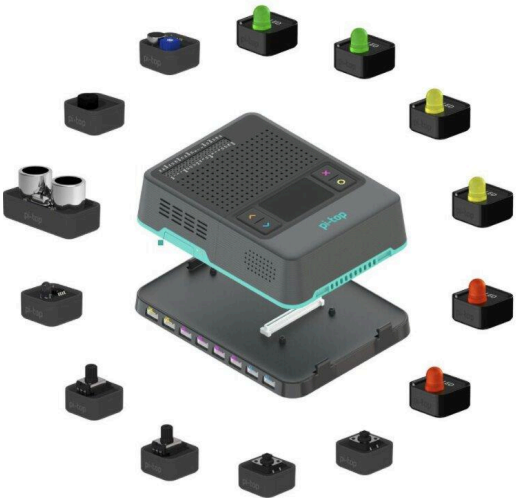
University Transportation Center for Railway Safety (UTCRS)

High School STEM Curriculum



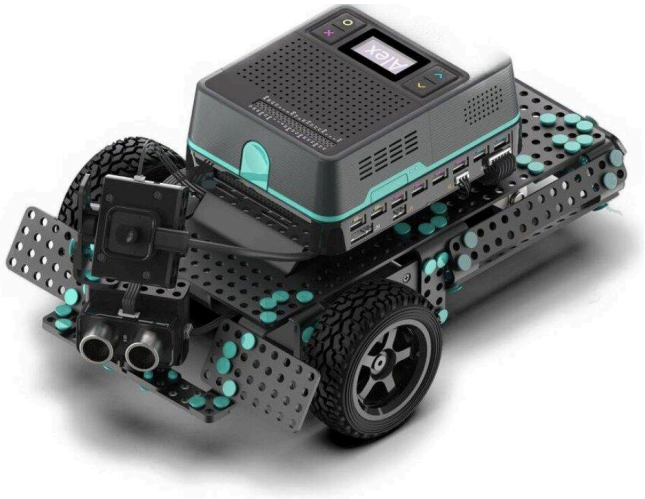


Table Of Contents

2017 Next Generation Science Standards 9-12

HS-PS2-1	Analyze data to support the claim that Newton's second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.
HS-PS3-3	Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.
HS-PS4-1	Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media.
HS-PS4-5	Communicate technical information about how some technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy.

International Technology and Engineering Educator Association (ITEEA) Standards

STEL-1N	Explain how the world around them guides technological development and engineering design.
STEL-2T	Demonstrate the use of conceptual, graphical, virtual, mathematical, and physical modeling to identify conflicting considerations before the entire system is developed and to aid in design decision making.
STEL-2Z	Use management processes in planning, organizing, and controlling work.
STEL-3H	Analyze how technology transfer occurs when a user applies an existing innovation developed for one function to a different purpose.
STEL-4P	Evaluate ways that technology can impact individuals, society, and the environment.
STEL-5H	Evaluate a technological innovation that arose from a specific society's unique need or want.
STEL-6F	Relate how technological development has been evolutionary, often the result of a series of refinements to basic inventions or technological knowledge.
STEL-7Y	Optimize a design by addressing desired qualities within criteria and constraints.
STEL-8P	Apply appropriate methods to diagnose, adjust, and repair systems to ensure precise, safe, and proper functionality.

Texas Essential Knowledge and Skills (TEKS)

SCIENCE TEKS

2021 Texas Essential Knowledge and Skills for Physics

Physics	
Process Standards	
P.P.1	asks questions, identifies problems, and plans and safely conducts classroom, laboratory, and field investigations to answer questions, explain phenomena, or design solutions using appropriate tools and models. P.1(B) apply scientific practices to plan and conduct descriptive, comparative, and experimental investigations and use engineering practices to design solutions to problems
P.P.2	analyzes and interprets data to derive meaning, identify features and patterns, and discover relationships or correlations to develop evidence-based arguments or evaluate designs. P.2(D) evaluate experimental and engineering designs
Readiness and Supporting Standards	
P.5(A)	analyze different types of motion by generating and interpreting position versus time, velocity versus time, and acceleration versus time using hand graphing and real-time technology such as motion detectors, photogates, or digital applications
P.5(B)	define scalar and vector quantities related to one- and two-dimensional motion and combine vectors using both graphical vector addition and the Pythagorean theorem
P.5(D)	describe and analyze acceleration in uniform circular and horizontal projectile motion in two dimensions using equations
P.5(E)	explain and apply the concepts of equilibrium and inertia as represented by Newton's first law of motion using relevant real-world examples such as rockets, satellites, and automobile safety devices
P.5(F)	calculate the effect of forces on objects, including tension, friction, normal, gravity, centripetal, and applied forces, using free body diagrams and the relationship between force and acceleration as represented by Newton's second law of motion
P.5(G)	illustrate and analyze the simultaneous forces between two objects as represented in
P.6(B)	identify and describe examples of electric and magnetic forces and fields in everyday life such as generators, motors, and transformers
P.6(D)	analyze, design, and construct series and parallel circuits using schematics and materials such as switches, wires, resistors, lightbulbs, batteries, voltmeters, and ammeters
P.7(A)	calculate and explain work and power in one dimension and identify when work is and is not being done by or on a system
P.7(D)	calculate and describe the impulse and momentum of objects in physical systems such as automobile safety features, athletics, and rockets
P.8(E)	compare the different applications of the electromagnetic spectrum, including radio telescopes, microwaves, and x-rays

