Full Speed Ahead!

{The Teacher Handbook}

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Project Introduction

The goal of this program, facilitated by the London Transport Museum (LTM), is to inspire students to pursue science, technology, engineering, and mathematics (STEM) by relating real world transportation problems to classroom concepts. The curriculum is designed to have students learn through hands-on research, testing, and inquiry rather than by lecturing and guidance from teachers. To enhance the program's adaptability to many classroom environments, it has a modular design; the depth and number of sessions run in your class is left to your discretion based off of your students' abilities, your available resources, and time you have to spend on each activity. If the program is run in full, however, each group of students, or "engineering firm" will have a rail line featuring a model train, track, tunnel, bridge, station. signaling system, and mathematical analyses. Regardless of the amount of the program students complete, it should enhance their understanding of engineering and the responsibilities of several engineering fields.

Project Instructions

The Full Speed Ahead curriculum is designed to be as flexible as possible, empowering students to be as creative or as explorative as they so choose. The format of the sessions are listed below in the table. Please note that not every activity will have all of these sections in it, and that the written time allocations are merely suggestions.

Section	**Description**
Introduction	Provides context for the activity and is read aloud to the students.
Concepts	Concepts that students will encounter in the activity.
Learning Outcome(s)	What students will understand or gain as a result of the activity. These learning outcomes are as follows: 1. To inspire students to pursue a career in engineering 2. To enable students to see the breadth and depth of engineering as a field 3. To guide students to see the benefits of 'soft skills' in engineering careers 4. To empower students to have the confidence in their ability to pursue careers in engineering.
LTM Exhibit Connection	The LTM has exhibits and handling objects that correspond with the listed activities.

Research Phase	Students explore the concepts they will need to complete the activity.
Design Phase	Students collaborate in groups to create a novel design.
Build Phase	Models are produced. Note that all building materials should be provided by the school, not the London Transport Museum.
Recap/Discussion Phase	Students develop soft skills by communicating their learning to others.
Above and Beyond	Options within each session to further challenge excelling groups.
Suggested Evaluation	Largely the selection of the "best" design is left to your discretion as the time and materials available to each class will greatly affect the students' output. In general, consider concepts such as strength, size, creativity, feasibility, environmental preservation, and cost (again, the relative "cost" of materials is left to your discretion).

In addition to the each sessions' lesson plan, this packet includes:

- **Student Handouts:** This packet contains student activity handouts for each session.
- **Engineer Instructions:** At any point throughout the program, you can request a real engineer from Transport for London to visit your class and speak about their work. This letter outlines the Full Speed Ahead Program for them and explains how their involvement can enhance the students' experiences.

Should students need extra background on a topic or more activities to complete, please refer to the **Resource Handbook**. The Resource Handbook is oftentimes necessary for a session to be successful, either because it contains an activity's description or provides crucial information. This is the other handout you received at the beginning of this program.

Your Role

For the Full Speed Ahead Program, you are the Mayor of London and the groups of students are engineering firms. At the beginning of each session, you should read the introductory paragraph aloud to brief students on the session's unique project. This reading should impress upon students that the activity they will complete is based on a challenge faced by real engineers, and that the solutions developed by these professionals affects ordinary people just like themselves.

Recommendations for running the project:

- Let the students be as creative as possible. If they are stuck or lost, feel free to help them, but try to avoid directly giving them a solution.
- Adding a competitive element to this curriculum may help engage students in the program as a whole, but ultimately the development of a system for awarding points or selecting a winning project has been left to your discretion.
- Requesting a Transport for London Engineering Ambassador to visit your class to provide constructive criticism to the students may well be the highlight of the program, and cement the idea that engineering is both approachable and impactful. A letter describing the project to visiting professionals is included in this packet.
- Visiting the London Transport Museum, this program's sponsor, will allow students to learn how engineers throughout history tackled the same challenges they considered, and how their work literally shaped London.

Project Description

To be read to students at the start of the program.

"London is a bustling city with a long history of public transportation. Since the city's humble beginning, its transportation network has been under constant improvement and expansion as the the system grows to fill the changing needs of London's citizens and visitors. With the city's population ever rising, the number of people using its public transportation system rises every year. Engineers are constantly in demand to design bigger and better systems to make the travelers' experiences safer and more convenient. For the duration of this program assume you, the students, are engineers working to propose a new rail line requested by me, the Mayor of London. This initiative should reduce the congestion of London's train network, cut down on pollution in the city, and ultimately improve the lives of the city's population. You will form engineering firms to compete for this lucrative government contract."

Conclusion

The Full Speed Ahead program was designed to be a departure from traditional, lecture based learning and manifests the philosophy that hands-on, student-led activities can foment a life-long passion for STEM. Thank you for participating in this program.

Engineer Instructions

Goal

The Full Speed Ahead program endeavors to inspire year 10 and 11 students to pursue engineering by developing a multi-disciplined, engineering-centric, project-based curriculum culminating in a visit to the London Transport Museum (LTM). This initiative will help relate real-world engineering concepts to classroom lessons and inspire young minds to explore science, technology, engineering, or mathematics (STEM) fields.

Structure

- In this simulation, the teacher is the Mayor of London. They have requested the construction of a new rail line through the heart of London.
- Students are divided into mock engineering firms competing for the Mayor's contract.
- Perhaps you may join the fun as a professional consultant!
- Depending on their level of progress and the activities selected by the teacher, the students will have created: a train and rail line; a bridge; a tunnel; an electronic signaling system; a station; and a construction schedule. Each of the program's ten sessions is outlined as follows:
    - **Session 1: Business as Usual-** Students are grouped together and form mock engineering firms which are tasked with developing a mission statement, logo, motto, and code of conduct. They are then set in a competitive negotiation game centered around trading for resources to meet contracts. This session sets behavior standards for the rest of the FSAP, and gives students a chance to practice communication and negotiation skills.
    - **Session 2: Train of Thought-** Students design and build a train and track. The train is the key part of the session, and students may be challenged to consider the propulsion and braking methods their train would use.
    - **Session 3: Mixed Signals-** Students build a light-sensing circuit that could be installed on their track as a simple signal. This activity challenges students' knowledge of circuits and encourages them to consider safety on rail lines. This activity introduces students to A-Level content.

- **Session 4: Rail Lines and Line Graphs-** Students relate kinematics to rail line optimization, specifically addressing acceleration and headway, the time interval needed between trains to prevent collisions.
- **Session 5: Mind the Gap-** Students will research some important elements of transportation and the history of bridge design. Then they will design and build a bridge across a small gap. The constructions are evaluated by the weight they can support, the cost of their materials, and the structure's weight.
- **Session 6: Tunnel Vision-** Students design and build a tunnel. This session is analogous to Session 5.
- **Session 7: Station Fixation-** Students research, design, and build a tube station. They can design advertisements for their station to develop persuasive reasoning skills, or determine where to place signs to best inform passengers of important information.
- **Session 8: Time is of the Essence-** Students create a schedule for the construction of a project using a form of mathematical analysis. This is designed to target critical thinking skills and challenge students to consider a real-world application of mathematics outside of their experience with the subject.
- **Session 9: Show Time-** Students present their proposed train, rail line, station, and other components created over previous sessions to the teacher. The aim is to show students the value of communication skills in engineering.
- **Session 10: A Journey through Time-** The final session includes a visit to the LTM where students connect concepts learned in the classroom to London's history of transportation. Relevant exhibits are highlighted throughout sessions, and summarized again in this session for reference.

Your role

- Feel free to contribute to the curriculum however you see fit. Consider some of the ideas below:
  - You may comment on certain elements of a firm's design, suggest additional challenges to thriving teams, or explain relevant scientific concepts.
  - Excite students about the relatability, impact, and diversity of STEM work by sharing your story. What projects have you worked on? How did you enter the

STEM industry? What do you like most about your job? What did you wish you knew in secondary school? What do people not know about engineering?

Suggested List of LTM Handling Objects

These objects, available through the LTM's Learning Office, may be used to compliment your discussion at the school.

Session	Handling Object/Link to LTM
Business As Usual	Frank Pick Metroland Exhibit
Train of Thought	Composite Conductor Rail Fact Sheet (T-06) Pandrol Clip Fact Sheet (T-02) (T-16) Pressure Switch Fact Sheet (T-11) (T-12) Rail Fastenings Fact Sheet (T-01) (T-13) (T-14)
Mixed Signals	Capacitors (E-07) (E-08) T-Piece Fact Sheet (T-05) Hawkbox Tuning Unit Component Fact Sheet (S-17) Indication Contact Arrangement Fact Sheet (S-13) (S-14) Indicator Push Rods Fact Sheet (S-0.5.1) (S-0.5.2)
Rail Lines and Line Graphs	Relay Fact Sheet (S-15) (S-16) Wiring Cables Fact Sheet (S-01) (S-02.1-2.9) (S-18.1) (S-18.2)
Mind the Gap	Post Tensioning Cable Fact Sheet (C02)
Tunnel Vision	Concrete Fact Sheet (C-01) Link to Tunneling Exhibit at LTM
Station Fixation	Water Meter (C-07)
Time is of the Essence	Microprocessors / Heatsinks (E-01) (E-06) Random Access Memory (RAM)
Show Time	N/A
Journey through Time	Refer to Session 10 of the Teacher Handbook

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Session 1: Business as Usual

Introduction

"Before you can work on the project at hand, you have to create a logo, motto, code of conduct, and a mission statement. Your logo and motto should be creative, concise, and quickly convey what your company does; of course, your logo should be aesthetically pleasing and iconic as well. Your mission statement should be an expansion of your motto; it should explain your company's goals and pursuits, why they matter, and how your company will reach them. Just as in a real workplace, you are individually responsible for behaving in a professional manner. As a group you should agree upon a code of conduct which describes what is expected of each team member and how potential problems may be resolved."

Concepts

- Teamwork
- Negotiation
- Delegation of responsibilities
- Graphic design

Learning Outcome(s)

- Benefits of soft skills (teamwork, behavior contract, logo design)

LTM Exhibit Connection

- Posters
- Important people: Frank Pick, Albert Stanley (or Lord Ashfield), Robert Hope Selbie
- Edward Johnston Roundel and Font
- Metro-land

List of Materials:

- Paper, Pens, Pencils, Markers, Ruler
- Optional: Computers

Session Agenda

Activity	**Description**
Research (15 min-1 hr)	• Have students try out a couple of creative problems (located in the Resource Packet) to get them into a creative, problem-solving mindset • Encourage students to look at logos from a variety of backgrounds (transport, energy, business, film, etc.)
Activity 1 (30 min-1.5 hrs)	Students should research and design a logo, motto, code of conduct, and mission statement.
Activity 2 (30 mins- 1 hr)	Transportation Transaction Game (included in the Resources Handbook)
Recap/Discuss (10 min-30 min)	• What did you learn about companies and the way they function you didn't know before? • Explain the reasoning behind your company name, motto, logo, mission statement, and code of conduct.
Above and Beyond	Create an advertisement for your company. This may be a promotional video or skit.
Suggested Evaluation (5 min)	• What logo is the most creative and laconic? • What slogan is the catchiest? • Which code of conduct is the most professional? Do any include mechanisms for student-led conflict resolution? • Which mission statement is the most focused?

Session 2: Train of Thought

Introduction

"The most essential part of any tube line is the track. The dimensions, path, and capabilities of a track govern much of the design of the remainder of the rail line. Therefore, the first part of this activity will be to design a railway track. After this is done you may then create an accompanying train."

Concepts

- Forces of motion (Physics)

Learning Outcome(s)

- Empower students (Considering design questions)
- Breadth and depth of engineering (Railway engineering)

LTM Exhibit Connection

- Interactive monitors/tablets
- Steam vs. Electric propulsion
  - Steam/Smoke ventilation display
- First through Third class coaches
- Changing straphanger designs

List of Materials

- Acrylic, cardboard, wood, newspaper, ruler, tape, glue, paper, pencils, etc.
- Legos, Kinex, Meccano set, Makedo (cardboard construction kits)
- Optional: Magnets, battery, LEDs, resistors, paint

Session Agenda

Activity	**Description**
Research (15 min-1 hr)	• Discuss the pros and cons of the 'cut and cover method' • Brainstorm other methods of building a railway • If you have access to a train, have students visit it. Otherwise, have student share their experiences/impressions of public transportation.
Activity (30 min-2 hrs)	Research, design, and build a tube line and/or a train. *Note: Constructing a rail line is optional. This means that you do not have the train run on a track or will have to provide a track.*
Recap/Discussion (10 min-1 hr)	• Preform a cost analysis on your train based on the prices of the materials you used. • How well does your train perform relative to your expectations? • How might improve your train's design? Could you decrease its weight?
Above and Beyond	• Include a curve in your track. • Design a propulsion system to power your train (Ideas: Electric motor, fan, deflating balloon, electric induction). • Design a braking system for your train (Ideas: Felt runners or paper flaps on the rail line). • Examine a map of London's existing railway network. Where might you place a new line and why?
Suggested Evaluation (5 min)	• Do the trains and tracks meet all the requirements? • Which train carries the most people/items? • Which train is the safest? The fastest? The lightest? The cheapest?

