 40-minute sessions)

NGSS Core Ideas: PS3: Energy | PS2: Motion and Stability | ETS1: Engineering Design

Program Alignment: Electrical/Electronic Technology · Instrumentation Technology · Engineering Technology · Physics Survey

Key Vocabulary: Kirchhoff's Voltage Law (KVL), Kirchhoff's Current Law (KCL), series circuit, parallel circuit, voltage drop, conductor resistance, insulated block, DCC decoder, PWM signal

Driving Question: A real commuter rail system runs dozens of trains on the same track simultaneously without collisions. How does the electrical system make that possible — and how do we model it in the lab?

Instructor Background

O Scale layouts use a straightforward two-rail DC electrical system that maps directly to circuit theory topics covered in EET 101 and similar introductory courses. The power pack outputs regulated DC voltage (0–18V), the two rails serve as bus conductors, and the locomotive's motor completes the circuit. At the community college level, students should recognize this as a practical application of Ohm's Law, Kirchhoff's laws, and series/parallel circuit topology.

Block wiring — dividing the layout into electrically isolated sections controlled by independent switches — introduces students to the concept of circuit segmentation and fault isolation, which are directly applicable in industrial control panels and building electrical systems. The extension into DCC (Digital Command Control, per Standard S-9.1) introduces PWM encoding and digital addressing — concepts that bridge directly to microcontroller and automation coursework.

Instructor note on voltage drop: at typical O Scale wire runs of 6–10 feet of 22 AWG wire, students can measure a meaningful voltage drop at the far end of the layout. This provides a real-world application of the conductor resistance calculation $V = I \times R$, where $R = (\text{resistivity} \times \text{length}) / \text{cross-section area}$.

NGSS Alignment

Standard	Practice / Concept	How O Scale Activity Addresses It	Program Link
HS-PS3-3	Design and evaluate a device to transfer electrical energy	Students design a two-block wiring schematic that transfers energy selectively to each locomotive	EET: Circuit design & documentation

HS-PS2-5	Plan and conduct an investigation on electric/magnetic forces	Students measure voltage and current at multiple points; test block isolation under load	Physics: lab investigation protocols
HS-ETS1-2	Design a solution to a complex real-world problem	Students must wire for independent train control within current/voltage constraints of the power supply	ET: Constraint-based design
Science Practice 5	Using Math & Computational Thinking	Students calculate expected current draw, voltage drop, and power dissipation; compare to measured values	All programs: quantitative analysis

Materials

Item	Qty (per group)	Cost Est.	Notes
O Scale oval track set (min. 12 sections)	1 set	~$45 (reusable)	Lionel FasTrack or Atlas O recommended
O Scale power pack (0–18V DC)	1	~$35 (reusable)	Lionel PowerMaster or equivalent; verify UL listing
O Scale locomotive (diesel starter)	1	Provided	Weigh and record resistance of motor coils if multimeter available
22 AWG hookup wire, red/black	8 ft each	$1	Pre-cut 6-inch segments; label ends
Insulated rail joiners	8	$3	Creates electrical blocks for isolation testing
Digital multimeter	1 per group	Provided	Measure V, I (with clamp adapter), and R
SPDT toggle switches	4	$4	For block control panels; label clearly
Breadboard + LED + resistor kit	1 per group	$3	For preliminary Ohm's Law verification before track work
DCC decoder (for demonstration)	1	Provided	Digitrax or NCE; instructor demo only
Circuit Schematic Worksheet	1 per student	Print	Includes KVL/KCL calculation template
Oscilloscope or phone-based scope app	1 per group	App: free	To visualize DCC PWM signal on rails (extension activity)

Lesson Sequence

Phase 1: Connect to Prior Knowledge (10 min)

Open by posing the driving question. Prompt brief discussion: "When SEPTA or Metro runs multiple trains, each train receives its own power and control signal. How is that possible if they're all on the same track?" Let students hypothesize before introducing the O Scale layout as the working model.

Quick review drill (call-and-response): What is Ohm's Law? What is the unit of resistance? What happens to current if resistance doubles at constant voltage? This activates prerequisite knowledge without a lengthy lecture.

Introduce the lab safety protocol: O Scale power packs output 14–18V DC at low amperage. Students should never bridge both rails simultaneously while power is applied; always verify power is OFF before modifying wiring connections.

Phase 2: Circuit Modeling on Breadboard (15 min)

Before touching the track, students build the equivalent circuit on a breadboard: a 12V supply, a 10Ω resistor (representing the motor), and an LED in series (representing the motor operating indicator). They measure voltage across each component and verify KVL: V_supply = V_resistor + V_LED.

Students record expected vs. measured values and calculate percent error. This step grounds track work in verifiable circuit theory before the physical complexity of the layout is introduced.

Calculation task: If the power pack outputs 14V and the motor's DC resistance is 12Ω, what is the theoretical current draw? What is the power dissipated by the motor? ($P = I^2R$) At what wattage would continuous operation begin to heat the motor noticeably?

Phase 3: Layout Wiring and Block Configuration (25 min)

Groups assemble an O Scale oval and connect to the power pack. Before applying power, each group draws a complete schematic on their worksheet with the following elements labeled: power supply, terminal block, feeder wires, rail 1, rail 2, motor (as resistor symbol), return path, and wire gauge annotation.

