

DESIGN · MODEL · PRINT · ROLL

Engineering O Scale Model Railroad Components with 3D Printing Technologies

A STEM Makerspace Unit · Grades 6–10 · All Nation Line Education Program

At a Glance

Duration	Period Length	Group Size	Scale / System
8–10 class periods	45–60 minutes	2–3 students	O Scale 2-Rail (1:48)

Overview

Students take on the role of junior engineers at a model railroad components manufacturer. Working in the context of O Scale 2-Rail modeling (1:48 scale), they apply the full engineering design process to design, CAD-model, 3D print, and test a functional or detail component for an O Scale locomotive or rolling stock car.

Drawing on real-world makerspace practices — including FDM 3D printing on Prusa-style printers using PLA filament — students experience the same production workflow used by small-batch O Scale manufacturers. The unit culminates in a “Product Showcase” where groups present their printed component alongside a design brief, print log, and iteration report.

Learning Objectives

By the end of this unit, students will be able to:

- Apply the engineering design process (define → research → ideate → prototype → test → iterate) to a real-world O Scale modeling problem
- Understand O Scale conventions including 1:48 proportion, prototype railroad dimensions, and 2-Rail track standards
- Design a dimensionally accurate 3D model using Tinkercad or Fusion 360, correctly scaled to 1:48
- Configure and operate an FDM 3D printer (Prusa-style) to produce PLA parts suitable for model railroad use
- Analyze print quality, identify common failure modes (layer adhesion, warping, support scarring), and apply iterative design improvements
- Evaluate a finished part against functional criteria: does it fit, roll freely, and survive handling on a test layout?
- Document design decisions, test results, and lessons learned in a structured engineering design journal
- Communicate their process through a product presentation modeled on a manufacturer’s design brief

Standards Alignment

Standard	Description
NGSS MS-ETS1-1	Define the problem in terms of criteria and constraints with sufficient precision to ensure

	a successful solution
NGSS MS-ETS1-2	Evaluate competing design solutions using systematic process to determine how well they meet criteria
NGSS MS-ETS1-3	Analyze data from tests to determine similarities and differences among competing design solutions
NGSS MS-ETS1-4	Develop a model to generate data for iterative testing and modification of a proposed object or tool
CCSS Math MP.4	Model with mathematics — scaling dimensions from prototype (1:1) to O Scale (1:48)
CCSS Math MP.6	Attend to precision in measurement, tolerances, and 3D model dimensions
CSTA 2-AP-13	Decompose problems and sub-problems into component parts to facilitate creation of solutions
ISTE 4c	Develop, test, and refine prototypes as part of a cyclical design process

Materials & Tools

Hardware

- FDM 3D printer (Prusa MK4, Mini, or equivalent) — 1 per 3–4 groups
- PLA filament — recommend black, grey, and oxide red for prototype-accurate railroad colors
- Digital calipers accurate to 0.01 mm — essential for 1:48 scale work
- Flush cutters, hobby knife, and spatula for support removal and bed release
- Safety goggles — required whenever printer is operating
- O Scale test track section — minimum 24" of straight track for rolling tests
- Sample O Scale rolling stock (locomotive or freight car) for reference and measurement

Software

- Tinkercad (browser-based, free) — recommended for beginners; supports mm units and export to .STL
- Fusion 360 (free for students) — extension track for advanced students
- PrusaSlicer (free) — configured for the school's printer; use 0.2 mm layer height profile
- Google Docs or Notion — for engineering design journal and group documentation
- Google Slides or Canva — for Product Showcase presentation

Reference Materials

- Prototype railroad dimension chart (prototype axle spacing, coupler height, wheel flange depth)
- O Scale 1:48 conversion table (prototype inches \div 48 = model dimension in inches; \div 1.87 for mm)
- All Nation Line sample assembly instructions — used as a model for student documentation
- O Scale standards sheet (S-1, S-4, S-7) for wheel, track, and coupler dimensions