Session 3: Mixed Signals

Introduction

"The next essential part of a tube system is to have a way to direct the trains. Trains need to be able to stop when they reach stations and slow down when another train gets delayed. As a passenger on the tube, we take these scenarios for granted, but who ensures we get to our destination safely and efficiently? That's the role of a signal engineer. Obviously, engineers need to know exactly where every train on a line is located; one way to do this is with signals. I, the Mayor, want the new railway to include such a system. Using a photoresistor, shine a green light when the track is clear, and a red light when a train is on the track and covering the resistor."

Concepts

- Signaling, Circuits (Electronics/Electrical Engineering)
- Algebra (Maths)

Learning Outcome(s)

- Breadth and depth of engineering (Electronics engineering, applications to physics)

LTM Exhibit Connection

- Harry Beck's Tube Map

List of Materials

- Wires, Resistors (Photoresistor), Integrated Circuit, Not Gate, Red and green LEDs , 9V battery, breadboard
- Diagram of a circuit

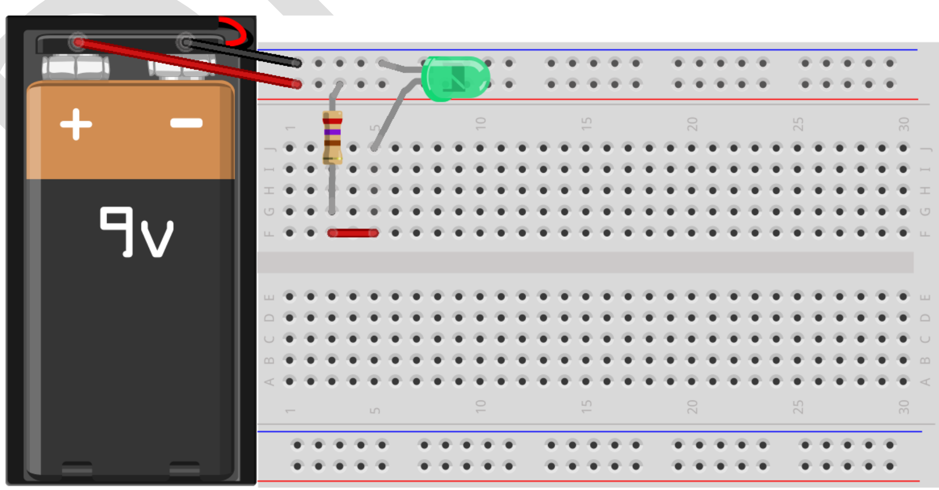
Session Agenda

Activity	Description
Research (10 min-1 hr)	• Research a circuit • Research voltage and current (Ohm's Law and Kirchoff's Laws) • Research railway signaling (see Resource Handbook)
Activity (45 min)	Use the diagram to build the circuit
Recap/Discussion (5 min- 30 min)	• What is the importance of electronic circuits in daily life and train engineering? • How might engineers design failsafe systems for train signaling? • Where else could you use the circuit you created in this activity on trains? • Why might the circuit you designed be impractical for real train applications, especially in the Tube?
Above and Beyond	• Use the circuit to add automatic headlights to your train to light the way through the tunnels.

Solutions

Note these boards use a TL081CP operational amplifier chip with a 3.3 kOhm resistor, two 5 mm LEDs, a 10 kOhm potentiometer, 22 kOhm photoresistor, 9 volt battery and two 270 Ohm resistors. Depending on available components, breadboard connections can change. These image serves as a guide for each circuit.

1.



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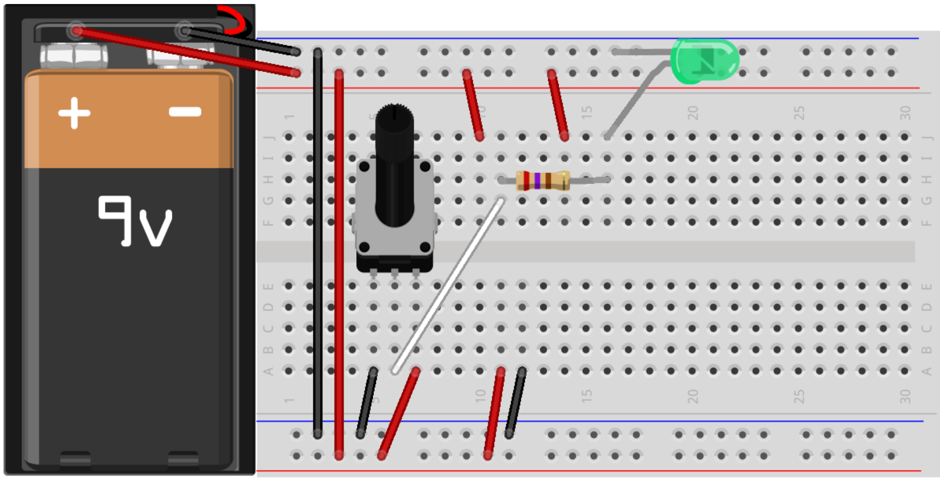

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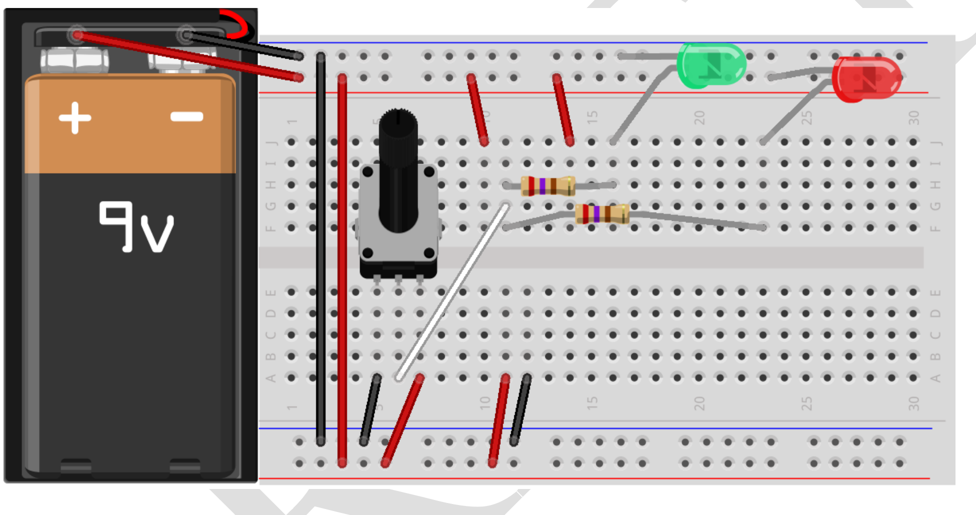

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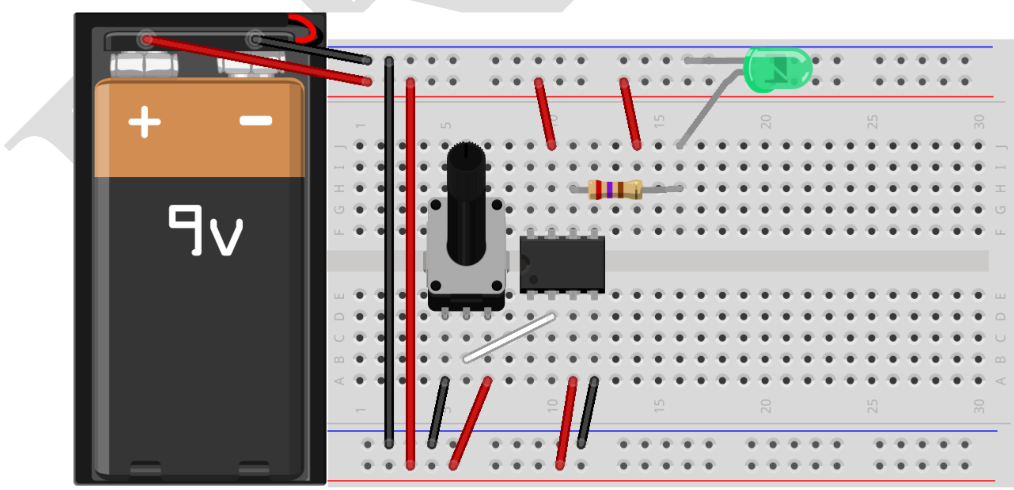

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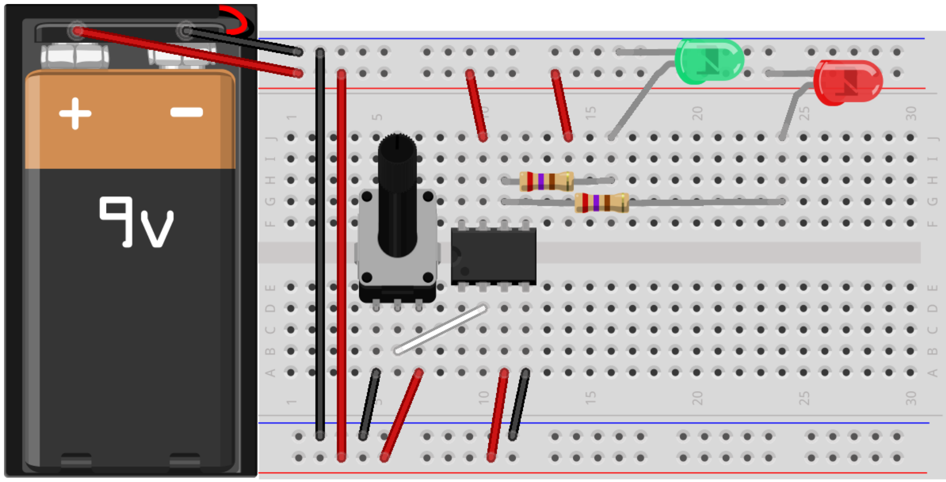

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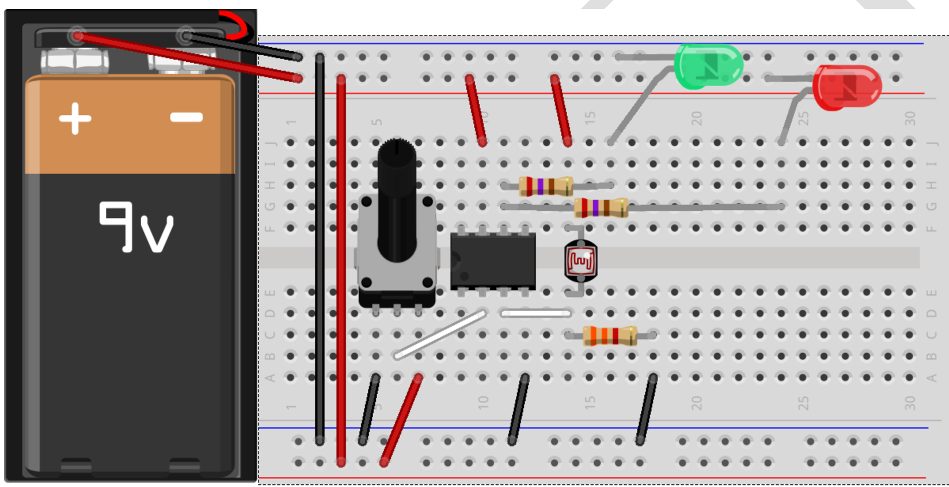


Session 4: Rail Lines and Line Graphs

Introduction

"Clap your hands together. Isn't it clear two objects can't occupy the same space at the same time? This idea is extremely important to transportation engineers; train collisions are almost always catastrophic. Ideally, only one train would run on a single line, but this would be terribly inefficient. Engineers are challenged with maximizing the number of trains that can safely travel on a single line, thereby moving the most people possible.