MATH TEKS

2012 Texas Essential Knowledge and Skills for Algebra [A] / Algebra2 [2A] / Geometry [G]

Content and Process Standards	
2A.P.1(A) G.P.1(A)	apply mathematics to problems arising in everyday life, society, and the workplace
A.P.1(B) 2A.P.1(B) G.P.1(B)	use a problem-solving model that incorporates analyzing given information, formulating a plan or strategy, determining a solution, justifying the solution, and evaluating the problem-solving process and the reasonableness of the solution
A.P.1(C) 2A.P.1(C) G.P.1(C)	select tools, including real objects, manipulatives, paper and pencil, and technology as appropriate, and techniques, including mental math, estimation, and number sense as appropriate, to solve problems
A.P.1(D)	communicate mathematical ideas, reasoning, and their implications using multiple representations, including symbols, diagrams, graphs, and language as appropriate
A.P.1(G)	display, explain, and justify mathematical ideas and arguments using precise mathematical language in written or oral communication
Readiness and Supporting Standards	
Algebra 1[A]	
A.2(A)	determine the domain and range of a linear function in mathematical problems; determine reasonable domain and range values for real-world situations, both continuous and discrete; and represent domain and range using inequalities
A.12(B)	evaluate functions, expressed in function notation, given one or more elements in their domains
A.12(C)	identify terms of arithmetic and geometric sequences when the sequences are given in function form using recursive processes
Algebra 2 [2A]	
2A.3(B)	solve systems of three linear equations in three variables by using Gaussian elimination, technology with matrices, and substitution
2A.7(I)	write the domain and range of a function in interval notation, inequalities, and set notation
2A.8(C)	predict and make decisions and critical judgments from a given set of data using linear, quadratic, and exponential models
Geometry [G]	
G.4(A)	distinguish between undefined terms, definitions, postulates, conjectures, and theorems
G.4(B)	identify and determine the validity of the converse, inverse, contrapositive of a conditional statement and recognize the connection between a biconditional statement and a true conditional statement with a true converse
G.4(C)	verify that a conjecture is false using a counterexample
G.9(B)	apply the relationships in special right triangles 30°-60°-90° and 45°-45°-90° and the Pythagorean theorem, including Pythagorean triples, to solve problems

Day 1: Introduction to Python

Theme: Programming Principles, Logic, and Team Collaboration

Day Overview: Students gain an understanding of how engineers collaborate in teams to achieve common goals. They are introduced to Python programming basics, including variables, functions, logic statements, and loops. Using Pi-top [4] robotics accessories such as LEDs, buzzers, and buttons, students program interactive tasks and apply logical thinking. The day emphasizes teamwork, problem-solving, and applying coding concepts to real-world scenarios.

Lesson Objectives:

By the end of Day 1, students will be able to:

- Demonstrate effective teamwork and communication when solving problems in interdisciplinary teams.
- Create Python programs using variables, functions, and logic statements.
- Apply loops to simplify repetitive programming tasks.
- Interface Pi-top [4] hardware components (LEDs, buttons, buzzers) with Python code.
- Build and execute programs that model real-world processes like traffic signals.
- Critically reflect on problem-solving strategies and iterative improvement.

Day 1 at a Glance

Time Frame	Activity	Focus / Goal
30–40 min	Team Building – Logic Labyrinth Challenge	Develop teamwork, communication, and algorithmic thinking by guiding a blindfolded “computer” through a maze.
45 min	Introduction to Variables	Learn to define, assign, and manipulate variables; import libraries and control Pi-top [4] accessories.
60–75 min	Understanding Loops and Logic	Use conditional and relational statements to create loops and algorithms; program an interactive counter on the Mini Screen.
100 min	Programming Hardware – Traffic Lights	Build and code a traffic light system using LEDs, buttons, and buzzers; define functions and handle multiple events.

Activity 1: Team Building – Logic Labyrinth Challenge

Estimated Time: 30–40 minutes

NGSS Connections: MS-ETS1-1, MS-ETS1-2

TEKS Connections: A.P.1(B)

Activity Overview:
Students work in small groups to solve a maze challenge using programming logic. One student is blindfolded ("computer") while the rest ("programmers") devise an algorithm to guide them safely through the maze without collisions. The activity emphasizes collaboration, communication, and algorithmic thinking.

Misconceptions:

Strand / Standard	Key Concept	Common Student Misconceptions	Camp Context Example
P.P.2, MS-ETS1-1	Programming Logic & Engineering Design	Algorithms always work the first time; steps are obvious	Students may give incomplete or incorrect instructions and expect the "computer" to navigate flawlessly
MS-ETS1-2	Team Problem Solving	Teamwork is optional	Students may try to solve the maze individually and fail
MS-ETS1-1	Planning Investigations	Steps can be skipped	Students may not follow a structured algorithm, causing collisions

Materials Needed:

- Maze (tape on floor or physical barriers)
- Pen and paper
- Blindfold
- Timer

Activity Flow:

1. Prep the maze with multiple pathways.
2. Divide students into teams of 3–4.
3. Assign roles: one "computer" and programmers.
4. Students write step-by-step instructions to guide the blindfolded "computer."
5. Execute the algorithm, adding penalties for collisions.
6. Record completion times and discuss strategies.

Reflection Questions:

- What was challenging, and how did you address those challenges?
- How important was communication in your team?
- What would you do differently to improve results?

Activity 2: Introduction to Variables

Estimated Time: 45 minutes

NGSS Connections: MS-ETS1-1, MS-ETS1-2

TEKS Connections: P.P.2, A.P.1(G), A.12(B)

Activity Overview:

Students learn to define and assign variables in Python and manipulate them through the Further website. They import libraries to control Pi-top [4] hardware like LEDs and buzzers.