Step-by-step wiring sequence:

1. Run locomotive on complete oval. Measure voltage at the power pack terminals and at a far rail feeder. Record the voltage drop and calculate the resistance of the wire run.
2. Insert insulated rail joiners to create two electrical blocks. Verify the locomotive stops at the break. Use the multimeter to confirm the isolated block reads 0V while the powered block reads 14V.
3. Wire each block to its own SPDT toggle switch. Operate both trains independently, starting and stopping each in its own block.
4. Extension: measure current draw with locomotive stalled at the block boundary. Compare to rated power pack output. Discuss overcurrent protection (fuses, circuit breakers) in real railroad systems.

Phase 4: DCC Introduction (10 min)

Instructor demonstration only (or guided observation with oscilloscope): install a DCC decoder in the locomotive and connect a DCC controller. Students observe that the locomotive now responds to address commands — two locomotives can operate on the same powered track segment simultaneously, each responding only to its own address.

Connect an oscilloscope (or phone app) across the rails. Students sketch the waveform: a square-wave PWM signal at approximately 8–22V, 4–8kHz. Explain: the DCC signal is a digital data stream superimposed on the power carrier. Decoders read the packet addressed to them; all others ignore it. This is the same principle as a CAN bus in an automobile or MODBUS in an industrial network.

Phase 5: Analysis and Exit Assessment (15 min)

Students complete the following on their worksheets:

5. Draw and fully label the schematic for your two-block layout, using standard electronic symbols (ANSI Y32.2 or IEC 60617 if available in the lab).
6. Calculate the total circuit resistance for your layout (wire resistance + motor resistance). Show all work and units.
7. A second locomotive is added to Block 2. How does total current drawn from the power pack change? Under what condition could two locomotives cause the power pack's thermal cutout to trip?
8. Explain in two sentences why DCC eliminates the need for electrical block segmentation for train control (though blocks are still used for other purposes such as detection and routing).

Assessment Rubric

Criterion	4 – Exceeds	3 – Meets	2 – Approaching	1 – Beginning
Schematic Accuracy	Complete, correct, uses standard symbols; all nodes labeled; KVL confirmed	Mostly correct; 1–2 labeling errors; current path verified	Incomplete; missing components or direction errors	Schematic does not form a closed loop or uses no symbols
KVL / KCL Calculations	All calculations correct with units; percent error < 5%; sources of error identified	1–2 arithmetic errors; units correct; percent error noted	Setup is correct but arithmetic errors cascade; units inconsistent	Cannot apply V = IR or KVL without direct instruction
Block Wiring Demonstration	Independently wires, tests, and explains two-block isolation; identifies fault conditions	Block wiring functional with minor prompting; explains concept	Block wiring attempted but requires significant assistance	Cannot explain purpose of insulated rail joiner
DCC Reflection	Accurately explains digital addressing; connects to industrial network analogy; identifies one real-world application	Explains basic operation; makes partial connection to prior knowledge	Description is mostly accurate but lacks technical vocabulary	Cannot distinguish analog block control from digital DCC
Lab Safety	Proactively identifies and mitigates all electrical safety risks; reminds peers	Follows all safety protocols correctly	Aware of safety rules but occasionally skips verification steps	Does not follow disconnect-before-modify protocol

Differentiation

- Students needing support: Provide pre-drawn schematic with blanks for labels and values. Allow oral circuit explanation in lieu of written schematic. Pair with a lab partner who has electrical background.
- On-level: Follow the standard sequence. Complete all calculations on the worksheet before comparing with lab group.
- Advanced: Calculate voltage drop for a 25-foot layout run using the AIEE/NEC conductor resistance tables. Design a power district scheme for a hypothetical layout with six blocks and calculate the minimum power pack amperage rating required. Research DCC Standard S-9.1 and explain the DCC packet structure.

LESSON 2

Applied Mechanics — Momentum, Friction & Grade Forces

Duration: 75 minutes

NGSS Core Ideas: PS2: Motion and Stability — Forces and Interactions

Program Alignment: Engineering Technology · Physics Survey · Skilled Trades (Rigging & Heavy Equipment) · Transportation Technology

Key Vocabulary: Tractive effort, rolling resistance, grade resistance, coefficient of friction, momentum ($p = mv$), impulse, braking distance, consist (multiple locomotive lash-up)

Driving Question: A loaded unit coal train weighing 15,000 tons needs 1.2 miles to stop from 50 mph. How do railroad engineers calculate braking distance — and how can we verify the physics on a 4-foot layout?

Instructor Background

O Scale equipment provides a measurable, controllable analog for real railroad physics. The 1:48 scale relationship means dimensional quantities (distance, height, radius) scale linearly, while force and mass scale as the cube of the ratio — a critical distinction that this lesson addresses explicitly.

At the community college level, students should move beyond qualitative Newton's Law descriptions toward quantitative force analysis. The key equations for this lesson are:

- Grade resistance (lbs): $F_{grade} = W \times (\text{grade\%} / 100)$, where W is total train weight in lbs
- Rolling resistance (lbs): $F_{rolling} = W \times$ (resistance coefficient, typically 0.002–0.005 for steel-on-steel)
- Required tractive effort: $TE_{required} > F_{grade} + F_{rolling}$
- Momentum: $p = mv$; Impulse–Momentum Theorem: $F \times \Delta t = \Delta(mv)$ → braking distance derivation

Students should also grapple with the scaling issue: the model locomotive's mass does not scale with the 1:48 dimensional ratio. Real locomotives weigh ~420,000 lbs; a mass-accurate O Scale model would weigh $420{,}000 / (48^3) = 3.79$ lbs. Comparing this to the actual model weight teaches students to think critically about the limits of physical scale models — a core engineering metrology concept.