To visualize this problem, engineers have developed charts called train graphs. These graphs display information about a train's speed, position, distance to another train, speed limitations, and stops on a particular line. Clearly train graphs are extremely useful tools, but they are also very complicated.

I, as the Mayor, want each rail company to be able to understand the basics of train graphs. It is important that you all realize these charts are all formed from basic kinematic equations. Work through the relevant physics problems to optimize a train's stop at a station, and then study the examples of real train graphs."

Note: The train graphs included in this activity are derived from an Excel program developed by Eric Wright, a professional signal engineer. They are modeled off of the London Underground's Victoria Line.

Concepts

- Reading train graphs
- Railway engineering, signaling
- Headway
- Kinematics (Physics)

Learning Outcome(s)

- Empower students (understand concepts used directly on the Victoria line)
- Breadth and depth of engineering (signals engineering)

List of Materials

- Computer (if possible)
- Graphs (provided in Resource Packet)

Session Agenda

Activity	**Description**
Research (Optional)	Ask students to look into the history of the Victoria Line.
Activity 1 (1 hour)	Physics problems (see below for solutions)
Activity 2 (45 min)	Train graphs (see below for solutions)
Recap/Discussion (1 hour)	• Connect to Mr. Wright's example of a train graph (Victoria line) • Having students summarize relatively complex technical ideas is an important writing challenge.
Above and Beyond	• This activity should show students the tradeoff between digital optimization and hand calculation: o Generate an Excel spreadsheet that can instantly calculate a train's position, velocity, and acceleration based on an assumed mass, breaking force, and kinetic energy. Use the results of Questions 1, 2, and 3. o Plot graphs of position vs. time, velocity vs. time, and acceleration vs. time, with data points at .25 second increments. o What are the benefits of using a computer program as opposed to completing calculations by hand? o Did it take more or less time to set up the computer program than to simply do the math on paper? o When does it become cost effective for your company to develop a computer program to replace manual calculations? • Have students go to a Tube station with a stopwatch and calculate the headway of the trains. Does the headway change throughout the day? • Let students explore Mr. Wright's train graph Excel file (provided via the LTM). Students may experiment with the program by changing the values contained in yellow cells.
Suggested Evaluation (5 min)	• What group wrote the clearest, most reader-friendly technical report?

Solutions to Background Problems

1. A train has a mass of 250,000 kg and is traveling with a kinetic energy of 15.125 MJ. What is the train's velocity?

$$KE = {}^{1}/_{2} * m * V^2$$

$$V = \sqrt{\frac{2 * KE}{m}}$$

$$V = \sqrt{\frac{2 * 15.125\ MJ}{250{,}000\ kg}}$$

$$Ans: V = 11\ {}^{m}/_{s}$$

2. Assume the train's air brakes can exert a force of -200,000 N on the train. At what rate does it decelerate? Include a free body diagram of this scenario.

$$F = ma$$

$$a = \frac{F}{m}$$

$$a = \frac{-200{,}000\ N}{250{,}000\ kg}$$

$$Ans: a = -.8\ {}^{m}/_{s^2}$$

3. Signals tell conductors the condition of the rail ahead. Put very simply: green means "Go"; double yellow means "The next signal is yellow"; yellow means "Slow down. The next signal is red"; and red means "Be at a full stop". Obviously, a station would display a red signal so passengers could enter and exit the train. How close to the station's red signal can a signal engineer place a yellow signal so the train can safely stop? How long does this deceleration take?

$V = V_o + a * t$

$t = \frac{-V_o}{a}$

$t = -\left(\frac{11\ ^{m}/_{s}}{-.8\ ^{m}/_{s^2}}\right)$

$Ans: t = 13.75\ s$

$X = X_o + V_o * t + {}^{1}/_{2} * a * t^2$

$X = 11\ ^{m}/_{s} * 13.75\ s + {}^{1}/_{2} * -.8\ ^{m}/_{s^2} * 13.75\ s^2$

$Ans: X = 75.625\ m$

4. (Optional Problem) Now assume the electric motor on your train can exert a force of 125,000 N on the train. Draw a free body diagram and find the rate at which your train can accelerate. If your train is 100 m long, how much time does it take for it to fully leave the platform? Assume the platform is the same length as the train. What is the momentum of your train at this instant (Hint: You will need to find the velocity of your train in order to calculate its momentum)?

$F = m * a$

$a = \frac{F}{m}$

$a = \frac{125{,}000\ N}{250{,}000\ kg}$

$Ans: a = .5\ ^{m}/_{s^2}$

$X = X_o + V_o * t + {}^{1}/_{2} * a * t^2$

$100\ m = {}^{1}/_{2} * .5\ ^{m}/_{s^2} * t^2$

$Ans: t = 20\ s$

$V = V_o + a * t$

$V = .5\ ^{m}/_{s^2} * 20$

$Ans: V = 10\ ^{m}/_{s}$

$p = m * V$

$p = 250{,}000\ kg * 10\ ^{m}/_{s}$

$Ans: p = 2.5 * 10^6\ ^{m}/_{s}$

Solution to Train Graphs

Headway is defined as the time between when identical points on two trains pass through the same point on a rail line. A simpler definition is: the time interval between two vehicles (automobiles, ships, or railroad or subway cars) traveling in the same direction over the same route. It can be calculated by finding the difference between the time coordinates of the fronts of two trains on a time vs. distance graph. The train length can be calculated by measuring the distance between the front and rear points in the vertical sections of the time vs. distance graph. The number of stations can be found from the number of vertical sections on the time vs. distance graph or minus one of the number of points with zero speed on the speed vs. distance graph (the first point with zero speed represents the train starting its journey and thus is not considered a station stop).

In all of the graphs, students should recognize the train may only accelerate to a higher speed when entering a high speed limit section of the track if every point on the train is within that new speed limit. Thus the max speed of the train in any given area is also dependent upon the length of the train.

Case 1:

Number of stations = 3

Headway = ~75s

Train length = 150 m

The trains will run without collisions, but either the headway or the length of the train can be changed to maximize the number of people it can serve.

Case 2:

Number of stations = 3

Headway = ~60s

Train length = 250 m

The trains will collide; the train length should be reduced or the headway should be increased.

Case 3:

Number of stations = 3

Headway = ~50

Train length = 150 m

The trains will collide; the train length should be reduced or the headway should be increased.

Solution to Digital Optimization

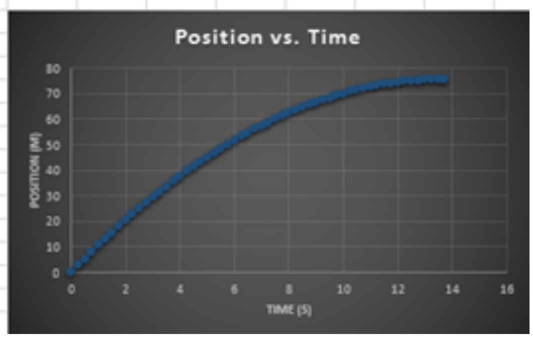
The original Excel file is available upon request at the LTM. A picture of a working Excel spreadsheet is included below. The equations used throughout the spreadsheet are:

- **B9:** =B11/B12*-1
- **B10:** =B11*B9+0.5*B12*B9^2
- **B11:** =SQRT(2*B4/B5)
- **B12:** =B6/B5
- **B15 (Drag down for the remainder of Column B):** =$B$11*A15+0.5*D15*A15*A15
- **C15 (Drag down for the remainder of Column C):** =$B$11+D15*A15
- **D15 (Copied for the remainder of Column D):** =$B$12

Rail Lines and Line Graphs Above & Beyond Excel Sheet

Given		
Kinetic Energy	15125000	J
Mass	250,000	kg
Brake Force	-200,000	N
Calculated		
Time	13.75	s
Position	75.625	m
Initial Velocity	11	m/s
Acceleration	-0.8	m/s/s

Time (s)	Position (m)	Velocity (m/s)	Acceleration (m/s/s)
0	0	11	-0.8
0.25	2.725	10.8	-0.8
0.5	5.4	10.6	-0.8
0.75	8.025	10.4	-0.8
1	10.6	10.2	-0.8
1.25	13.125	10	-0.8
1.5	15.6	9.8	-0.8
1.75	18.025	9.6	-0.8
2	20.4	9.4	-0.8
2.25	22.725	9.2	-0.8
2.5	25	9	-0.8
2.75	27.225	8.8	-0.8
3	29.4	8.6	-0.8



Rail Lines and Line Graphs Above & Beyond Excel Sheet

Given		
Kinetic Energy	15125000	J
Mass	250,000	kg
Brake Force	-200,000	N
Calculated		
Time	13.75	s
Position	75.625	m
Initial Velocity	11	m/s
Acceleration	-0.8	m/s/s

Time (s)	Position (m)	Velocity (m/s)	Acceleration (m/s/s)
0	0	11	-0.8
0.25	2.725	10.8	-0.8
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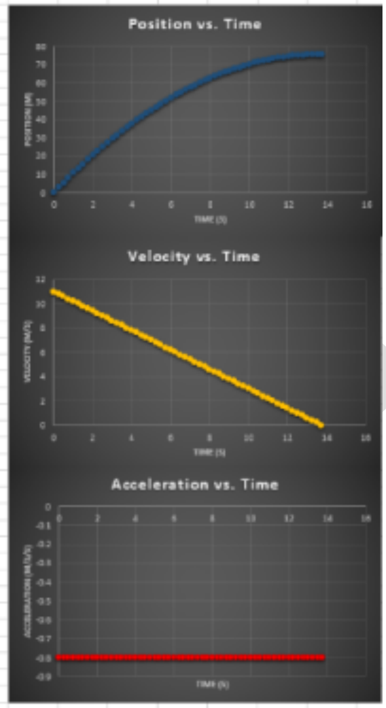
1.75	18.025	9.6	-0.8
2	20.4	9.4	-0.8
2.25	22.725	9.2	-0.8
2.5	25	9	-0.8
2.75	27.225	8.8	-0.8
3	29.4	8.6	-0.8
3.25	31.525	8.4	-0.8
3.5	33.6	8.2	-0.8
3.75	35.625	8	-0.8
4	37.6	7.8	-0.8
4.25	39.525	7.6	-0.8
4.5	41.4	7.4	-0.8
4.75	43.225	7.2	-0.8
5	45	7	-0.8
5.25	46.725	6.8	-0.8
5.5	48.4	6.6	-0.8
5.75	50.025	6.4	-0.8
6	51.6	6.2	-0.8
6.25	53.125	6	-0.8
6.5	54.6	5.8	-0.8
6.75	56.025	5.6	-0.8
7	57.4	5.4	-0.8
7.25	58.725	5.2	-0.8
7.5	60	5	-0.8
7.75	61.225	4.8	-0.8
8	62.4	4.6	-0.8
8.25	63.525	4.4	-0.8
8.5	64.6	4.2	-0.8
8.75	65.625	4	-0.8
9	66.6	3.8	-0.8
9.25	67.525	3.6	-0.8
9.5	68.4	3.4	-0.8
9.75	69.225	3.2	-0.8
10	70	3	-0.8
10.25	70.725	2.8	-0.8
10.5	71.4	2.6	-0.8
10.75	72.025	2.4	-0.8
11	72.6	2.2	-0.8
11.25	73.125	2	-0.8
11.5	73.6	1.8	-0.8
11.75	74.025	1.6	-0.8
12	74.4	1.4	-0.8
12.25	74.725	1.2	-0.8
12.5	75	1	-0.8
12.75	75.225	0.8	-0.8
13	75.4	0.6	-0.8
13.25	75.525	0.4	-0.8
13.5	75.6	0.2	-0.8
13.75	75.625	0	-0.8



Session 5: Mind the Gap

Introduction

“Your track must have a bridge to cross over a river. It will need to accommodate the weight of your train at minimum though the stronger your bridge is the more likely I, the Mayor, will select it for the new rail line. Consider the cost of the materials you decide to use, as well as their weight, as these will be part of your bridge’s evaluation score. I will specify the minimum length your bridge must span, but in general the longer your bridge goes the better it will be judged.”