Misconceptions:

Strand / Standard	Key Concept	Common Student Misconceptions	Camp Context Example
P.P.2, MS-ETS1-1	Variables & Assignment	Variables automatically update or perform calculations without explicit instructions	Students may expect an LED or counter to change without coding proper logic
A.P.1(G)	Library Imports	Libraries are optional or unnecessary	Students may not realize that importing Pi-top SDK functions is required for hardware control
A.12(B), MS-ETS1-2	Programming Practices	Typos or syntax errors are trivial	Students may be confused when code doesn't run due to incorrect variable names

Materials Needed:

- Pi-top [4] and Expansion Plate
- Laptop or smart device with Internet access
- LEDs

Activity Flow:

1. Turn on the Pi-top [4] and connect to a smart device.
2. Sign up for Further (https://www.further.pi-top.com) and join the class with code **E4Z4MJDRHM** (You will need to access Further for the remainder of these activities).
3. Open "Python Principles: Intro to Variables" and follow guided instructions.
4. Connect LEDs to Pi-top [4] and manipulate variables to control them.
5. Optionally explore "Python Principles: The Import System."

Reflection Questions:

- Why should programmers be specific when writing code?
- How do import statements work?
- How can we teach the computer what each Pi-top accessory is and how to control it?

Activity 3: Understanding Loops and Logic

Estimated Time: 60–75 minutes

NGSS Connections: MS-ETS1-3, MS-ETS1-4

TEKS Connections: P.P.1, P.P.2, A.2(A), A.12(C), 2A.7(I), 2A.3(B), G.4(A), G.4(B)

Activity Overview:
Students create complex algorithms using conditional statements and loops to program an interactive counter on the Pi-top [4] Mini Screen. They practice simplifying repetitive tasks and understanding logical flow.

Misconceptions:

Strand / Standard	Key Concept	Common Student Misconceptions	Camp Context Example
P.P.2, MS-ETS1-3	Loops & Conditional Logic	Loops are unnecessary; if statements always behave predictably	Students may misuse "if" or "for" statements and expect sensors to behave without proper logic
A.2(A)	Algorithm Design	Repetition is inefficient	Students may write long repetitive code instead of using loops
G.4(A), G.4(B), MS-ETS1-4	Computational Thinking	Sensors automatically interact correctly	Students may assume the Mini Screen or LED responds correctly without proper programming

Materials Needed:

- Pi-top [4] and Expansion Plate
- Laptop with Internet access
- Button, LEDs

Activity Flow:

1. Access “Understanding Logic” course on Further.
2. Complete “If Statements,” “Loops,” and “Tutorial: Mini Screen” lessons.
3. Program an interactive counter using loops and conditional logic.

Reflection Questions:

- What is an “if statement,” and why is it used?
- Describe what happens when a condition is true vs. false.
- How do different loops differ, and why use them with sensors?

Activity 4: Programming Hardware – Traffic Lights

Estimated Time: 100 minutes

NGSS Connections: MS-ETS1-3, MS-ETS1-4

TEKS Connections: P.6(D), P.8(E), A.P.1(A), A.P.1(B), A.P.1(C), A.P.1(G), A.2(A), 2A.7(I), A.12(B), A.12(C), 2A.3(B), 2A.8(C), G.9(B)

Activity Overview:
Students program traffic light sequences using Pi-top [4] hardware, defining functions and handling multiple events simultaneously. This reinforces loops, event handling, and real-world application of programming logic.

Misconceptions:

Strand / Standard	Key Concept	Common Student Misconceptions	Camp Context Example
A.P.1(A-C, G), MS-ETS1-3	Functions & Event Handling	Functions automatically handle multiple events; event handling is optional	Students may expect LEDs and buzzers to react correctly without proper function definition
A.2(A), MS-ETS1-4	Algorithm Design	Complex sequences are unnecessary	Students may try to control traffic lights manually instead of using loops
2A.7(I), 2A.8(C)	Computational Thinking	Loops are optional	Students may code sequential commands without using loops
P.6(D), P.8(E)	Hardware Integration	LEDs/buttons don't require code	Students may assume traffic lights function automatically without code

Materials Needed:

- Pi-top [4] with Expansion Plate
- Pi-top [4] Robotics Kit
- Laptop with Internet access
- LEDs, Buttons, Buzzer

Activity Flow:

1. Watch "How Do Traffic Signals Work" video.
2. Access Further and open "Programming Hardware" course, Traffic Lights lesson.
3. Follow instructions to program LEDs, buttons, and buzzer with functions and loops.

Reflection Questions:

- How do traffic signals improve safety?
- How does your model compare to real-world systems?
- Why are loops important for programs mimicking safety signals?

Day 2: Sensor Programming

Theme: Applying Python and Sensor Technology for Railroad Safety

Day Overview: Students will explore how Python programming can control various sensors, including light, sound, and ultrasonic sensors. They will design and build a railroad intersection, integrating traffic signals and servo motors, and construct the “Alex” robot while programming its movement. The day emphasizes coding, sensor integration, and teamwork, reinforcing real-world applications of technology in railway safety systems.

Lesson Objectives:

By the end of Day 2, students will be able to:

- Apply Python programming to control light, sound, and ultrasonic sensors.
- Design and implement traffic signals at a railroad intersection using servo motors and LEDs.
- Build and program the “Alex” robot to move forward, backward, and turn using code.
- Combine hardware and software to simulate real-world railway safety systems.
- Collaborate effectively to plan, test, and refine robotic and sensor-based solutions.