Lesson Phases

Phase / Time	Activities
Phase 1 Days 1–2 · ~90 min	Define & Discover <ul style="list-style-type: none"> – Introduce the engineering challenge: design a functional or structural O Scale component (truck bolster, draft gear box, air hose, brake shoe, grab iron bracket, or similar detail part) – Tour the makerspace; observe Prusa printer in operation; examine existing O Scale PLA-printed parts – Handle real O Scale rolling stock; measure prototype features with calipers; record in design journal – Each group selects a component and writes a How Might We... design problem statement – Introduce the 1:48 scale conversion and compute at least three real prototype dimensions into model scale
Phase 2 Day 2–3 · ~60 min	Research & Constraints <ul style="list-style-type: none"> – Research the prototype function of the chosen component (what does it do on a real railroad car?) – Identify design constraints: max print size 60 × 60 × 40 mm; PLA only; must be printable without soluble supports; wall thickness minimum 1.2 mm – Review O Scale dimensional standards for the component; record required dimensions – Examine existing commercial or 3D printed versions of similar parts; note strengths and limitations – Write a Design Brief: component name, prototype function, scale dimensions, fit requirements, material rationale
Phase 3 Day 3 · ~45 min	Ideate & Sketch <ul style="list-style-type: none"> – Individual brainstorm: each student produces 4–6 rough sketches of their component approach with labeled features – Group gallery walk with dot-voting on most promising approach – Select one concept and produce a dimensioned technical sketch with at least three views (top, side, front) – Mark any features that may require support material or post-processing; flag overhangs greater than 45° – Dry-run a manual scale check: confirm key dimensions convert correctly to 1:48 using the conversion table
Phase 4 Days 4–5 · ~120 min	CAD Modeling <ul style="list-style-type: none"> – Tinkercad guided session: set units to millimeters, import reference grid scaled to the component footprint – Build the model from the dimensioned sketch; use calipers to verify real O Scale reference part dimensions at each stage – Peer CAD review: partner checks wall thickness, overhangs, and that all critical fit surfaces are modeled – Export as .STL; open in PrusaSlicer; preview layer-by-layer; estimate print time and filament gram weight – Teacher approves print file before queue submission; document estimated vs. actual filament use in design journal
Phase 5 Days 6–8 · ~150 min	Print, Test & Iterate <ul style="list-style-type: none"> – Submit print queue; observe first three layers for bed adhesion and line width consistency – While printing: complete companion documentation (BOM draft, tool list, preliminary assembly notes)

	<ul style="list-style-type: none"> – Functional test: does the part fit the reference car or truck correctly? Does it sit square? Do wheels roll freely past it? – Dimensional inspection: measure three critical dimensions with calipers; record variance from designed dimension – Identify failures, revise CAD model, and reprint at least once; document the change and its rationale in the design journal
Phase 6 <i>Days 9–10 · ~90 min</i>	Document & Present <ul style="list-style-type: none"> – Compile engineering design journal into a polished Product Brief: problem → research → design → print log → test results → lessons learned – Produce a simple draft Assembly Instruction for the component, modeled on the All Nation Line instruction standard – Product Showcase: each group presents their printed part, design brief, and iteration story (5 minutes + Q&A) – Peer feedback using warm / cool / wonder protocol; instructor scoring against rubric – Individual written reflection: what would change in a version 2, and why?

O Scale 1:48 Conversion Quick Reference

Prototype dimension	O Scale model (inches)	O Scale model (mm)
1 foot (12 inches)	0.250"	6.35 mm
1 inch	0.021"	0.529 mm
Standard rail gauge (4' 8½")	1.177"	29.9 mm
Truck wheelbase (5'6")	1.375"	34.9 mm
Coupler height centerline (3'3")	0.823"	20.9 mm
Box car height (14' 6")	3.625"	92.1 mm

Assessment Rubric

Criteria	Exceeds (4)	Meets (3)	Approaching (2)	Beginning (1)
Design Journal	Detailed, consistent entries with labeled dimensioned sketches, 1:48 conversion calculations, and reflections at every phase	Most phases documented; sketches present; some gaps in reflection or calculations	Incomplete entries; sketches lack dimensions or scale conversions; reasoning unclear	Minimal or missing documentation
CAD Model Quality	Accurate, well-organized model; all critical dimensions within 0.2 mm of design; print-ready with no critical geometry errors	Functional model; minor dimension errors; required one correction before printing	Model mostly complete; required significant teacher support; key dimensions off by more than 0.5 mm	Model incomplete, unprintable, or grossly out of scale
Scale Accuracy	All modeled dimensions convert correctly to 1:48; part is visually proportionate and matches prototype photograph or drawing	Key dimensions correct; minor proportional deviation in one non-critical feature	Part is recognizable but has noticeable scale errors in one or more major features	Part does not conform to 1:48 scale; dimensions appear arbitrary
Functional Testing	Part fits reference rolling stock correctly; no binding; rolls freely on test track; two measured iterations documented	Part fits with minor adjustment; at least one documented iteration with explained rationale	Part partially functional; iteration attempted but poorly documented	Part does not fit or function; no meaningful iteration
Product Brief & Presentation	Brief clearly explains prototype function, design process, and decisions; group responds confidently to questions; all members contribute	Covers key points; mostly clear; all members speak; one section underdeveloped	Presentation missing key design stages; uneven participation	Minimal communication of design process or prototype context