Concepts

- Forces (Physics)
- Static systems (Civil/Mechanical Engineering)

Learning Outcome(s)

- Empower students (consider design questions, using knowledge of forces)
- Breadth and depth of engineering (civil engineering)

LTM Exhibit Connection

- Blackfriars Bridge

List of Materials:

- Acrylic, cardboard, wood, newspaper
- Ruler, paper, pencils, etc.
- Legos, Kinex, Meccano set, Makedo (cardboard construction kits)
- Tape, glue, wire, string
- Optional: paint

Session Agenda

Activity	**Description**
Research (15 min-1 hr)	• Discuss different types of bridges. • Guide them to the Additional Resources Packet for more information on bridge types.
Activity (30 min-2 hours)	Research, design, and build a bridge
Recap/Discussion (10 min- 30 min)	• What happened to the Tacoma Narrows Bridge? How has the incident impacted bridge design? • How did the Millennium Bridge in London earn its nickname the "Wobbly bridge"? • What is the longest bridge in the world? What are some of the challenges the engineers responsible for the project faced? • Maintain your company's professional image. Write a letter to the community near the construction site of your bridge that apologizes for any inconvenience, thanks them for their patience, and explains why this project is important and how it benefits them.
Above and Beyond	• Design a drawbridge to allow large boats to pass beneath your bridge. • Add another deck to your bridge. How does this affect the type of bridge you may use?
Suggested Evaluation (5 min- 30 min)	• Consider the weight, length, strength, and cost each of the bridges. • Test each bridge until failure. Which bridge held the most weight?

Session 6: Tunnel Vision

Introduction

"As your track goes through the center of London, it must go underground as there is not enough space for it above ground; thus your train will need to travel through a tunnel like the rest of the Tube. Your tunnel will need to accommodate the size of your train and the weight of the rock and water above it. Longer, stronger tunnels will be more likely to be included on the finished tube line. Be sure that your planned tunnel does not disrupt any existing tube lines!"

Concepts

- Forces (Physics)
- Static systems (Civil/Mechanical engineering)
- Construction materials (Materials science/Engineering)

Learning Outcome(s)

- Breadth and depth of engineering (Civil engineering, materials engineering, applications to physics)

LTM Exhibit Connection

- Brinell reinforcements
- Greathead Shield model
- Cut-and-cover diorama

List of Materials

- Acrylic, cardboard, wood, newspaper
- Ruler, tape, glue, wire, string, paper, pencils, etc.
- Legos, Kinex, Meccano set, Makedo (cardboard construction kits)
- Optional: paint

Session Agenda

Activity	**Description**
Research (15 min-1 hr)	• What is the objects used for? • Discuss various materials used to build the underground tunnels. • Brainstorm new shapes for tunnels.
Activity (30 min-2 hours)	Research, design, and build a tunnel
Recap/Discuss (10 min- 30 min)	• What costs were associated with your structure? • Could your structure have any unexpected impacts on the area around it? • What sort of maintenance might be associated with your structure?
Above and Beyond	• Add lighting to your tunnel with a simple circuit. • Have students research and design a way to dig a tunnel. If possible, have them implement their method/machine to make a tunnel through sand or clay.
Suggested Evaluation (5 min- 30 min)	• Consider the width, length, strength, and cost each of the tunnels. • Test each bridge until failure. Which bridge held the most weight?

Session 7: Station Fixation

Introduction

"I, the Mayor of London, now want your company to design a station which will be the signature station for the line. Your company must design, create, and build a station that is not only iconic but gets passengers off of the train in a timely manner."

Concepts

- Traffic flow (Mathematics)

Learning Outcome(s)

- Benefits of soft skills (Advertisements and persuasive skills)
- Breadth and depth of engineering (Civil engineering)

LTM Exhibit Connection

- Architecture plans
- Escalators/Lifts
- Important people: Charles Holden
- Waterloo Station

List of Materials

- Acrylic, cardboard, wood, newspaper, tape, glue, wire, string
- Ruler, paint, paper, pencils, etc.
- Legos, Kinex, Meccano set, Makedo (cardboard construction kits)

Session Agenda

Activity	**Description**
Research (15 min-1 hr)	Research various stations (i.e.: Baker Street, Tottenham Court Road, Canary Wharf, etc.)
Activity (30 min-2 hrs)	Students will research, design, and build a tube station
Recap/Discussion (10 min-1 hr)	• Can you design signs and directions for passengers at your station? • Where would you place signs to make them the most effective? • What would you name your station? Write a brief speech to give to the public to explain why you picked this name.
Above and Beyond	• Many of London's Tube stations are very old and need to be renovated. Switch stations with another team and see if you can improve their design. Be sure to keep elements that work well! • Sometimes severe storms can flood an underground train station. Can you design a pump/drainage system to quickly get trains up and running again? • Add lighting to your station with a simple circuit.
Suggested Evaluation (5 min)	• Which station is the most environmentally sound? • Which team best addresses the concept of passenger flow? • Which team had the most laconic posters? • Which station has the most innovative design?

Session 8: Time is of the Essence

Introduction

"Planning out the design of a train or railway station does not end with proposing a model and materials involved. Preparing a schedule and planning use of resources for complex projects is an important part of your proposal to make sure your project finishes quickly and efficiently."

Note: It is critical to the success of this activity that you, the teacher, read through the related materials in the Resource Handbook. There are three handouts for students (Theater Production, Station Design, and Float Time) and an explanation of the Critical Path Method (CPM) for your reference.

Concepts

- Critical Path Method (CPM) (Mathematics, computer science)

Learning Outcome(s)

- Benefits of soft skills (Critical thinking and logistics)

List of Materials

- Paper, pencils
- Sticky notes (Optional, 1 1/2" x 2" or 2" x 2" size will work best)

Session Agenda

Activity	Description
Research (15 min)	• Ask students what they think of when they hear the word “schedule”. • Ask students if they have made a schedule, and what methods they used. Collect terms mentioned in this and the previous question that relate to those used in CPM.

Activity 1
(Design)
(30 min)
	• Hand out the Theater Production sheet (from the Resources Handbook).
	• Introduce the definitions for projects, activities, and network diagrams.
	• Work through the steps using the Theater Production sheet as a class.
	    o Look at the tasks involved in creating a theater production. Notice which activities depend on other activities and the logic involved. This can be very brief if the lesson needs to finish quickly.
	    o Create the network diagram using the start provided on the sheet. (Optionally, have students use sticky notes to represent each activity and stick the sticky notes to a sheet of paper to draw in arrows, instead of using the provided diagram.)

Activity 2
(Build)
(1 hr)
	• Hand out the Station Design sheet (from the Resources Handbook).
	    o Companies will work through the station design.
	    o Go over the questions as a group, emphasizing how the students determined their answers.
	    o These questions are motivation for the concept of float time, so it is important that students see the connection between these questions and the next activity.
	• Hand out the Float Time sheet (from the Resources Handbook).
	    o Work through the theater production example together, and have students complete the station design problem in their companies.

Recap/Discuss
(20 min)
	• What patterns did you notice in the float time for different activities?
	    o Activities on the critical path will always have zero float time.
	• What happens to the float time on activities like Rehearsals and Actor Runthrough if choosing a cast takes one day longer than expected?
	• This method is often used with much larger projects containing hundreds of activities. What challenges would you expect with something of this size?
	    o Relate the history information on the CPM from the Resources Handbook, or have students look up its origins.
	• Accidents and delays happen. Which paths are near critical paths, and what are some likely delays for the theater or station schedules that could cause a new critical path to appear?

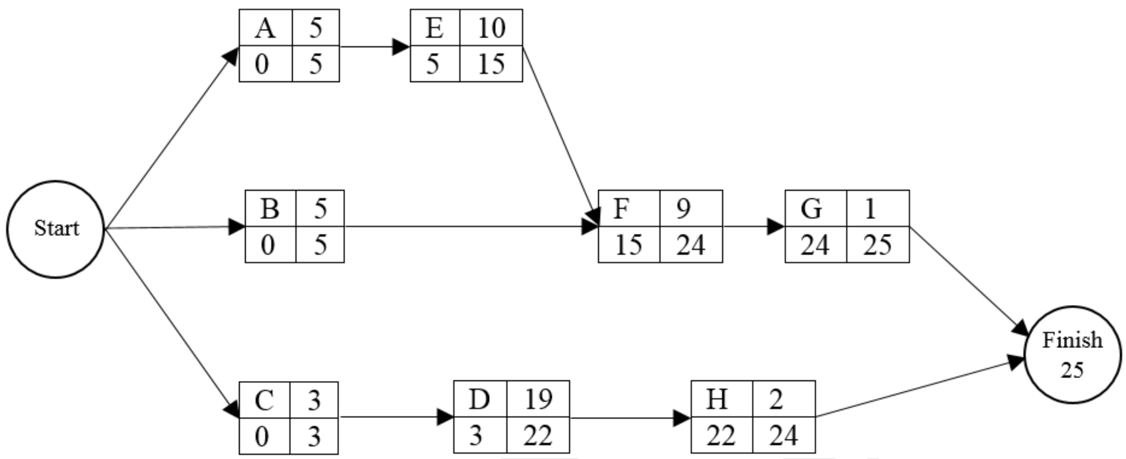
Above and Beyond	• Communicating your ideas clearly to others is important. Present your station design schedule to the Mayor of London, who is unfamiliar with network diagrams and the critical path method.

	o Have students compare their results. Where did each company do well, and what was unclear? • Look further into how scheduling computer programs have developed since the CPM. Create a timeline, or compare the methods used over the years, and look into what motivated the changes. • There are ways to challenge students using additional complications from the method for students particularly strong in logical thinking and mathematics. Providing the cited calculations paper may be useful at this point, or have students conduct research as needed. o Have students modify the station or theater schedule or create a new one to use one of the following concepts: ▪ These examples used finish-to-start links between activities, where the subsequent activity cannot begin until the preceding activity has finished. ▪ Sometimes lag is used to specify a number of time units that must pass between one activity ending and another beginning. Lead time, or negative lag, allows an activity to start before the preceding activity has finished. o The chosen links or lag times should come with brief explanations relevant to the schedule scenario.

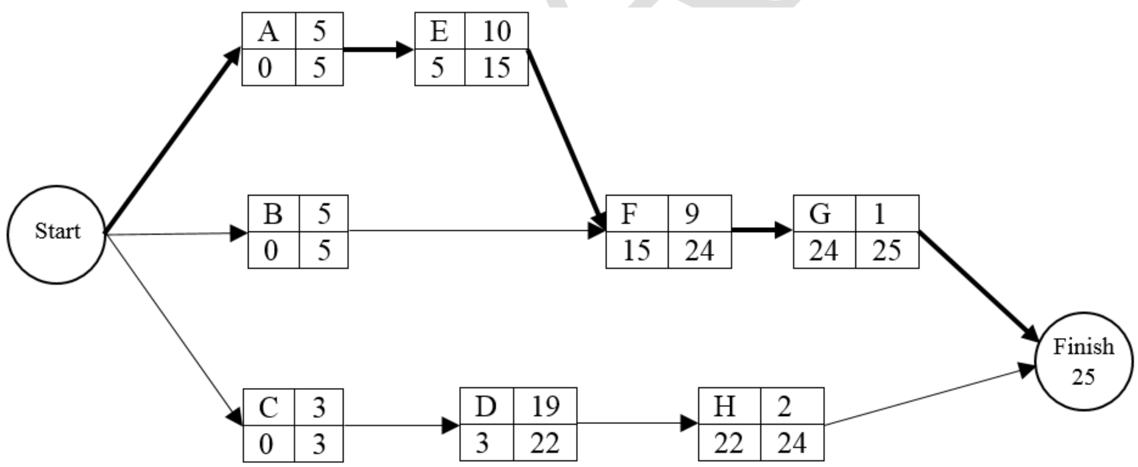
Solutions to Theater Production

Finish adding the remaining tasks in this diagram. What happens when a task has multiple preceding tasks? Choose the latest finish time of the preceding tasks as the start time of the next task.

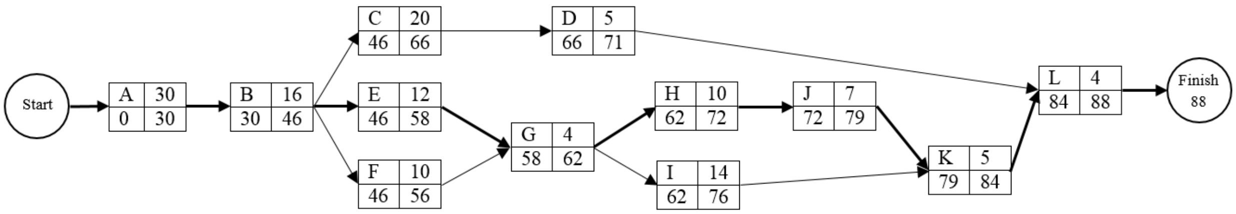
The diagram with all tasks added should look like this:



This version has the critical path marked:



Solutions to Station Design



What is the total time estimate for the project? Which tasks are on the critical path?