NGSS Alignment

Standard	Practice / Concept	How O Scale Activity Addresses It	Program Link

HS-PS2-1	Analyze data to support Newton's Second Law	Students measure acceleration across different grades and car counts; plot F vs. a	Engineering Technology: force analysis
HS-PS2-2	Use mathematical representations for Newton's Laws	Students calculate TE_required for each experimental condition; compare to observed stall point	Physics: quantitative mechanics
HS-PS2-3	Apply Newton's Third Law to design solutions	Students explain why grade resistance is a reaction to gravity; design optimal grade transitions	ET: systems thinking
Science Practice 4	Analyzing and Interpreting Data	Students produce force-vs-grade graphs; identify linear relationship and outliers	All: data literacy
Science Practice 6	Constructing Explanations	Engineering lab report applying Newton's Laws to experimental observations with numerical support	All: technical writing

Materials

Item	Qty (per group)	Cost Est.	Notes
O Scale oval with adjustable grade sections	1 set	Provided	Use foam blocks to create precise 1%, 2%, 3%, 4% grades; verify with digital level
O Scale locomotive (known weight)	1	Provided	Weigh to 0.1g before class; record DC motor resistance
O Scale freight cars loaded with calibrated weights	8	$2	Use split-shot fishing weights or steel washers; each car identical weight
Digital postal scale (0–2 kg, 1g resolution)	1	Provided	Weigh each car + load; record on data sheet
Digital level / smartphone inclinometer	1	App: free	Verify grade at each foam block height
Tape measure and masking tape	1 each	$1	Mark start/stop positions; measure coasting distances
Stopwatch or smartphone timer	1	App: free	Time runs over known distances to calculate velocity
Graph paper or graphing calculator / Desmos	1	Free	Students plot grade vs. max cars pulled
Lab Report Worksheet	1 per student	Print	Includes data tables and calculation scaffolding
Force diagram templates (blank FBD sheets)	1 per student	Print	Students draw Free Body Diagrams for each condition

Lesson Sequence

Phase 1: Scaling the Problem (10 min)

Present the driving question. Ask students to estimate: on a 2% grade, how much of a 15,000-ton train's weight acts as a resistive force along the track? (Answer: 15,000 × 0.02 = 300 tons = 600,000 lbs.) Compare to a typical locomotive's tractive effort of ~90,000 lbs — one locomotive cannot do this alone.

Introduce the scale discussion: our model locomotive weighs approximately 1.5 lbs. The prototype it represents weighs ~210,000 lbs. The dimensional scale is 1:48 but the mass scale is 1:140,000. What does this mean for our experiments? Students should recognize that absolute force values will not scale — but ratios (grade resistance as a percentage of weight, rolling resistance coefficient) will still be valid.

Phase 2: Free Body Diagram Analysis (10 min)

Before running any trains, students draw a Free Body Diagram of a locomotive on a grade. They must label: weight (W, vertical), normal force (N, perpendicular to grade surface), grade resistance component ($W \times \sin \theta$, along-track opposing), rolling resistance (μN, along-track opposing), and tractive effort (along-track propulsive). Students verify: $TE > W \sin \theta + \mu N$ is the condition for motion.

Calculation checkpoint: For a 2% grade ($\theta \approx 1.15°$), $\sin \theta \approx 0.020$. If your locomotive + consist weighs 800g = 0.8 kg, what is the gravity component opposing motion? ($F = 0.8 \times 9.8 \times 0.020 = 0.157$ N.) What rolling resistance force would you add if $\mu = 0.003$? ($F_r = 0.003 \times 0.8 \times 9.8 = 0.024$ N.) Minimum TE required = 0.181 N.

Phase 3: Experiment A — Grade vs. Stall (20 min)

Set up track at each grade. Run locomotive pulling 0, 2, 4, 6, and 8 cars. Record maximum cars pulled without stalling. Repeat at each grade level.

Grade (%)	Cars Pulled	Total Consist Weight (g)	Theoretical TE Required (N)	Stall Observed?	Notes
1%					
2%					
3%					
4%					

After data collection, students plot grade (x-axis) vs. maximum cars pulled (y-axis). They should observe an approximately linear decrease. Students calculate the slope and interpret it: how many cars of capacity are lost per 1% increase in grade?

Phase 4: Experiment B — Momentum and Braking Distance (15 min)

On level track, accelerate locomotive + 4 cars to full throttle over a fixed acceleration distance. Mark the power-cut position with masking tape. Measure coasting distance to full stop. Repeat with 8 cars at the same throttle setting and initial speed (verified by timing).

Students calculate momentum for both consists ($p = mv$), using timed velocity estimation. They verify: the heavier consist has greater momentum and therefore longer braking distance. They use the Impulse-Momentum Theorem to estimate the average friction braking force: $F_{brake} = \Delta p / \Delta t$.

Scale-up calculation: If your 4-car consist takes 0.9 meters to stop at model scale, what does this represent in prototype feet? (0.9 m × 48 = 43.2 m = 141.7 ft.) How does this compare to published AAR braking distance standards for loaded freight cars? (Typically 1,500–4,000 ft at speed — discuss the role of speed, which was not proportionally represented in the model.)