Day 2 at a Glance

Time Frame	Activity	Focus / Goal
30–45 min	Understanding the Sensors	Learn how light, sound, and ultrasonic sensors work; collect data using Python; explore sensor limitations
90 min	Simulating a Railroad Intersection (Active Sign Creation)	Apply Python and hardware integration to design active railroad crossing signs; understand the difference between passive and active signals
120 min	Rover Build and Navigation (“Alex” Robot)	Build and program a robot to follow commands; understand hardware-software integration and motion control
15 min	Reflection & Debrief	Discuss successes, challenges, and real-world applications of sensors, robotics, and railroad safety systems

Activity 1: Understanding the Sensors

Estimated Time: 30–45 minutes

NGSS Connections: HS-PS4-1, HS-PS4-5

TEKS Connections: P.P.2, P.6(D), P.8(E), A.P.1(A), A.P.1(B), A.P.1(C), A.P.1(G), 2A.3(B), 2A.8(C), G.9(B)

Activity Overview:
Students learn how light, sound, and ultrasonic sensors collect data and interact with Python code. They will experiment with each sensor, including measuring distance with the ultrasonic sensor and detecting light or sound changes, while understanding limitations of each sensor.

Misconceptions:

Strand / Standard	Key Concept	Common Student Misconceptions	Camp Context Example
HS-PS4-1	Waves & Signals	Sensors automatically detect everything accurately	Students may expect the ultrasonic sensor to measure distances through all materials
HS-PS4-5	Information Transfer	All sensors detect signals in the same way	Students may assume the light sensor works like a sound sensor or vice versa
P.P.2	Programming Practices	Code alone controls the sensor; hardware doesn't matter	Students may overlook sensor placement and environment effects
A.P.1(G)	Algorithm Design	One approach works in all scenarios	Students may assume a single code snippet works for every sensor situation

Materials Needed:

- Pi-top [4]
- Expansion Plate
- Laptop with Internet Access
- Light Sensor
- Sound Sensor
- Ultrasonic Sensor
- Flashlight
- Acoustic Foam (optional)

Activity Flow:

1. Show videos explaining how each sensor works (sound, ultrasonic, light).
2. Open Further website and navigate to the “Understanding the Sensors” course.
3. Guide students through each sensor lesson.
4. Demonstrate limitations, e.g., how acoustic foam interferes with ultrasonic sensors.

Reflection Questions:

- How can data be collected from a sound sensor using code?
- How can a sensor detect distance to an object using code?
- How can code be modified to display data in different units?
- Why are events used in programming?
- What program would alert a user if a room is too bright?

Activity 2: Simulating a Railroad Intersection (Active Sign Creation)

Estimated Time: 90 minutes

NGSS Connections: HS-PS4-5

TEKS Connections: P.P.1, P.P.2, P.5(E), P.6(B), P.6(D), P.7(D), P.8(E), 2A.P.1(A), A.P.1(B), A.P.1(D), A.P.1(G)

Activity Overview:
Students will integrate servo motors, LEDs, and buzzers to create active railroad crossing signs that respond to a simulated train. This activity teaches programming logic, hardware control, and the importance of active safety signals.

Misconceptions:

Strand / Standard	Key Concept	Common Student Misconceptions	Camp Context Example
HS-PS4-5	Information Transfer	All railway signals are the same	Students may confuse passive signs with active signs
P.P.2	Programming Practices	Servo motors function without coding	Students may place gates but forget to write code for activation
A.P.1(B)	Algorithm Design	One code block works for every sensor	Students may write a code that works for the light sensor but not the ultrasonic sensor
P.5(E)	Hardware Integration	Hardware is plug-and-play	Students may overlook wiring or component orientation

Materials Needed:

- Pi-top [4]
- Expansion Plate
- Pi-top [4] Robotics Kit
- Laptop
- 2 Servo Motors
- 2 Red LED Lights
- 1 Buzzer
- 1 Ultrasonic Sensor

Activity Flow:

1. Discuss the difference between passive and active railway crossing signs.
2. Demonstrate flashing red lights, gates, and bells.
3. Students design and program an active railroad crossing using their components.

Reflection Questions:

- Which signs at a railroad crossing are active vs. passive?
- How do these signals improve safety?
- What sensors could enhance the crossing design further?

Activity 3: Rover Build and Navigation ("Alex" Robot)

Estimated Time: 120 minutes

NGSS Connections: HS-PS3-3

TEKS Connections: P.5(D), P.6(D), G.9(B)

Activity Overview:

Students will construct the "Alex" robot and program it to move forward, backward, and turn using Python. They learn how hardware and software work together to create intelligent behavior and control motion.

Misconceptions:

Strand / Standard	Key Concept	Common Student Misconceptions	Camp Context Example
HS-PS3-3	Energy Transfer	Motors and wheels move automatically	Students may expect the robot to move without coding commands
P.5(D)	Robotics Programming	One algorithm fits all navigation tasks	Students may not account for left/right turns or obstacles
P.6(D)	Hardware/Software Integration	Software is separate from hardware	Students may not understand how motors respond to Python code
G.9(B)	Algorithm Testing	Code works perfectly the first time	Students may not test and iterate robot movement

Materials Needed:

- Pi-top [4]
- Expansion Plate
- Pi-top [4] Robotics Kit
- Laptop with Internet Access

Activity Flow:

1. Students build the “Alex” robot using provided instructions.
2. Introduce the drive controller for navigation.
3. Students write Python code to move the robot forward, backward, left, and right.
4. Practice adjusting code for distance, speed, and turning accuracy.

Reflection Questions:

- How do hardware and software combine to collect and exchange data?
- How is intelligent behavior conveyed through robotics?
- How can negative values affect robot motion?
- What are the pros and cons of using sleep commands to control movement?