Total time is 88 days, critical path tasks are A, B, E, G, H, J, K, and L.

Consider the following questions independently of one another, working from the initial schedule:

- The inspection of the electrical work reveals a safety violation that takes three days to fix. How does this impact the total project time? It adds three days to the total project time.
- The workers hired for the flooring go on strike, causing a delay of four days. How does this impact the total project time? It adds one day to the total project time.
- Under pressure to finish the station, one of the managers brings in a larger and more efficient crew to install fixtures, reducing the time required from seven days to two. How much time is saved by this over the entire project? Three days are saved over the entire project.
- There is a shortage on the materials used for the siding on the station's exterior. How many days can the siding be delayed by without delaying the entire project? The siding can be delayed by 13 days without delaying the entire project.

Solutions to Float Time:

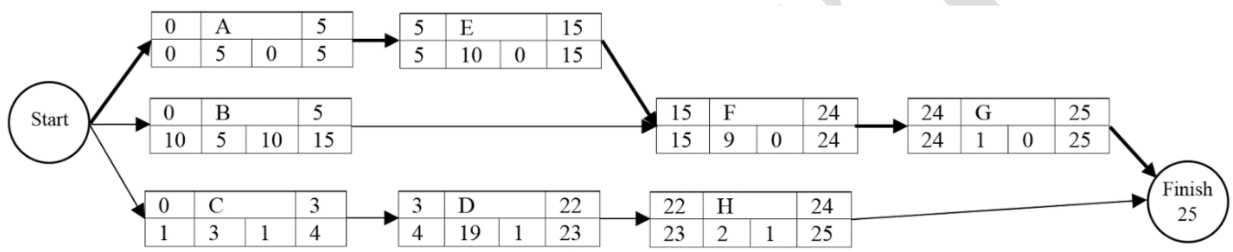
Find the LFT and LST for G and H. From the definition of float given above, what is the float time for G and H? What is the calculation you are using to determine float?

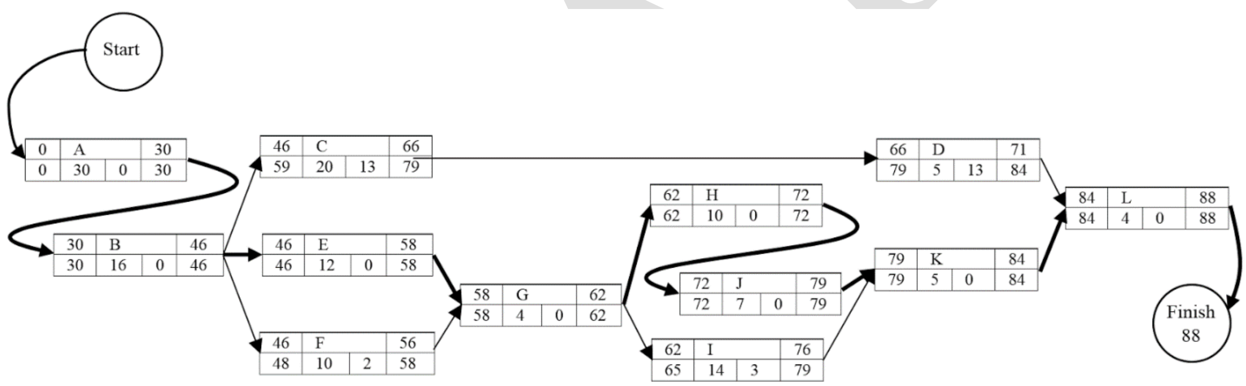
The LFT and LST for G are 25 and 24 respectively, and its float is 0.

The LFT and LST for H are 25 and 23 respectively, and its float is 1.

Float = LST - EST or Float = LFT - EFT

What happens when a task has multiple tasks depending on its completion, as in the start node? The task with the earliest LST determines the LFT of the preceding task.





Session 9: Show Time!

Introduction

"You have worked hard to create what you did, be it a tunnel or a full rail line. You have learned a lot, considered many different ideas, and tested and improved your designs. Now is the time to show off! Present your proposals to myself as well as your competitors."

Concepts

- Public speaking skills
- Persuasive writing skills
- Explain your ideas
- Confidence

Learning Outcome(s)

- Benefits of soft skills (Presentation, communication)
- Empower students (Boost confidence)

Medium

- Ultimately up to the discretion of the teacher. However, some suggestions are:
- Persuasive written justification
- Slide-based presentation; a demonstration
- Submitting a technical report of theorized performance
- Testing data
- Cost analysis

Session Agenda

Activity	**Description**
Main Activity	Present your proposal
Suggested Evaluation	• Once again, up to the discretion of the teacher. • Does the train work? • Did the students show overall improvement in presentations? • Was the team professional? • Did the team engage with their audience? • Did they provide a clear description of the steps they took in designing their railway?

Session 10: A Journey Back in Time

Explore the Museum!

Introduction

"Throughout this program you have been working through real engineering and mathematical problems that have affected transportation infrastructure for centuries. The London Transport Museum beautifully displays many of these concepts, and explains how engineers have tackled these challenges throughout history. As you explore the museum think about your how responses to real problems differ from the engineers', and realize the power engineering has to literally shape a city. "

Learning Outcome(s)

- Inspire students (Hands-on examples of engineering)

On the way to the museum:

Have students consider the transportation that they are taking (Tube, bus, foot).

At the museum:

- Have students consider the following questions:
    - Methods of creating tunnels used over time (Cut-and-cover vs. Crossrail).
    - The effect public transportation has had on the shape, economy, and culture of London.
    - How Victorian-era technology is integrated with modern innovations.
    - Efficient methods of moving the maximum number of people through stations and onto trains.
    - How transportation companies have maintained their image.

Full Speed Ahead!

{The Student Handbook}

The London Transport Museum (LTM) features all modes of transport, old and new

Session Outline

Research Phase

Every session will begin with some background research. Like all engineers, you must do your research first before designing anything. This phase is your chance to learn about how each activity applies to the real challenges engineers face.

Design Phase

Use the information from the Research Phase to fuel your design process. Make sure your design follows the Mayor's specifications.

Build Phase

After designing a railway component, you will build and test it. Be creative and take risks! Oftentimes you will learn more from watching what does not work than merely picking what does. Note that this section may not be present in every session.

Recap/Discussion Phase

This phase will conclude each activity. This is where you will communicate and justify your ideas to other companies and the Mayor in the form of a presentation, essay, or other medium.

Session 1: Business as Usual

Task: Create a company, logo, motto, code of conduct, and mission statement.

From the early days of the roundel to Edward Johnston's custom typeface, the London Transport Museum (LTM) portrays the development of the London Underground brand

Research

- Brainstorm logos (i.e.: sports, transportation, science, film, food, drink, etc).
- What logos and mottos do you find appealing?

Design

- Create your company. Select a name, choose a motto, and design a logo.
- Collaborate on a company mission statement to convey your company's purpose and goals.
- Deliberate on a code of conduct. How will you handle distribution of labor and disagreements? What other issues might your company face?
- Make sure all of the above elements highlight your company's strengths and help it stand out from its competitors.

Build

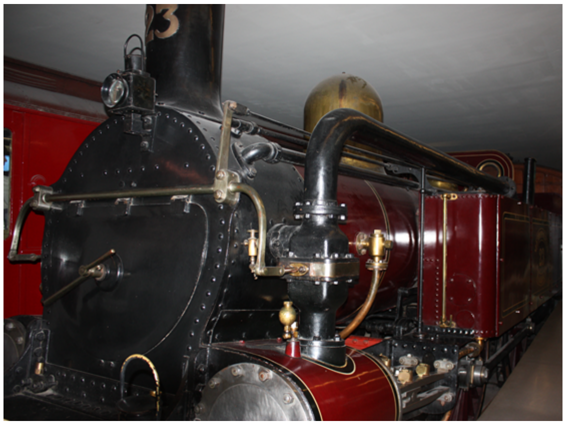
- Play the Transportation Transaction game

Recap/Discussion

- What did you learn about companies and the way they function you did not know before?
- Explain the reasoning behind your company name, motto, logo, mission statement, and code of conduct in a brief presentation.

Session 2: Train of Thought

Task: Design and build a train and track.



This specially modified train (left), now housed at the London Transport Museum (LTM), once ran through the first Tube tunnels. As the model on the right shows, pollution in these early tunnels was a major problem.

Research

- What factors are contributing to greater use of London's public transportation systems?
- What is the basis of the modern design of Tube maps? Who introduced this system, and in what year? What was his or her professional background?
- What factors affect a train's performance?
- How have trains evolved since their inception?
- What types of track exist?

Design

- Weigh the benefits and drawbacks of each available material.
- What will you try to optimize with your train's design?
- How will you ensure a safe and comfortable journey for your passengers?
- How can you make your train more environmentally friendly?

Build

- Your train may have a minimum of 2 compartments.
- Your train must fit in an imaginary box 50 cm long, 15 cm high, and 15 cm wide.
- Your track must be at least 1 meter long.
- Your train must be able to carry the amount of weight or number of passengers requested by the Mayor.

Recap/Discussion

- Perform a cost analysis on your train based on the prices of the materials you used.
- How well does your train perform relative to your expectations?
- How might you improve your train's design? How would you reduce its cost or weight? How would you make it more aerodynamic?

Session 3: Mixed Signals

Task: Research rail signaling and construct a light sensor.

A multi-aspect signal from the Victoria line on display at the London Transport Museum (LTM).

Research

- How do engineers really know where a train is at all times?
- What types of signals do trains use and why?
- How does a circuit work?
- What is current and voltage and how are they related (Hint: research Ohm's Law)?
- What objects do you need in a circuit?
- Research and explain in your own words Kirchhoff's Voltage and Current Laws.
- Research the various symbols used in circuit diagrams.

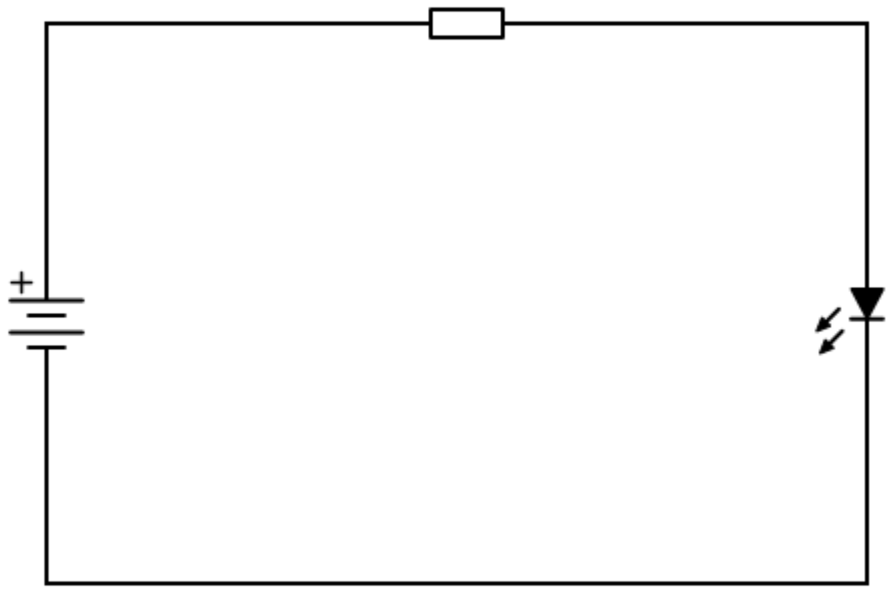
Design

- Design a conceptual signaling system for your train and track.
- Where might you place signals to ensure your train operates safely?
- What is the minimum number of unique signals you need to employ?