Phase 5: Engineering Analysis Report (20 min in-class start, complete as homework)

Students write a one-page Engineering Analysis Report following this structure:

9. Problem Statement: Restate the driving question in precise engineering terms.
10. Free Body Diagram: Include the labeled FBD from Phase 2.
11. Data and Calculations: Present the grade-vs-stall data table and momentum calculations with all work shown.
12. Graph and Interpretation: Include the grade vs. cars plot with trend line equation and interpretation.
13. Scale Analysis: Identify one way the model accurately represents prototype behavior, and one way it does not — explain why.
14. Real-World Connection: Name one specific mountain railroad route (e.g., the Moffat Tunnel route, the Raton Pass), identify its ruling grade, and explain how railroad engineers managed the grade limitation.

Assessment Rubric

Criterion	4 – Exceeds	3 – Meets	2 – Approaching	1 – Beginning
Free Body Diagram	All forces correctly drawn, labeled with equations and units; sign conventions consistent	All major forces present; 1–2 label errors; sign conventions mostly correct	FBD present but missing grade or friction component	FBD absent or shows only weight and normal force on level surface
Data Collection & Graph	Complete data with units; graph has labeled axes, plotted points, trend line, and equation	Data mostly complete; graph correct but missing trend line or axis labels	Significant data gaps; graph lacks labels or is plotted incorrectly	Data table largely incomplete; no graph produced
TE Calculations	Correct for all conditions; units consistent; theoretical and observed values compared with % error	2–3 conditions correct; percent error calculated	Sets up formula correctly but errors in execution; units inconsistent	Cannot calculate grade resistance force without direct instruction
Momentum Analysis	Correctly calculates p for both consists; derives F_brake from impulse-momentum; scale-up completed	Momentum calculated; impulse-momentum applied with minor errors	Momentum calculated but impulse-momentum theorem not applied	Cannot connect braking distance to momentum concept

Engineering Report	All 6 sections complete; writing is precise; scale limitations clearly articulated; real route accurately cited	4–5 sections complete; analysis is mostly accurate	2–3 sections; analysis present but lacking quantitative support	Report largely incomplete; no connection between data and Newton's Laws

Differentiation

- Students needing support: Provide labeled FBD template; pre-calculate consist weights; allow collaborative data analysis.
- On-level: Standard sequence; complete report independently.
- Advanced: Derive the theoretical braking distance formula from F = ma and kinematics equations. Calculate the kinetic energy of the prototype freight train at 50 mph and compare to the energy absorbed by retarder brakes. Research dynamic braking (regenerative braking on diesel-electrics) and explain how it alters the momentum analysis.

LESSON 3

Technical Drawing & Scale — Track Planning to Drafting Standards

Duration: 75 minutes + optional CAD extension session

NGSS/Standards Alignment: ETS1: Engineering Design · CCSS-Math 7.G.A.1, 7.RP.A.2, 8.G.B.7 · ASME Y14.5 (GD&T context)

Program Alignment: Architectural Technology · CAD/Drafting Technology · Engineering Graphics · Construction Technology

Key Vocabulary: Scale ratio, prototype, right-of-way, tangent track, easement curve, superelevation, clearance envelope, radius of curvature, survey baseline, bearing

Driving Question: A railroad right-of-way through a mountain pass was surveyed, designed, and approved before a single spike was driven. How do engineers translate a real landscape into a precise 2D plan — and back again?

Instructor Background

O Scale's 1:48 ratio is mathematically ideal for drafting instruction: 1 inch on paper equals exactly 4 prototype feet, so no conversion lookup tables are needed. This makes it feasible to work fluidly between model and prototype dimensions within a single class period.

At the community college level, this lesson introduces students to the disciplinary conventions of engineering drawing, connecting mathematical scale concepts to professional drafting practice. Students who are taking or have taken an engineering graphics course will recognize the sheet border, title block, and annotation conventions introduced here.

The lesson also introduces a concept rarely covered in introductory drafting: the clearance envelope. Every structure (bridge, tunnel, signal, station platform) must not encroach on the clearance envelope around a moving train. This is a direct analog to the concept of tolerance zones in geometric dimensioning and tolerancing (GD&T).

NGSS / Standards Alignment

Standard	Practice / Concept	How O Scale Activity Addresses It	Program Link
ETS1-1	Define design problem with precise constraints	Students define space, curve radius, clearance, and operational constraints before drawing	Drafting: constraint-driven design
ETS1-2	Evaluate competing design	Students compare two	Architecture:

	solutions	alternative track plans against measurable criteria; select and justify	design development process
7.G.A.1 (CCSS)	Solve problems with scale drawings	All layout dimensions converted between model and prototype in both directions	Drafting: scale reading/annotation
8.G.B.7 (CCSS)	Apply Pythagorean Theorem	Students calculate diagonal clearances and determine whether equipment clears corners	Engineering Graphics: geometric construction
ASME Y14.5 context	Tolerance and fit concepts	Clearance envelope as analog to tolerance zone; nominal vs. actual dimension discussion	CAD/Drafting: GD&T introduction