Day 3: Driving the Rover

Theme: Programming Motion and Computer Vision in Robotics

Day Overview: Students continue practicing Python programming, focusing on motion, speed, and acceleration. They apply coding skills in the context of robotics to simulate a “Mini Baja Race” and explore computer vision for creating a line follower program. Students integrate sensors, loops, and functions to control the “Alex” robot, develop graphs to understand motion, and apply the Engineering Design Process to optimize their robot performance.

Lesson Objectives:
By the end of Day 3, students will be able to:

- Determine and calculate speed and acceleration of a robot using Python and encoder data.
- Apply loops, functions, and iterative statements to control robot motion.
- Analyze motion data with graphs and compare results to theoretical predictions.
- Design, program, and control the robot for a simulated race using sensors.
- Integrate a camera and computer vision functions to create a line follower program.
- Apply problem-solving, coding logic, and engineering design skills to optimize robot performance.

Day 3 at a Glance

Time Frame	Activity	Focus / Goal
60 min	Rover Speed and Acceleration	Measure velocity, acceleration, and graph motion data; apply loops and Python calculations.
60 min	Rover Race	Apply coding and iterative statements to control the robot in a race challenge; refine designs.
120 min	Line Follower (Rover Vision)	Learn computer vision basics; implement line-following code and integrate camera functions.

Activity 1: Rover Speed and Acceleration

Estimated Time: 60 minutes

NGSS Connections: HS-PS3-3

TEKS Connections: P.5(A), P.5(D), P.5(E), P.5(F), P.5(G), P.6(B), P.6(D), P.7(D), P.8(E), A.P.1(D), A.12(C), G.9(B)

Activity Overview:
Students use Python to calculate the rover's speed and acceleration based on encoder motor data. They generate graphs automatically with matplotlib and compare experimental results to hypotheses, learning the effects of mass, speed, and motion on robot performance.

Misconceptions:

Strand / Standard	Key Concept	Common Student Misconceptions	Camp Context Example
HS-PS3-3	Energy & Motion	Acceleration is only affected by speed, not mass	Students may assume the rover accelerates the same regardless of weight
P.5(A), P.5(D), P.5(E)	Using iterative statements for calculations	Loops automatically handle units or conversions	Students may miscalculate graphs if units aren't explicitly included
A.P.1(D), A.12(C)	Functions & Graphing	Graphing is optional and not connected to understanding motion	Students may skip labeling graphs, leading to misinterpretation

Materials Needed:

- Pi-top [4]
- Expansion Plate
- Pi-top [4] Robotics Kit
- Laptop with Internet Access
- "Alex" Robot Model

Activity Flow:

1. Navigate to Further class and open "Rover Speed and Acceleration" lesson.
2. Explain speed = distance/time and acceleration = speed change/time.
3. Students run scripts `test_speed.py`, `constant_velocity_experiment`, and `acceleration_experiment`.
4. Generate distance-time and velocity-time graphs and add units.
5. Compare results to hypotheses and discuss variations.

Reflection Questions:

- Did your graphs match your hypothesis? Why or why not?
- How does changing the speed factor over time affect the distance-time graph?
- How would a deceleration graph look?
- How does mass affect speed?
- Compare your rover speed to NASA's Perseverance rover.

Activity 2: Rover Race

Estimated Time: 60 minutes

NGSS Connections: HS-PS3-3

TEKS Connections: P.5(A), P.5(D), P.5(E), P.5(F), P.5(G), P.6(B), P.6(D), P.7(D), P.8(E), A.P.1(B), A.P.1(D), A.P.1(G), A.12(C), 2A.8(C), G.9(B)

Activity Overview:
Students implement loops and iterative statements to control robot motion in a race challenge. They optimize robot performance by applying the Engineering Design Process and prior coding lessons.

Misconceptions:

Strand / Standard	Key Concept	Common Student Misconceptions	Camp Context Example
HS-PS3-3	Motion & Control	Loops always execute perfectly without debugging	Students may assume robot responds instantly, ignoring lag or code errors
A.P.1(B), A.P.1(D), A.P.1(G)	Iterative programming	Adding more keys doesn't affect robot performance	Students may struggle with keyboard polling loops and delays
P.5(D), P.6(D)	Engineering Design	Design adjustments are unnecessary	Students may not refine the robot design, leading to slower race times

Materials Needed:

- Pi-top [4]
- Expansion Plate
- Pi-top [4] Robotics Kit
- Laptop with Internet Access
- "Alex" Robot Model
- Ultrasonic Sensor

- LEDs

Activity Flow:

1. Open Further class and the “USB Keyboard” lesson.
2. Implement `direction_arrows.py` to control the robot via loops and key events.
3. Test controls and optimize performance for the race.

Reflection Questions:

- How responsive was the robot using loops?
- Did adding more keys slow performance?
- How did your robot design affect race results?

Activity 3: Line Follower (Rover Vision)

Estimated Time: 120 minutes

NGSS Connections: HS-PS3-3

TEKS Connections: P.P.2, P.5(A), P.5(B), P.5(D), P.6(B), P.6(D), P.8(E), A.P.1(B), A.P.1(G), A.2(A), A.12(C), 2A.8(C), G.9(B)

Activity Overview:
Students use a camera with their Pi-top to implement a line follower program. They learn computer vision concepts such as kernels, centroids, and masks, and integrate Python functions to navigate the robot along a path.

Misconceptions:

Strand / Standard	Key Concept	Common Student Misconceptions	Camp Context Example
HS-PS3-3	Motion & Vision	Computer vision is instant and always accurate	Students may assume line follower will perfectly track lines without calibration
P.P.2, A.P.1(B), A.12(C)	Functions & Programming	Functions are unnecessary for complex tasks	Students may write repetitive code instead of using reusable functions
G.9(B)	Sensors & Hardware	Sensors always give perfect data	Students may not account for lighting or contrast affecting line detection

Materials Needed:

- Pi-top [4] Robotics Kit
- Laptop with Internet Access
- “Alex” Robot Model
- Activity Worksheet
- Pencil / Notebook
- Calculator

Activity Flow:

1. Show the “Computer Vision” video.
2. Open Further class and complete “Rover Vision” and “Path Finder” lessons.
3. Integrate camera and line detection functions to navigate robot.
4. Test and refine robot performance.