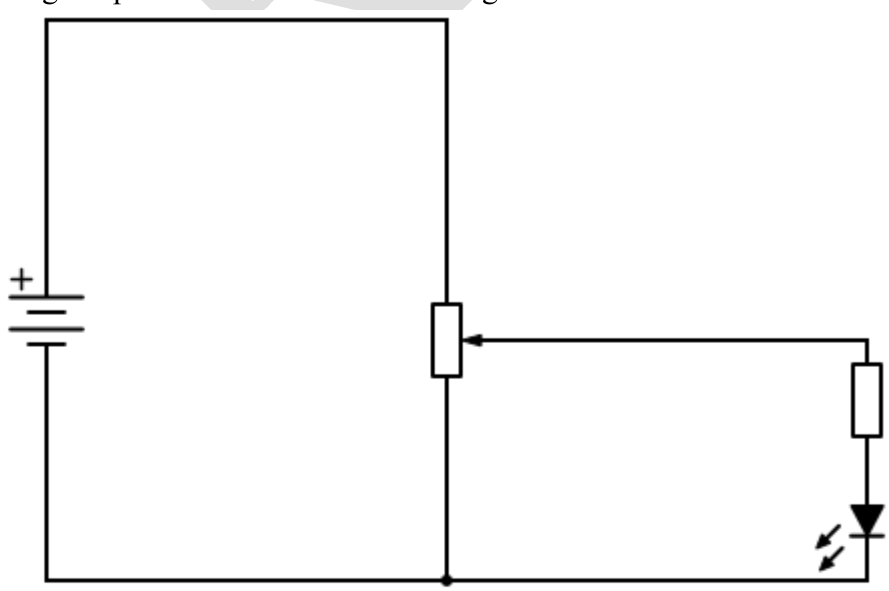
Build

You will need to refer to this session's material in the Resource Handbook in order to build the circuits.

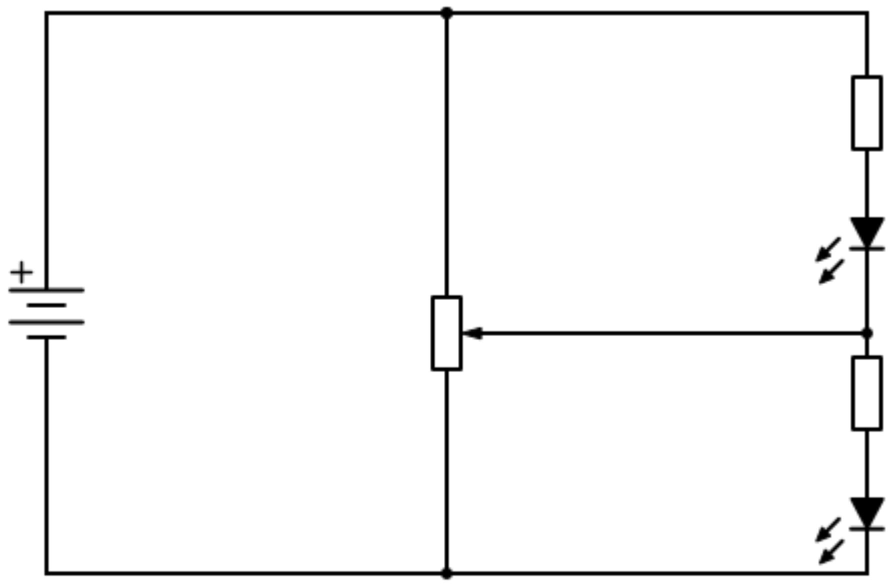
1. Begin by constructing a simple circuit to power a light emitting diode (LED) using the circuit diagram below. Unlike resistors, diodes only let electricity flow in one direction. Make sure you put yours in the right way using the diagram found in the Resource Handbook or you could burn out the component. You can also look there for details on how a breadboard works.



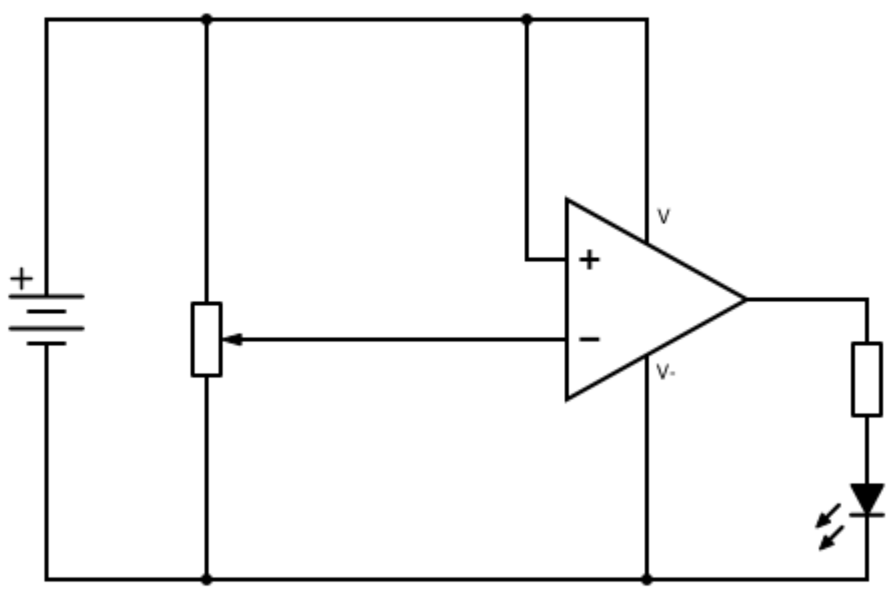
2. Now that you understand how the rows of a breadboard are connected and how to place a diode in a circuit, add the potentiometer to the circuit. This will allow you to dim the led by rotating the potentiometer's knob or using a screwdriver.



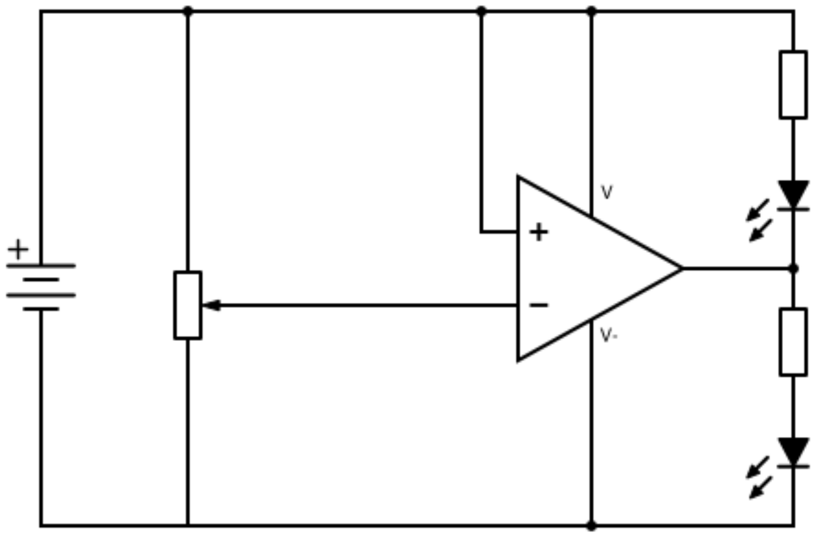
3. The next step is to add another LED to the circuit. You should see the LEDs gradually fade in and out as you rotate the potentiometer. When the potentiometer is completely rotated to either side, only one of the LEDs should be lit.



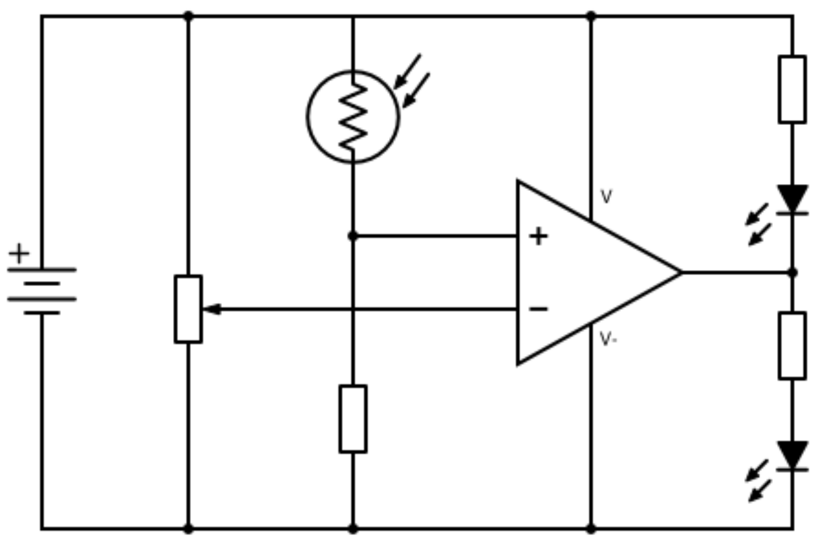
4. Now comes the tricky part, adding the operation amplifier (or the op amp, for short). You will need to look at its datasheet to figure out how to connect each pin, the silvery pieces that insert into the breadboard, of the chip. You will need to connect voltage supply, ground (GND), the + and - inputs, and the output. Your teacher may provide the datasheet or can be found with an internet search of the text on the top of the chip. Notice that the LED only turns off when the potentiometer is rotated completely to one side.



5. Just as you added the other LED in step 3, you will do the same here. Note, only one LED should be on at any one time and they will only change when the potentiometer is rotated all the way to one of its sides.



6. The last two components to add are a resistor and photoresistor. Adding these components will allow your circuit to react to changes in light. You will have to tune your circuit by rotating the potentiometer until the LEDs change.



Recap/Discussion

- What is the importance of electronic circuits in daily life and train engineering?
- How might engineers design failsafe systems for train signaling?
- Where else could you use the circuit you created in this activity on trains?
- Why might the circuit you designed be impractical for real train applications, especially in the Tube?
- Swap the positions of the photoresistor and the 3.3kΩ resistor. How does this affect the circuit?

Session 4: Mind the Gap

Task: Using your gathered research, design and build a bridge.

These pictures at the London Transport Museum (LTM) show how Blackfriars Bridge has changed over time

Research

- What is a truss bridge? Why was this type of bridge so common? Look into three different types of truss designs (Pratt, Warren, Howe, or others). Weigh the pros and cons of each.
- What is a more modern type of bridge design (Suspension, girder, segmental, etc)? Why have these designs become so popular in recent years?
- Why were arches so common in early bridges? Are they still used today?
- What materials are used in bridge design? How do engineers reinforce concrete?

Design

- How will you make your bridge as strong as possible? Remember, in many bridges, including trusses, the main support lies below the deck.
- How can you add a support in the middle of the span?
- What type of bridge will you make? What are the benefits of the style you chose?
- How can you make your bridge aesthetically pleasing? Remember, bridges are highly visible.
- How can you make your bridge more environmentally friendly? Study the solar panels on Blackfriars Bridge for inspiration.

Build

- Your bridge must be at least 30 cm long.
- Your structure should be able to support as much weight as possible.
- You may use any materials the Mayor approves. However, lighter, cheaper bridges will receive more points.

Recap/Discussion

- What happened to the Tacoma Narrows bridge? How has the incident impacted bridge design?
- How did the Millennium bridge in London earn its nickname the "Wobbly bridge"?
- What is the longest bridge in the world? What are some of the challenges the engineers responsible for the project faced?
- Maintain your company's professional image. Write a letter to the community near the construction site of your bridge that apologizes for any inconvenience caused by the construction, thanks them for their patience, and explains why this project is important and how it benefits them.

Session 5: Tunnel Vision

Task: Using your gathered research, design and build a tunnel.

These models at the London Transport Museum (LTM) show two ways to tunnel by hand, the cut-and-cover method (top) and with a Greathead Shield (bottom).

Research

- Why have arches and tubes consistently been used for tunnels for thousands of years?
- What is the main problem with using coal locomotives in tunnels? How did Victorian engineers attempt to solve this problem?
- Some cities have elevated rail lines instead of underground networks. What are the pros and cons of this system? Is this solution feasible for modern London?
- What is the cut-and-cover method of tunneling? Is this technique feasible today?
- What is tunnel shielding? Who was the engineer responsible for the first successful deployment of this technique, and on what project was it used?
- What materials are used in the construction of tunnels?
- How have engineers been able make bridges and tunnels longer and deeper than ever before?

Design

- How many lanes will your tunnel have?
- How can you maintain the air quality of your tunnel?
- How will you make your tunnel as large and strong as possible?
- What materials are most useful for this application?

Build

- Your tunnel must be at least 30 cm long.
- Your structure should be able to support as much weight as possible. Points will also be awarded for the cheapest and largest tunnel.

Recap/Discussion

- What costs were associated with your structure?
- Could your structure have any unexpected impacts on the area around it?
- What sort of maintenance might be associated with your tunnel?

Session 6: Station Fixation

Task: Design and build a tube station.