Differentiation

Scaffolded Support	On-Grade Core Pathway	Extension Challenges
<ul style="list-style-type: none"> Pre-built Tinkercad starter template scaled to 1:48 Printed 1:48 conversion reference card at workstation Completed sample design brief to model against Step-by-step PrusaSlicer guide with screenshots Peer mentor pairing within group Reduced constraint count: 2 	<ul style="list-style-type: none"> Standard design brief with 4 functional constraints Full design journal with structured prompts Minimum one documented redesign iteration 5-minute Product Showcase presentation Draft Assembly Instruction (introduction + step 1 only) 	<ul style="list-style-type: none"> Use Fusion 360 with parametric modeling for 1:48 constraints Design a part with moving or interlocking elements (e.g., working coupler knuckle) Calculate material cost and print-time efficiency; propose design changes to reduce both Write a complete Assembly

fit requirements instead of 4		Instruction to ANL standard (all sections) <ul style="list-style-type: none"> • Design for two-color or dual-material print
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Makerspace Safety Protocols

Safety Rule	Rationale
Safety goggles required whenever the printer is operating	Filament debris or failed prints can release material at head height
Never touch the nozzle, heated bed, or heat block (190–220°C)	Contact causes immediate burns; the heat block is not insulated on most Prusa models
Ensure room ventilation or use enclosure with exhaust fan	PLA fumes are mild but real; prolonged exposure without airflow is not recommended
Teacher approves all print files before queue submission	Prevents runaway prints, bed damage, and wasted filament from modeling errors
Flush cutters and hobby knives require demonstration before student use	Sharp tools are necessary for support removal; misuse is the most common makerspace injury
CA glue (if used for post-assembly) bonds skin instantly	Keep fingers separate during application; have paper towel ready; no children under 14 should handle CA without supervision

Teacher Notes & Pacing Tips

- Print overnight to maximize class time. Stagger group submissions so the printer runs continuously across days 6–8.
- While groups wait for their print, keep them active: finalize their design brief, draft the assembly instruction, or research the prototype history of their component.
- Build a Failure Gallery on the wall — post every failed print with a one-sentence diagnosis. Normalizing failure is one of the most important things this unit teaches.
- Pre-slice all student files in PrusaSlicer before approving. Flag any estimated print time over 3 hours for design revision (break the part into sub-components instead).
- If you have only one printer: run a print queue sign-up sheet, allow 15 minutes between job end and test start (bed cool-down), and run a print during any class where another group is presenting.
- Connect the unit to real industry: All Nation Line and similar small-batch O Scale manufacturers use exactly this workflow. If possible, invite a local model railroad club member or hobby shop owner to the showcase.
- The 1:48 scale conversion is excellent cross-curricular math. Tie it to ratios and proportional reasoning — most students find it clicks much faster when the ratio results in a real object they can hold.
- Encourage groups to document in real time during printing, not after. The print log (what settings, what happened, what to change) is more valuable than a retrospective summary.

Suggested Resources

Resource	Notes
Tinkercad (tinkercad.com)	Free, browser-based CAD; set to mm units; supports .STL export; has classroom account management for teachers
PrusaSlicer (prusa3d.com)	Free slicer software; use the 0.2 mm QUALITY profile as the baseline; show students the layer preview before printing
O Scale Standards (S-1, S-4, S-7)	Download S-1 (scales), S-4 (wheels), S-7 (couplers) for O Scale; these are the industry dimensional standards your parts must meet
All Nation Line (allnationline.com)	Sample O Scale 3D printed components and assembly instructions for reference; YouTube channel shows real Prusa print sessions
O Scale Trains Magazine	Back issues contain prototype photographs and scale drawings useful for the research phase
Prusa Knowledge Base (help.prusa3d.com)	First-layer calibration, support settings, and troubleshooting guides; bookmark the “First layer issues” article

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