Reflection Questions:

- What is the fastest forward speed achieved?
- Name two real-life applications of line detection.
- What potential issues could arise when applying these techniques in real-world situations?
- What are the benefits of using functions in your code?

Day 4: Hardware Applications

Theme: Exploring Force, Energy, and Engineering Design Through Robotics

Day Overview: Students will apply Python programming and robotics to simulate collisions, calculate acceleration, force, work, energy, and power, and collaborate to design and program a forklift to manipulate a wheel-axle assembly. The day emphasizes the connection between coding, physics, and hands-on engineering design.

Lesson Objectives

By the end of Day 4, students will be able to:

1. Understand the relationship between force, work, energy, and power.
2. Calculate acceleration, force, work, and power using experimental data.
3. Simulate collisions using their Pi-top [4] rover and interpret results.
4. Design and build a forklift attachment for the robot using the Engineering Design Process.
5. Program the forklift to pick up and drop off a wheel-axle assembly.
6. Analyze and refine designs through testing and iteration.

Day 4 at a Glance

Time Frame	Activity	Focus / Goal
10 min	Welcome & Safety Review	Establish safe lab practices and review the day's theme
90 min	Collision Simulation	Calculate acceleration, force, work, and power using rover collisions; graph data
15 min	Break	Refresh and discuss observations from collisions
90 min	Forklift Assembly Challenge	Design, build, and program a forklift to lift and move a wheel-axle assembly
15 min	Reflection & Debrief	Discuss lessons learned, Newton's laws in practice, and engineering design insights

Activity 1: Collision Simulation

Estimated Time: 90 minutes

Lesson Objectives:
By the end of this activity, students will be able to:

- Understand the relationship between force and energy through experimentation.
- Create a work vs. time graph representing power from collected data.

NGSS Connections: HS-PS1, HS-PS3-3

TEKS Connections: P.5(A), P.5(D), P.5(E), P.5(F), P.5(G), P.6(B), P.6(D), P.7(A), P.7(D), P.8(E), A.P.1(A), A.P.1(B), A.P.1(C), A.P.1(G), A.2(A), A.12(B), A.12(C), 2A.8(C), G.9(B)

Materials Needed:

- Pi-top [4] Robotics Kit
- Laptop with Internet Access
- The “Alex” Robot Model
- Calculator
- Box with a known mass

Activity Flow:

1. Navigate to the “Collision Simulation” lesson on Further.
2. Explain Newton’s laws of motion and the relationship between acceleration, force, kinetic energy, work, and power.
3. Students calculate the acceleration of the robot at top speed.
4. Determine the force used by motors and allow robots to collide with an object.
5. Record distance traveled after collision; repeat 3–4 times.
6. Calculate force of the collision, work performed, and plot power vs. time.

Misconceptions:

Strand / Standard	Key Concept	Common Student Misconceptions	Camp Context Example
HS-PS1	Force & Energy	Mass and force are independent	Students may think a heavier robot has the same effect on the object as a lighter robot
HS-PS3-3	Work & Power	Work is always equal to energy	Students may misinterpret work as just movement without considering force × displacement

P.5(D), P.5(E)	Newton's Laws	Newton's laws only apply in idealized conditions	Students may think the laws don't apply to small robots
P.6(B), P.6(D)	Measurement & Calculation	Units are not important	Students may calculate force, work, or power without correct units
A.P.1(B), A.P.1(C)	Analysis	Graphing is optional	Students may not plot work vs. time accurately, missing trends

Reflection Questions:

- What happened to the box during the collision? Why did it move?
- Did the robot maintain the same speed before and after the collision? Why?
- How would a heavier box or robot affect the results?
- Which of Newton's Laws of Motion apply in this activity?

Activity 2: Forklift Assembly Challenge

Estimated Time: 90 minutes

Lesson Objectives:
By the end of this activity, students will be able to:

- Design and build a forklift for their robot to pick up/drop off a wheel-axle assembly.
- Create a program for the robot to approach, pick up, and drop off a wheel-axle assembly.

NGSS Connections: HS-PS3–3

TEKS Connections: P.5(D), P.5(E), P.5(F), P.5(G), P.6(B), P.6(D), P.7(D), P.8(E), A.P.1(A), A.P.1(B), A.P.1(C), A.P.1(G), A.2(A), A.12(B), A.12(C), 2A.8(C), G.9(B)

Materials Needed:

- Pi-top [4] Robotics Kit
- Laptop with Internet Access
- 1 Servo Motor

Activity Flow:

1. Navigate to the “Forklift Assembly Challenge” lesson on Further.
2. Discuss train wheel-axle maintenance and consequences of bearing/wheel failure.
3. Show demonstration of an axle being replaced quickly.
4. Students use the Engineering Design Process to design and build a forklift capable of picking up a wheel-axle assembly.
5. Test forklift with angle limits:
    - Maximum lift: 0°–90°
    - Minimum lift: 0°–90°

Misconceptions:

Strand / Standard	Key Concept	Common Student Misconceptions	Camp Context Example
HS-PS3-3	Force & Work	All designs function equally	Students may design a forklift without considering leverage or motor power limits
P.5(D), P.5(E)	Engineering Design	One design is correct	Students may assume first prototype will succeed without iteration
P.6(B), P.6(D)	Measurement	Angles and distances aren’t critical	Students may set forklift too high or low, missing constraints
A.P.1(A), A.P.1(G)	Problem Solving	Coding logic is optional	Students may not integrate program commands with hardware correctly
2A.8(C)	Testing & Iteration	Test once is sufficient	Students may not evaluate performance or refine their design

Reflection Questions:

- Did you use your first forklift design? If not, why?
- Why are angle limits important in your design? What could happen if they are ignored?
- What aspects of your design were most successful?
- Did your design take inspiration from real-world applications?

Day 5: Final Challenge

Theme: Applying STEM Skills: Engineering Solutions for Railway Safety

Day Overview: Students will apply the Python programming language, hardware programming, and engineering skills they have learned throughout the week to complete a final obstacle course challenge. Teams will collaborate to remotely pilot their robot, swap the locations of two objects, and simulate the real-world process of replacing a wheel-axle assembly. This hands-on activity emphasizes teamwork, coding, sensor integration, and problem-solving in a real-world railway context.

Lesson Objectives

By the end of Day 5, students will be able to:

- Modify scripts to control their robot for picking up and dropping off objects.
- Program the robot to drive using servo motors and integrate a camera for remote operation.
- Incorporate sensors such as ultrasonic, light, and line followers to optimize robot performance.
- Apply teamwork, planning, and problem-solving to complete a timed challenge.
- Evaluate hardware and wireless limitations based on their performance during the final task.

Day 5 at a Glance

Time	Activity	Focus / Goal
15 min	Camp Review	Review key concepts and challenge rules; reinforce prior learning and prepare for the final task
180–200 min	Final Challenge	Apply the Engineering Design Process to complete the obstacle course, swap axles, and integrate sensors and camera control; practice coding and mechanical design principles
10–15 min	Reflection & Clean-Up	Discuss lessons learned, team collaboration, and real-world applications; disassemble robots and clean up

Activity 1: Camp Review

Estimated Time: 15 minutes

NGSS Connections: HS-PS3-3

TEKS Connections: P.5(D), P.5(E), P.5(F), P.5(G), P.6(B), P.6(D), P.7(D), P.8(E), A.P.1(A), A.P.1(B), A.P.1(C), A.P.1(G), A.2(A), A.12(B), A.12(C), 2A.8(C), G.9(B)

Activity Overview:
Students review previous lessons, including Python programming concepts, sensor integration, and mechanical operations through discussion and a brief recap of key points. This ensures that teams are prepared to complete the final challenge successfully.

Misconceptions:

Strand / Standard	Key Concept	Common Student Misconceptions	Camp Context Example
HS-PS3-3	Forces & Motion	Students may confuse how velocity, acceleration, and force affect the robot	Students might miscalculate the effect of motor force when moving objects
P.5(D), P.5(E)	Energy, Work & Power	Students may forget formulas or misapply them during collision simulations	Students may assume mass doesn't affect acceleration or force
A.P.1(A), A.P.1(B)	Engineering Design	Students may think programming and sensors can be applied without testing	Students may skip debugging or iterative improvements on the final track
A.2(A), A.12(C)	Collaboration & Problem Solving	Students may not effectively communicate within teams	Instructions for axle pickup/drop-off might be unclear due to lack of coordination

Materials:

- Pi-top [4] Robotics Kit
- Laptop with Internet Access
- "Alex" Robot Model
- 2 Servo Motors
- 2 Red LED Lights
- 1 Buzzer
- 1 Ultrasonic Sensor

Activity Flow:

1. Open the Further website and access the “Final Challenge” lesson.
2. Review all challenge rules and functionality of robot components (drive, LEDs, buzzer, sensors, camera, servo forklift).
3. Students practice the engineering design process, testing sensor integration, camera control, and movement.
4. Build the obstacle course track and explain the task: pick up the first axle, drive to the end, swap with the second axle, and return to the start.
5. Conduct the timed final challenge, recording completion times and bonus points.

Reflection Questions:

- How much control did you have over the robot? Was modifying the robot speed helpful? Why?
- Can you add any sensors to help you pick up the axle?
- Can you add the line follower to help you stay within the track?
- Was your camera fixed or controlled by a servo motor?
- What lessons about teamwork, coding, and sensor integration did you learn from this challenge?

Appendices

Appendix A: Video Links

Day 1
Activity 4:
Traffic Signals: How Do Traffic Signals Work?

Day 2
Activity 1:
Ultrasonic Sensor: How Do Ultrasonic Distance Sensors Work? - The Learning Circuit
Light Sensor (Photoresistor): How does a photoresistor work?
Sound Sensor: Sound Sensors

Activity 3:
The Alex Robot: pi-top [4] Robotics Kit: Build instructions - Alex

Day 3
Activity 3:
Computer Vision: Computer Vision: Crash Course Computer Science #35

Day 4
Activity 2:
Wheel-Axle Assembly Replacement: Wheel-Axle Assembly Replacement