Model train stations on display at the LTM

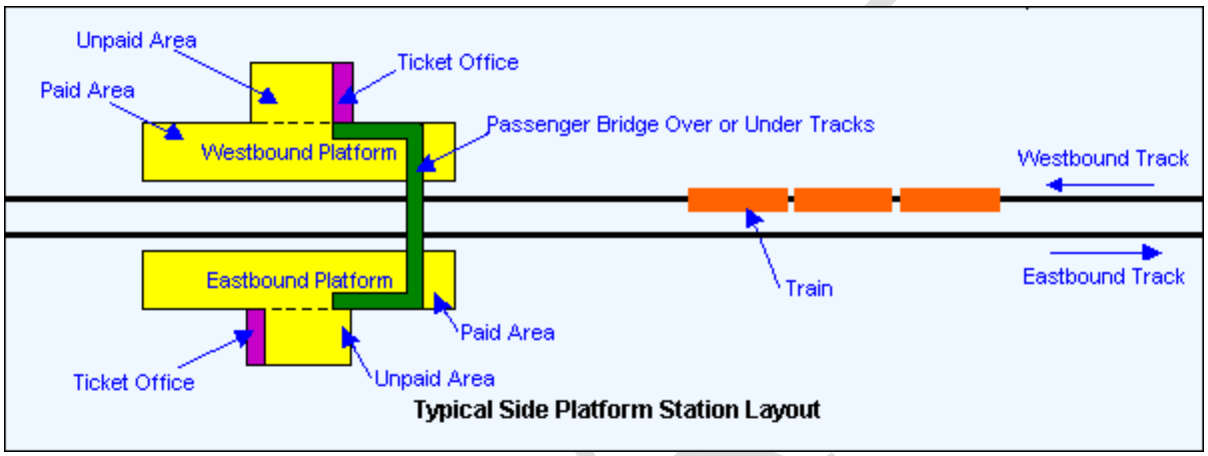
Research

- Brainstorm underground tube stations that you have visited in London. Are there any tube stations that stand out? Why? If not, how would you make them stand out?
- What materials are used in building a station? Think about what materials you would use.
- What area of London will your tube line service? Make sure it goes through all the zones of the tube (zones 1 through 6). Will it cross other tube lines? For each zone, decide where your stations will go. Refer to the Resource Packet for the tube map.
- Decide where your signature station will go. Why did you choose that location? Be prepared to justify this choice.

Design

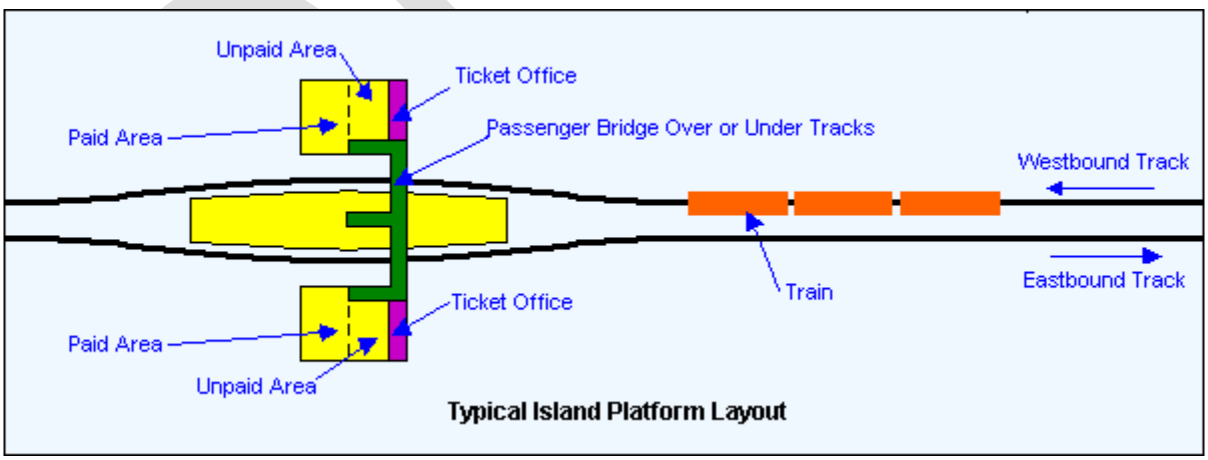
There are multiple designs for station platforms, including: side platform, island platform, elevated platforms, and an elevated with ticket halls below platforms.

- **Side platforms** are the most basic design for a double track railway line. It has two platforms (one for each direction of travel). Each platform has a ticket office and other passenger facilities (i.e.: bathrooms, refreshments, etc.). The two platforms are connected by a footbridge.



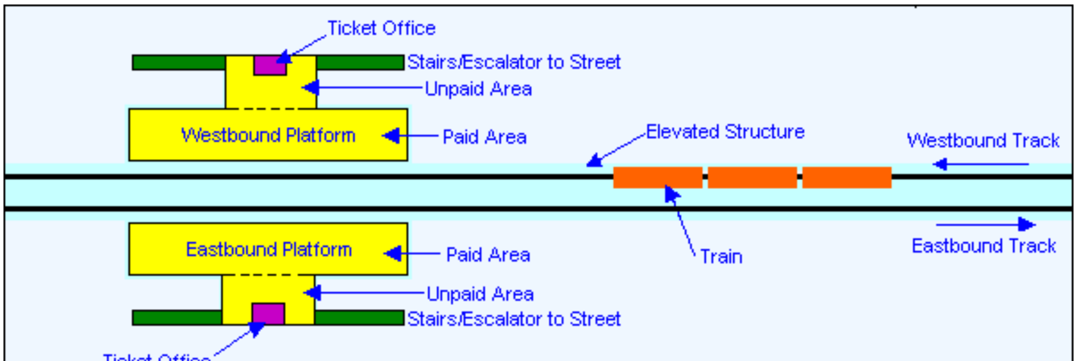
Typical Side Platform Station Layout

- **Island Platform Station** is the cheaper form of station construction. It is a single platform serving two tracks passing on either side. Island platforms are generally wider than single platforms. A bridge or underpass is usually provided.



Typical Island Platform Layout

- **Elevated Station with Side Platforms are popular in cities.** They are cheaper than underground railways and are better at flowing passengers out of the station. *Note: the track is elevated.*



Typical Elevated Side Platform Station Layout

- The **Elevated Station with Ticket Hall Below Platforms** have the ticket office and gate lines above or below the platform level. Because many of the stations are built at road intersections, this station design may have a required height structure to be built in order to allow road traffic (cars, buses, trucks, etc.) to pass beneath.

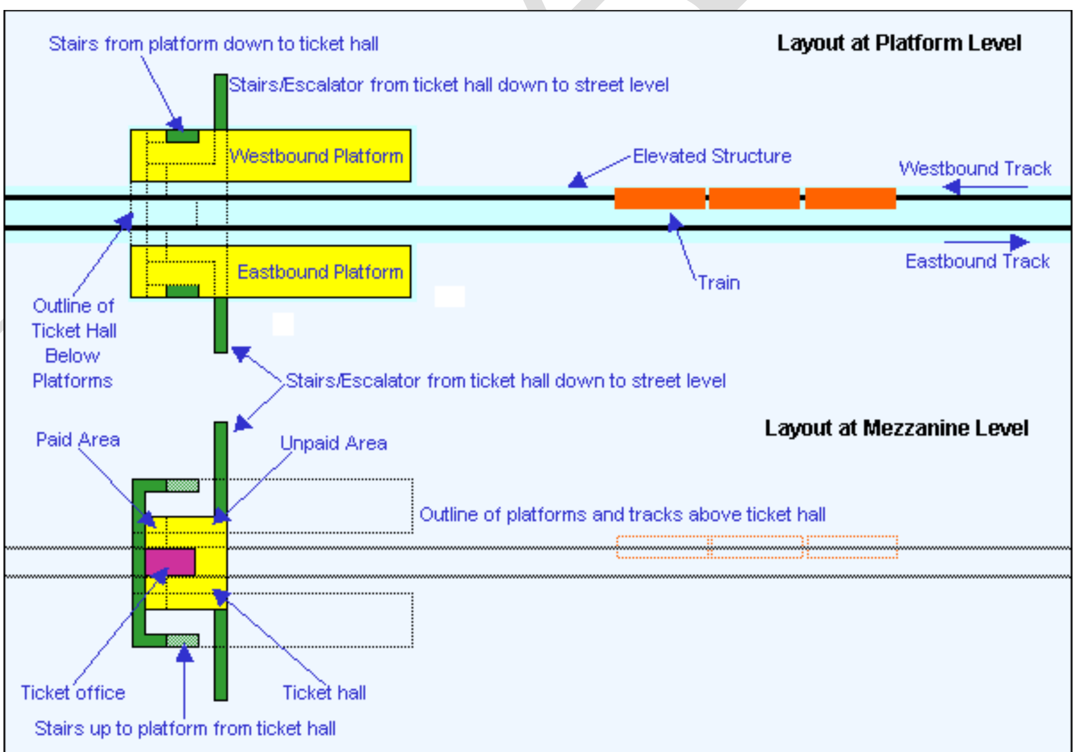


Diagram of Elevated Station with Ticket Hall Below Platforms

Keeping the above platform designs in mind as well as your own experience travelling on the tube, design your platform. Remember, train stations get very hectic during rush hour. How would you guide your crowds around the platform? Create a floor plan of your platform and entrances/exits.

- How will:
    - Passengers reach the trains from street level? And how will you make your station accessible to people with disabilities?
    - Electrical devices in your station be powered? How will you reduce the environmental impact of your station?
    - Customers receive travel updates?
    - Passengers be able to buy tickets or Oyster cards?
- How much will your design cost? When all the elements are put together, perform a cost analysis.

Build

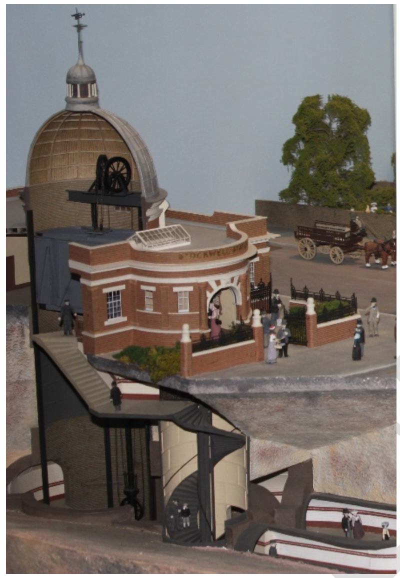
- Your platform must accommodate all cars of your train.
- Include placeholders for escalators, stairs, ramps, and/or elevators.
- Ensure passengers can move about your station quickly.
- Mind the gap! Make sure your train gets as close to the platform as possible.

Recap/Discussion

- Can you design signs and directions for passengers at your station? What would your signs say? Where would you place signs to make them the most effective?

Session 7: Time is of the Essence

Task: Use the Critical Path Method (CPM) to schedule a complex project.



This model at the London Transport Museum (LTM) shows the many complex features of an early Tube station. As modern stations feature ever more amenities, efficiently constructing them has become a complicated challenge.

Research

- Explore your previous knowledge of schedules and your intuitions on how they may be designed.

Design

- As a class, explore the design of the Critical Path Method using the **Theater Production** example.

Build

- Create a schedule for the station design using the provided table.
- What is the shortest length of time required to complete all activities in the station design? Which tasks are on the critical path?
- Answer the remaining questions included with the station design activities, keeping in mind how you arrived at your answers.

Recap/Discussion

- What patterns did you notice in the float time for different activities?
- What happens to the float time on activities like “Rehearsals” and “Actor Runthrough” if choosing a cast takes one day longer than expected?
- This method is often used with much larger projects containing hundreds of activities. What challenges would you expect with something of this size?
- Accidents and delays happen. Which paths are near critical paths, and what are some likely delays for the theater or station schedules that could cause a new critical path to appear?

Session 8: Rail Lines and Line Graphs

Task: Analyze rail graphs.

This model of London at the London Transport Museum (LTM) shows the connection between the city's buildings and the Underground's Tube lines (the front and back of the model are the top and bottom images, respectively.

Research

Work through the next few physics problems using basic kinematic relations. Try to find the necessary formulas online or in your textbooks (Hint: look for the major kinematic equations, Newton's Second Law, and energy and momentum equations), but if you are stuck ask the Mayor for help. How might engineers use the information derived from this mathematical analysis? How might you use it in your own railway design?