Materials

Item	Qty (per group)	Cost Est.	Notes
1:48 scale grid paper (¼" grid = 1 prototype foot)	2 per student	Print	Can be substituted with 1/4" graph paper and a note on the scale bar
O Scale track sections (assorted: straight, O36/O54 curves, #5 turnout)	Assorted	Provided	For hands-on measurement before drawing
Architects' scale ruler (triangular)	1 per student	$4	Covers 1:48 and adjacent scales for discussion
Protractor and compass	1 each per student	$2	For measuring and drawing curve radii and angles
Technical pencil (0.5mm) and erasers	1 set per student	$1	Encourage single-line weight first draft
O Scale equipment dimension card	1 per group	Print	Locomotive and car lengths, heights, truck centers
Drafting template sheet (standard title block)	1 per student	Print	Students complete title block: name, date, scale, revision
Rulers and tape measures (metric + imperial)	1 each	Provided	Both units; cross-conversion practice
CAD software access (optional: TurboCAD, AutoCAD LT, Fusion 360)	1 per student	Campus license	For extension activity; not required for core lesson

Lesson Sequence

Phase 1: Prototype Research Exercise (10 min)

Distribute the O Scale dimension card. Open with the driving question and show an aerial photograph of a real rail yard from Google Maps (projected). Ask: "How did the survey crew translate this landscape into the plan on which the engineer based the design?"

Rapid conversion drill — students calculate, then check with a partner:

- A locomotive is 70 feet long on the prototype. How long is the O Scale model? (70 ÷ 4 = 17.5 inches)
- An O36 curve has a 18-inch model radius. What is the prototype curve radius in feet? (18 × 4 = 72 feet) Is this realistic for a mainline railroad? (No — mainline curves are typically 1,500–3,000 ft radius; short-radius curves appear only in yards and industrial spurs.)
- A standard passenger car is 85 feet long. What is the minimum O Scale curve radius it can navigate without mechanical interference? (Consult equipment card — typically O72 = 36 inches model = 144 prototype feet, far below real mainline standards.)

Emphasize: model railroading compresses prototype space dramatically for practical reasons. A 1:1 representation of a one-mile stretch of mainline at O Scale would require a 110-foot room.

Phase 2: Field Measurement of Track Sections (15 min)

Students measure physical O Scale track sections and complete the conversion table:

Track Component	Model Measurement	Prototype Equivalent	Calculation / Notes
Straight section length	___ in	___ ft	Multiply by 4
O36 curve radius	18 in	72 ft	18 × 4 = 72
O54 curve radius	27 in	108 ft	27 × 4 = 108
Rail gauge (between rails)	1.25 in	5 ft 0 in	Standard gauge = 4'8.5" — model is slightly simplified
Rail height (code 148 or 125)	___ in	___ in prototype	Note: rail height is typically not exact-scale; discuss prototype RE-section sizes
Tie spacing	___ in	___ in prototype	Compare to AAR standard of 19.5" typical spacing
#5 Turnout total length	___ in	___ ft	From points to frog
Frog angle on #5 turnout	___ degrees	Same (angle is dimensionless)	Tan(angle) = 1/N where N = turnout number

Discussion: "The rail gauge is 1.25 inches, which scales to exactly 5 feet — not the actual 4 feet 8.5 inches. Why do you think manufacturers rounded this? What would the consequences be of manufacturing a track system to exact-scale gauge?" (Answer: 4.875-inch model gauge would create tooling complexity with no operational benefit at this scale. Discuss the concept of functional tolerance in manufacturing.)

Phase 3: Design Challenge — Industrial Track Plan (25 min)

Scenario: You have been commissioned as the track geometry engineer for the Pocono Pass Mining Terminal. Your assignment: produce a dimensioned track plan on 1:48 scale grid paper, complete with a standard title block, for a 6 × 4 foot switching layout that must include:

15. A mainline loop of at least 12 sections with a minimum curve radius of O36.
16. A 3-car freight classification siding with a passing clearance of at least 6 inches between parallel track centers (prototype: 24 feet).
17. A locomotive runaround track enabling the engine to reach either end of a spotted car cut.

18. A clearance envelope annotation: show the 3.5-inch-wide (model) dynamic clearance rectangle around all curves, and confirm no structure conflicts.
19. A title block on the drawing: project name, drafter name, date, scale (1:48 / 1 in = 4 ft), revision number, sheet number.

Students annotate all major elements with both model measurements (inches) and prototype equivalents (feet). The finished plan should be readable as a professional engineering drawing, not a sketch.

Phase 4: Peer Review and Design Critique (15 min)

Exchange plans with another group. Reviewers complete a structured checklist:

20. Does the plan fit within the 6 × 4 foot constraint? Circle any element that appears to violate this.
21. Are all required functional elements present? Check each against the design brief.
22. Are the scale annotations correct? Spot-check three dimensions by measuring with the architects' scale ruler.
23. Is the title block complete and correctly formatted?
24. What is one design decision that demonstrates sound engineering judgment?
25. What is one revision you would recommend and why?

Return plans with written review comments. Students review feedback and note one revision they would make in Version 2 of the plan.

Assessment Rubric

Criterion	4 – Exceeds	3 – Meets	2 – Approaching	1 – Beginning
Scale Conversions	All 8 conversion table entries correct; work shown; units consistent; percent error < 2%	6–7 correct; minor arithmetic; units mostly correct	4–5 correct; unit errors present; inconsistent method	Fewer than 4 correct; scale ratio not consistently applied
Track Plan — Constraints	Meets all 5 constraints; minimum radius verified geometrically; siding length calculated, not estimated	Meets 4 of 5; one minor constraint violation	Meets 3 of 5; clearance envelope missing or incorrect	Plan does not demonstrate understanding of spatial or design constraints
Track Plan — Annotation	All features labeled in model and prototype units; calculations shown for 5+ features; title block complete	Most features labeled in both units; title block mostly complete	Labels in one unit only; title block incomplete	Labels absent, incorrect, or no unit analysis shown
Clearance Envelope	Correctly calculated and drawn for all	Envelope drawn correctly; 1 explanation error	Envelope present but incorrectly sized or	Clearance concept not demonstrated

	curves; no structural conflicts; dynamic envelope concept explained		positioned	
Peer Review Quality	Written review is specific, measurement-based, actionable; identifies both a strength and a precise improvement	Review identifies issues with some measurement support	Review is qualitative only; no measurement verification	Review is absent or purely subjective

CAD Extension Activity

For students with access to CAD software: redraw the hand-drafted track plan in AutoCAD, TurboCAD, or Fusion 360. Set the drawing units to inches at 1:1 scale (model inches) and apply a 1:48 viewport scale. Annotate with both model and prototype dimensions using the dimstyle feature. Export as DWG and present to the class with a 2-minute explanation of one CAD technique used.

Assessment addition: students who complete the CAD extension demonstrate competency in setting drawing units, applying viewport scale, using dimension styles, and exporting to standard format — which maps directly to competencies in ARC 110, CAD 101, and similar program courses.

LESSON 4

Structural Engineering — Bridge Load Analysis and Design

Duration: 75 minutes (lab period) + recommended 30-minute out-of-class write-up

NGSS Core Ideas: ETS1: Engineering Design | PS2: Forces and Interactions

Program Alignment: Civil/Construction Technology · Architectural Technology · Structural Mechanics · Engineering Technology Survey

Key Vocabulary: Dead load, live load, impact load, factor of safety (FOS), shear force, bending moment, neutral axis, compression member, tension member, efficiency ratio, failure mode, Euler buckling

Driving Question: The 1877 Kinzua Viaduct (in McKean County, PA, not far from here) collapsed in a 2003 tornado. Forensic engineers determined the original design factor of safety was insufficient for extreme wind load. How do structural engineers quantify safety — and how do we test it in the lab?

Instructor Background

This lesson applies the complete NGSS Engineering Design loop within a single lab period: define the problem, generate and evaluate solutions, build a prototype, test, and iterate. The bridge-building and load-testing format is common in introductory civil and construction technology courses and should be positioned explicitly as a professional skill — engineering test reports follow the same format students will use in internships and entry-level positions.

Community college students should be capable of working with the following concepts at quantitative depth:

- Statics: sum of vertical forces = 0 at supports; reaction forces at each abutment
- Bending moment: $M_{max} = P \times L / 4$ at midspan for a simply supported beam with central point load
- Factor of Safety: FOS = failure load / design load; for railroad bridges, AREMA specifies FOS of 3–4
- Weight scaling: force scales as the cube of the linear scale ratio: $F_{model} / F_{prototype} = (1/48)^3 = 1/110{,}592$
- Efficiency ratio: failure load / bridge self-weight — a measure of structural efficiency independent of absolute size

The Kinzua Viaduct reference is geographically relevant (McKean County, PA) and pedagogically rich: it illustrates the difference between static design loads and dynamic/wind loads, and introduces the concept of load cases in structural engineering.

NGSS Alignment

Standard	Practice / Concept	How O Scale Activity Addresses It	Program Link
MS-ETS1-1	Define design problem with sufficient precision	Students produce a written design brief: span, load, material limit, clearance, FOS — before construction	CT: project specifications
MS-ETS1-2	Evaluate competing design solutions	Three bridge types tested; students compare efficiency ratios and failure modes	Structural: comparative analysis
MS-ETS1-3	Analyze test data for similarities and differences	Class data compiled in shared table; students identify which type achieves best FOS and why	Engineering: data synthesis
MS-ETS1-4	Build and test a designed system	Physical construction and calibrated load testing — not simulation	All: lab competency
HS-PS2-1	Apply Newton's 2nd Law with force and mass	Students calculate reaction forces, bending moments, and compare to failure observations	Physics/ET: force analysis

Materials

Item	Qty (per group)	Cost Est.	Notes
Craft sticks (tongue depressors), 150mm	50 per group	$1	Building material; record actual weight before construction
Hot glue gun (teacher-operated) or white glue	1 per group	Provided	Hot glue for 75-min period; white glue for stronger cure if multi-day
Wax paper (work surface)	1 sheet per group	$0.10	Prevents bonding to table during construction
Calibrated weights (50g increments, up to 2 kg)	1 set	Provided	For controlled load testing; record each increment
Digital kitchen scale (0.1g resolution)	1	Provided	Weigh bridge before and after construction for dead load
2 sawhorses or stacked books as abutments	2	Provided	Set exactly 12 inches apart; verify with ruler before each test
Ruler, pencil, carpenter's square	1 set per group	Provided	For marking and verifying 90° joints
Bridge Design Brief Worksheet	1 per student	Print	Includes statics calculation scaffolding and test data table
FBD and Bending Moment Diagram template	1 per student	Print	Pre-drawn beam; students annotate forces and moments
Images: Kinzua Viaduct, Kinzua collapse, AREMA bridge	1 set (projected)	Print/project	For Phase 1 engagement

standards excerpt			

Lesson Sequence

Phase 1: Forensic Failure Analysis (10 min)

Show the before and after images of the Kinzua Viaduct. Ask: "What failed? Where did it fail? Was it the material, the geometry, or the load assumption?" Let students speculate. Then reveal: NTSB analysis identified that the original 1882 design did not account for the dynamic resonance effects of extreme wind loading — the tower bases failed in combined axial compression and lateral bending.

Introduce the three questions every structural engineer must answer before approving a design:

26. What are all the loads this structure must carry? (Dead load, live load, impact load, wind load, seismic load)
27. What is the maximum stress at any point in the structure under those loads?
28. What factor of safety separates the design load from the failure load — and is that factor sufficient for this structure's consequence of failure?

Explain: today's lab addresses all three questions at model scale. Students will define the loads, build for a calculated design load, then test to failure and evaluate whether their design achieved the required FOS.

Phase 2: Load Calculation and Design Brief (15 min)

Each group completes the following calculations on their worksheet before construction begins:

29. Prototype span: 12 inches (model) × 48 = 576 inches = 48 feet prototype
30. Live load: measured weight of O Scale locomotive = ___ g = ___ lbs
31. Dead load estimate: 0.5 lbs (students weigh their completed bridge after construction and refine this value)
32. Impact factor (AREMA standard: +100% for railroad live load): Design live load = measured locomotive weight × 2
33. Total design load = (impact-adjusted live load) + dead load
34. Factor of safety = 3 (per AREMA Class A railroad bridge standard)
35. Required failure load = total design load × 3 → convert to grams for calibrated weight testing

Statics check: For a centrally loaded simply supported beam, reaction at each abutment = $P/2$. The maximum bending moment at midspan $M_{max} = P \times L / 4$. Students calculate M_{max} for their design load and identify which part of their bridge cross-section will experience maximum tension and compression. This informs their design choice.

Phase 3: Bridge Design and Construction (25 min)

Assign each group one bridge type (or allow selection if time permits comparison discussion):

- Group A — Beam Bridge: flat deck; students should calculate that it will perform worst per unit weight but requires least construction time. Good for understanding baseline bending behavior.
- Group B — Pratt Truss: vertical members in compression, diagonal members in tension. Most efficient for the span-to-depth ratio available with craft sticks. Students label which members they expect to be in compression (vertical) and tension (diagonal) before building.

- Group C — Arch Bridge: curved form transferring load to horizontal thrust at the abutments. Students must design abutment blocks that can resist outward thrust — a common real-world design constraint.

All groups must meet these constraints:

36. Span: exactly 12 inches between support points — no intermediate supports.
37. Deck: level, at least 1.5 inches wide (to accept O Scale track), with a minimum 2-inch vertical clearance beneath.
38. Material limit: 50 craft sticks maximum. Count and record actual number used.
39. Design sketch required before construction: labeled members, dimensions, compression/tension designation.

Students sketch and label their design, noting expected compression and tension members, before beginning construction. Instructor approves sketch before glue gun is issued.

Phase 4: Load Testing and Comparative Analysis (15 min)

Allow bridges to cure for at least 10 minutes (hot glue) before testing. Testing procedure:

40. Weigh the completed bridge. Update the dead load value in the Design Brief calculations.
41. Place bridge on abutments exactly 12 inches apart. Verify with ruler and level.
42. Center the O Scale locomotive on the bridge at midspan (point of maximum bending moment).
43. Add calibrated weights in 50g increments. Record load at first audible crack, at first visible deformation, and at structural failure.
44. Record failure mode: location, member type (compression, tension, joint), and failure character (sudden vs. gradual).

Group / Type	Bridge Weight (g)	Design Load (g)	First Crack (g)	Failure Load (g)	Efficiency Ratio	Failure Mode / Location
A — Beam						
B — Pratt Truss						
C — Arch						

Efficiency Ratio = Failure Load (g) ÷ Bridge Weight (g). A higher ratio indicates more structural efficiency per unit of material.

Class discussion questions:

- Which design type had the highest efficiency ratio? Why does truss geometry typically outperform a solid beam?
- Which failed most gradually (providing warning) vs. suddenly (brittle failure)? What are the professional implications of sudden vs. gradual failure in a bridge that carries passengers?
- Did any bridge achieve the required Factor of Safety of 3? If not, what design change would you make in Version 2?
- The Kinzua Viaduct failed under wind load, not vertical live load. Which of the three bridge types you tested would best resist lateral loading? Why?

Engineering Test Report (Homework or Extended Lab)

Students submit a formal Engineering Test Report containing:

45. Title Page: project name, bridge type, designer name, date, course section.
46. Design Brief: span, load calculations (all 7 steps with work shown), required failure load, FOS.
47. Design Sketch: labeled drawing with dimensions; compression members highlighted in red, tension members in blue.
48. Test Results: completed data table; failure load; efficiency ratio; actual FOS achieved = failure load ÷ total design load.
49. Failure Analysis: which member failed, what type of stress caused failure (compression buckling vs. tension fracture vs. joint shear), what this tells you about the design's weakest point.
50. Design Iteration: specific change to Version 2 with predicted effect on efficiency ratio; explain using structural mechanics vocabulary.
51. Real Bridge Connection: identify one real railroad bridge (provide location and image source), identify its structural type, and explain in 3–4 sentences why that type was selected for that application.

Assessment Rubric

Criterion	4 – Exceeds	3 – Meets	2 – Approaching	1 – Beginning
Load Calculations	All 7 steps correct; impact factor applied; FOS correctly used; units consistent throughout	5–6 steps correct; FOS understood; minor arithmetic errors	3–4 steps; FOS confused or omitted; units inconsistent	Fewer than 3 steps; load concept not demonstrated
Design Sketch	All members drawn with dimensions; compression/tension labeled; constraints verified before construction	Sketch present; comp/tension labeling has 1–2 errors	Sketch present but missing labels or dimension information	No pre-construction sketch produced
Construction Quality	Meets all 4 constraints; joints are planar; deck is level; bridge load-tests as designed	Meets 3 of 4 constraints; minor quality issues	Meets 2 constraints; quality issues affect test validity	Does not meet span or deck requirements
Failure Analysis	Correctly identifies member type and stress mode; uses Euler buckling or tension fracture vocabulary; connects to	Failure location and mode identified; one vocabulary error	Failure location described but not connected to stress type	Report lacks engineering analysis of failure

	design geometry			
Test Report	All 7 sections complete; writing is precise and professional; real bridge connection is specific and accurate	5–6 sections complete; analysis mostly accurate	3–4 sections; lacks quantitative support	Report largely incomplete; test results not connected to engineering principles

Differentiation

- Students needing support: Provide statics FBD template; pre-calculate design load; allow group construction with individual written analysis.
- On-level: Full independent sequence. Complete test report outside class.
- Advanced: Derive the maximum bending stress at midspan using $\sigma = M \times c/I$ (beam bending formula). Calculate the theoretical failure load for the beam bridge based on the craft-stick material's modulus of rupture (look up value for white birch wood). Compare to experimental result and identify sources of discrepancy. Research the AREMA Manual for Railway Engineering Chapter 15 (steel structures) and explain one design provision that addresses the failure mode observed in your lab bridge.

Capstone Project: The Pocono Pass Terminal

The Capstone integrates all four lesson competencies into a single team design-build project, suitable for a final project in a survey course or a stand-alone community exhibition.

Project Brief

Design and build a fully operational O Scale switching layout on a 4 × 3 foot baseboard that meets all of the following performance requirements:

Requirement	Lesson Origin	Success Criteria
Two-block wired oval with independent throttle control	Lesson 1	Two trains operate simultaneously without interference; verified with multimeter
One grade section of at least 2% with reliable operation	Lesson 2	Locomotive pulls a 4-car consist up the grade without stalling; braking distance measured and recorded
Complete dimensioned track plan drawn to 1:48 scale	Lesson 3	Drawing meets all drafting standards: title block, annotations in both model and prototype units, clearance envelope shown
One bridge spanning at least 8 inches, with load calculations	Lesson 4	Bridge carries the layout locomotive + 2 cars at the design load; load calculations on file; FOS calculated
5-minute operational demonstration	All	Layout runs without electrical fault, derailment, or bridge failure for a continuous 5-minute demonstration

Deliverables

52. Portfolio: all four lesson worksheets, with any calculations corrected and annotated based on capstone experience.
53. Final Track Plan: professional-quality drawing as described in Lesson 3, updated to reflect the built layout.
54. Load Calculation Package: bridge design brief, construction sketch, test data, and Version 2 improvement plan from Lesson 4.
55. Systems Summary: one-page document linking each STEM concept to a real-world professional application in the student's target program area.
56. Presentation: 5-minute verbal presentation to a visiting reviewer (instructor, industry mentor, or fellow student cohort) explaining one STEM concept demonstrated by the layout, with quantitative support.

Grading

Component	Weight	Assessment Method
Operational demonstration (5 min continuous)	25%	Pass/fail checklist; verified live

Load calculations accuracy	20%	Rubric from Lesson 4
Track plan drawing quality	20%	Rubric from Lesson 3
Portfolio completeness and accuracy	20%	Lesson rubrics 1–4 averaged
Verbal presentation	15%	Rubric: clarity, accuracy, use of technical vocabulary, quantitative support

Program Articulation Note

Instructors in accredited Engineering Technology or Architectural Technology programs may consider aligning the Capstone with ABET Student Outcome criteria, particularly SO 1 (apply math/science/engineering), SO 4 (design within realistic constraints), and SO 6 (use appropriate techniques and tools). The Capstone's combination of calculation, physical construction, and verbal presentation addresses multiple outcome types within a single assessment instrument.

Series-Wide Differentiation and Accessibility

Student Context	Accommodations and Modifications
Students with disabilities (motor)	Assign to measurement, calculation, or documentation roles; virtual simulation tools (JMRI for circuits, OnShape for bridge modeling) available as alternatives to physical build tasks
English Language Learners	Provide bilingual vocabulary cards for key terms; allow schematic diagrams and mathematical notation in lieu of English prose in lab reports; pair with bilingual peer during lab phases
Students with strong prior knowledge (ET/trades background)	Fast-track to extension activities; assign as lab lead; provide access to DCC Standards documents (S-9.1, RP-9.2.1) for independent research
Students without prior physics or algebra	Provide pre-worked example problems; allow calculator use throughout; pair with peer tutor; focus assessment on procedure and units rather than complex derivations
Makerspace / non-credit context	Omit formal rubric assessments; use self-assessment checklists; focus on design-build cycle; offer a competency portfolio pathway for documentation of skills achieved

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