Appendix B: Teacher Notes

1	To connect a tablet or iPad to a wireless keyboard using a usb adapter or Bluetooth, first ensure the keyboard is turned on and in pairing mode. On your tablet or iPad, go to Settings, select Bluetooth, and turn it on if necessary. Your device will search for available Bluetooth devices; when the keyboard appears in the list, tap on its name. You may need to enter a pairing code displayed on your screen using the keyboard. Once paired, your device should show the keyboard as connected. [Use the pi-top [4] with Wi-Fi and the Further website] Continue after connecting to the pi-top [4] hotspot. Once connected, open a web browser on your Tablet, iPad, or laptop and navigate to the pi-top [4] IP address (192.168.90.1). This should give you access to the pi-top [4] dashboard. Select Wi-Fi Settings and connect to your own Wi-Fi network. After a successful connection, the pi-top [4] will get a different IP address (e.g. 10.0.0.1), check any Further lesson to access and use this new IP address on the Further website. [Use the pi-top [4] with the Display Cable and Further/RealVNC Viewer] Alternatively, if you have the green Pi-top [4] display cable, you can use it to connect to your Laptop or Tablet by plugging it into the USB adapter and then connecting the other end to the Pi-top [4] USB-C display port (located next to the charging port). After completing this step, the Pi-top [4] can be accessed through the RealVNC Viewer or the Further website using the IP address 192.168.64.1. [Use the pi-top [4] with the Hotspot and RealVNC Viewer] To connect a tablet to the pi-top [4] using Wi-Fi, follow these steps: First, using the pi-top [4] Mini Screen, ensure your pi-top [4] is powered on and has Wi-Fi Hotspot enabled in the Settings page. Now, navigate to the Network page in the pi-top [4] Mini Screen, then look for the hotspot credentials there. On your tablet, go to the Wi-Fi Settings and look for the pi-top [4] network name (SSID) in the list of available networks. Select this network and enter the password. Once connected to the pi-top [4] hotspot, you may open the RealVNC Viewer App and create a connection to the pi-top [4] IP address (192.168.90.1), and connect to that address with the following credentials: Username: *pi*, and Password: *pi-top.*
2	The Sound Sensor consists of a simple microphone that detects the vibrations of the air entering the sensor and produces an analog reading based on the amplitude of these vibrations.
3	The Ultrasonic Sensor consists of two main components: a transmitter that sends ultrasonic sound waves forward, and a receiver that detects those waves once they bounce off an object in front (both components are labeled on the sensor as T and R, respectively). The sensor calculates distance based on the time it takes the sound wave to bounce and return to the receiver (distance = speed of sound in the medium * time).
4	The Light Sensor consists of a photoresistor and a pair of wires; a photoresistor is a light-sensitive device, the resistance of which decreases (more current can pass through the wire) with the increase in light intensity detected by the sensor.
5	Instruct your students to remove the Servo Motors and other components that might get damaged at the front of the robot.
6	Explain to students that a wheel-axle assembly replacement in under 3 minutes is preferred because several train cars may require several wheel-axle assemblies to be replaced while in the railyard. To minimize downtime and avoid costly delays associated with prolonged train stoppages in railyards, optimizing the time needed to complete the wheel-axle assembly replacement is of utmost importance.

References

pi-top. (2021, January 22). *pi-top Robotics Kit: Alex Build Instructions*. HubSpot. https://f.hubspotusercontent40.net/hubfs/4368942/Robotics%20Kit%20instructions/pi-top_RoboticsKit_AlexBuild_22012021.pdf

Crash Course. (2017, November 15). *Computer Vision: Crash Course Computer Science #35*. YouTube. https://youtu.be/-4E2-0sxVUM?si=mSSksMsn-OD6FgK1

Element14. (2021, January 27). *How Do Ultrasonic Distance Sensors Work?-The Learning Circuit*. YouTube. https://www.youtube.com/watch?v=2ojWO1QNprw

Loveland, T. (2020). *Standards for technological and engineering literacy*. Standards - International Technology and Engineering Educators Association. https://www.iteea.org/stel

MaxBotix. *How Ultrasonic Sensors Work*. MaxBotix Inc. (2023, March 1). https://maxbotix.com/blogs/blog/how-ultrasonic-sensors-work?utm_term=&utm_source=google&utm_medium=cpc&gad_source=1&gclid=Cj0KCQjwvb-zBhCmARIsAAfUI2sVexH654KswgVdUe5BWd3ZmYiHrX-cKI0_7yHonPIav1XD7UbnufsaAkg1EALw_wcB

Next Generation Standards by Topic. (2013). https://www.nextgenscience.org/sites/default/files/HSTopic.pdf

Practical Engineering. (2019, May 14). *How Do Traffic Signals Work?*. YouTube. https://www.youtube.com/watch?v=DP62ogEZgkI

STEM Basics. (2017, February 3). *How Does A Photoresistor Work?*. YouTube. https://www.youtube.com/watch?v=u9Riurh4y9U

STEM Basics. (2020, January 2). *Sound Sensors*. YouTube. https://www.youtube.com/watch?v=H3JacSVipVA

Team, P. (2021, March 9). *Pi-top [4] robotics kit: Build instructions - alex*. YouTube. https://youtu.be/8c-T1KmL0lY?si=RI7HwLM2oSFS8jPJ

Texas Education Agency. (2012). *Math*. https://tea.texas.gov/academics/subject-areas/math

Texas Education Agency. (2021). *Science*. https://tea.texas.gov/academics/subject-areas/science

UTC Railway Safety. (2024, June 20). *Wheel and Axle Replacement.* YouTube. https://youtu.be/bP_T0oEUL78?si=EvKAx_9JjTlt7QSH

Physics. StudySmarter UK. (n.d.). https://www.studysmarter.co.uk/explanations/physics/modern-physics/photoresistor/#:~:text=is%20a%20Photoresistor%3F-,A%20photoresistor%2C%20also%20called%20light%2Ddependent%20resistor%20(LDR),light%20and%20increases%20with%20less

Czernia, D. (n.d.). Car crash calculator. Omni Calculator. https://www.omnicalculator.com/physics/car-crash-force#how-to-calculate-impact-force-g-force-in-car-crashes

Curriculum Writers

K-12 STEM Teachers	UTRGV Faculty Mentors
Carlos Pena-Caballero	Angela Chapman
Dario Hinojosa	Constantine Tarawneh