1. Your train has a mass of 250,000 kg and is traveling with a kinetic energy of 15.125 MJ. What is the train's velocity? **Ans: V = 11 m/s**

2. Assume your train's air brakes can exert a force of -200,000 N on the train. What rate of deceleration does this cause? Include a free body diagram of this scenario.
   Ans: a = -.8 m/s/s

3. Signals tell conductors the condition of the section of rail ahead. Put very simply: green means “Go”; double yellow means “The next signal is yellow”; yellow means “Slow down. The next signal is red”; and red means “Stop”. Obviously, a station would display a red signal to allow passengers to enter and exit the train. How close to the station’s red signal can an engineer place a yellow signal so your train can safely stop? How long does this deceleration take? **Ans: t = 13.75 s; X = 75.625 m**

4. (Optional Problem) Now assume the electric motor on your train can exert a force of 125,000 N on the train. Draw a free body diagram and find the rate at which your train can accelerate. If your train is 100 m long, how much time does it take for it to fully leave the platform? Assume the platform is the same length as the train. What is the momentum of your train at this instant (Hint: You will need to find the velocity of your train in order to calculate its momentum)?
   Ans: a = .5 m/s/s; t = 20 s; V = 10 m/s; p = 2.5*10^6 kg*m/s

Design

Analyze the simple graphs shown below. For each scenario find:

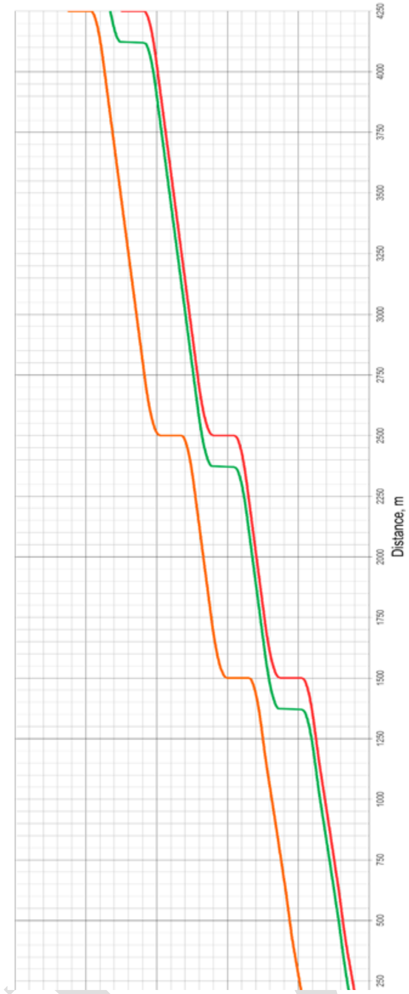
- The number of stations on this section of line.
- The rail line’s headway. Headway is defined as the time between when identical points on two trains pass through the same point on a rail line. A simpler definition is: the time interval between two vehicles (automobiles, ships, or railroad or subway cars) traveling in the same direction on the same route.
- The length of the train being analyzed.
- Whether or not a collision will occur; if so, how can you fix the problem? If there are no collisions, how can you increase the efficiency of the line?
- The trains delay a certain distance before accelerating when they enter a zone with a higher speed limit; why do you think that is?

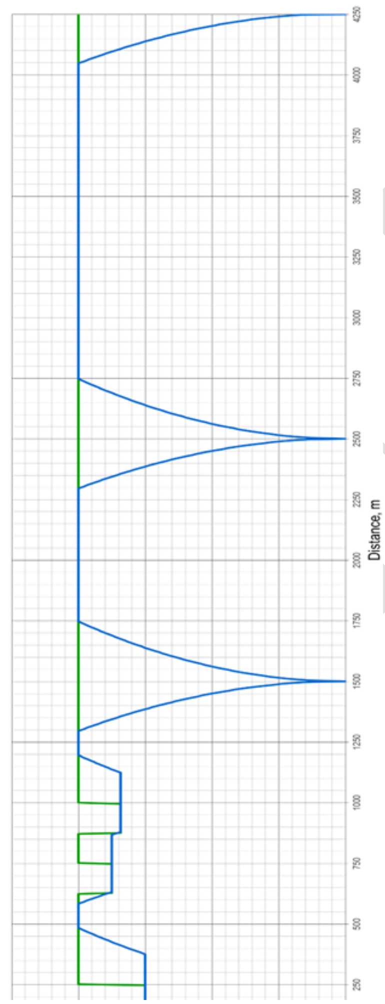
Identify differences between the speed versus time graphs of successful cases and problematic ones. Compare the train length and headway from each of the three graphs; can either of these values be changed to optimize the line or prevent collisions?

KEY:

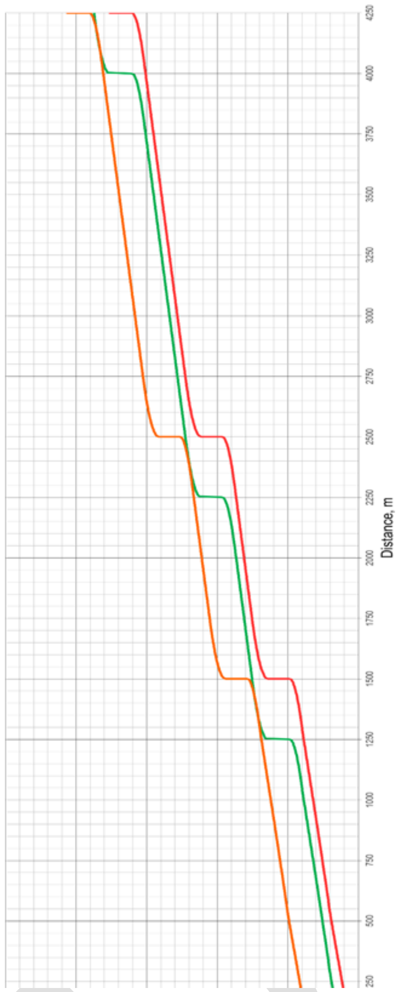
- Top Graph
  - Front of Train 1 (red)
  - Back of Train 1 (green)
  - Front of Train 2 (orange)
- Bottom Graph
  - Train’s speed (blue)
  - Speed limit (green)

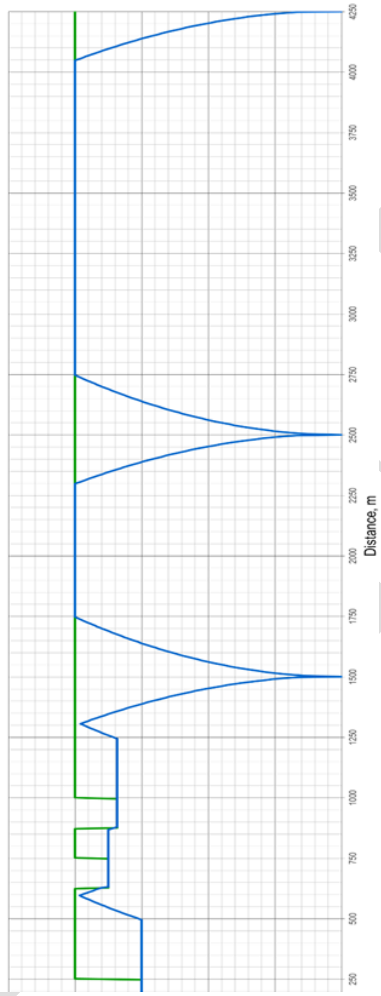
Case 1:



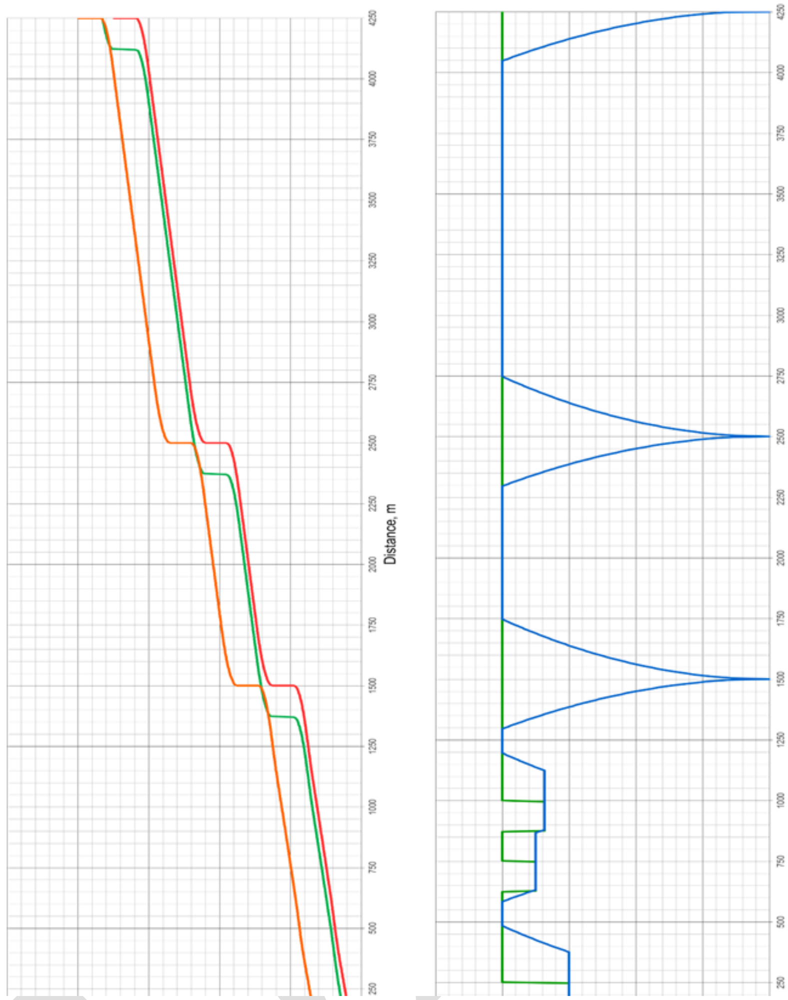


Case 2:





Case 3:



Recap/Discussion

Communicating complex ideas to people without a science background is one of the many challenges engineers face each day. Write a clear, concise report of the calculations you completed, but keep your audience in mind. Remember, the Mayor probably will not want too much detail on how you generated your solutions (although other engineers certainly will), but will only be concerned with your final results. Include an explanation of the features shown on the train graphs (~250-500 words).

Session 9: Show Time

Task: Present your proposal to the Mayor and competitors.

The Skills Room at the London Transport Museum (LTM) is used for professional presentations

You have worked hard to create what you did, be it a tunnel or a full rail line. You have learned a lot, considered many different ideas, and tested and improved your design. Now is the time to show what you have achieved!

Present your model to the Mayor and your competitors. This is your chance to explain everything you have learned, and by extension why your design is the best. You can focus on many different and important aspects of your design (i.e. - strength, safety, longevity, cost, appearance, etc.) in your presentation as long as you remember to make your business stand out.

Ultimately the Mayor will decide how they want proposals, but consider: a persuasive written justification; a slide-based presentation, a demonstration, submitting a technical report of theorized performance and actual testing data, and/or a cost analysis. The ability to explain your ideas to people, especially those without a background in science, is an absolutely crucial part of the team-based world of engineering!

Session 10: A Journey Back in Time

Task: Trip to the London Transport Museum.

A view from the mezzanine at the London Transport Museum (LTM)

Suggested exhibits to visit that correlate to the sessions studied in the program are listed in the table below. Feel free to explore the museum!

Time Period	Exhibit
1800s	• First railway • Carriage wheels versus railway wheels • River transport/bridges • Important People: , Elizabeth Birch (Westminster Omnibus Association)

1900s	• **Business as Usual**
	    o Posters
	    o Edward Johnston’s roundel and font
	    o Important People: Frank Pick, Albert Stanley (or Lord Ashfield), Robert Hope Selbie, Harry Beck
	• **Train of Thought**
	    o Interactive monitors/tablets
	    o Steam vs. electric propulsion
	    o Steam/Smoke ventilation display
	    o First through Third class coaches
	• **Tunnel Vision**
	    o Brinell reinforcements
	    o Greathead Shield model
	    o Steam vent diorama
	    o Cut-and-Cover diorama
	• **Station Fixation**
	    o Architecture plans
	    o Escalators/Lift design
	    o Waterloo Station
	    o Important People: Charles Holden

Present-day London	• Train driving simulator • Crossrail* • Future Designs*

(Please note that these exhibits are temporary and may change in the future)*

Jot down some ideas below as you explore the museum: