Tufts UNIVERSITY | Center for Engineering Education and Outreach

SMART LAB ACTIVITY GUIDE

MUSICAL INSTRUMENT DESIGN

DESIGN CHALLENGE

Create a musical instrument that uses a sensor to play tones.

DIFFICULTY LEVEL

Building: Beginner – no prior experience necessary

Programming: Medium – uses a mathematical formula to make sounds from sensor readings

MATERIALS

LEGO MINDSTORMS EV3 kit

INDONESIAN HIGH SCHOOL CORE COMPETENCIES

Two-Variable Linear Equation (Mathematics - Mandatory, Year X, 2.3 – 2.5 and 3.3 – 3.7, 4.3 – 4.7)

Linear Equations (Mathematics - Mandatory, Year XI, 2.3 – 2.4)

Some solutions may contain: Absolute Value (Mathematics - Mandatory, Year X, 3.2, 4.2, 4.7)

SMART LAB DISCIPLINES

Science	**Math**	**Art**	**Technology & Engineering**
Sound	Linear equations	Creating sounds & music	Instrument design

STUDENT OUTCOMES

- Application of linear equations
- Introduction to sound and frequency
- Advanced programming skills with sensor measurement and data operations blocks

DETAILED OBJECTIVE

Write a program that:

- Takes a measurement from sensor data
- Uses data operations to scale the measurement
- Plays a tone with scaled measurement as frequency
- Uses a loop to repeat program

For example:

Program reads a value of 30 cm from the ultrasonic sensor	Program scales sensor value (equation from Example Solutions section below): 30 cm (ultrasonic value) x 16.6 +300 = 798	Program plays scaled value: Sound block plays a tone at 798 hz frequency

EXAMPLE SESSION

Introduction: 10 minutes
Put students into small groups (preferably groups of two)
Explain the design challenge and detailed objectives.

Program: 10 minutes
Introduce the blocks being used in this activity: loop, measurement, data operations, and sound blocks.

- For the measurement sensor blocks: tell students the range of values of the EV3 sensors
  - Ultrasonic sensor: measures distance in centimeters (0 - 255 cm)
  - Light sensor: measures ambient or reflective light in arbitrary intensity units (0 – 100)
  - Gyroscope: measures angle of rotation (positive and negative) in degrees
  - Motor: measures angle of rotation (positive and negative) in degrees
- For the sound block: explain some of the characteristics of sound such as frequency and period
  - Sound – vibrations that travel through a medium (usually air) that can be heard when these vibrations reach the ear.
  - Frequency – the rate that the sound vibrations occur per second
  - Period – the time to complete one cycle (inverse of frequency:1/T)
- Explain to students the hearing range of humans (20 Hz – 20,000 Hz), and the frequency range of the EV3 (250 Hz – 10,000 Hz).

You may want to write the detailed objectives, sensor ranges and frequency ranges in a place where students can see them.

Brainstorm and Build: 15 minutes
Have students brainstorm their musical instrument and consider which sensor they will use.
Have students build their musical instrument by attaching the sensor to the brick.

Brainstorm Programming: 10 minutes
Ask students: how can they use math to scale sensor measurements to an appropriate frequency?
Allow the groups to try to figure out the problem. Then have the class share their ideas and guide them into using linear equations.

Programming: 20 minutes
Explain (or have a group that thought of this method explain) how to use a sensor measurement range & sound frequency range in a linear equation to produce a formula for scaling the measurement.

- Drawing an x, y graph can help students understand this concept.

Have students choose a sensor measurement range and a frequency range and derive their equation.
Now students can program the EV3 to read a sensor measurement, scale the value using their linear equation and the data operations blocks to play sound.

Present: 10 minutes
Have students present their designs

Share: 15 minutes
Groups should take videos of their design being used and post the video and a short description of their musical instrument to the website. The description should include an explanation of how the device works.

POSSIBLE MODIFICATIONS

If students have not used linear equations before, or are not ready to learn about them, just ask the students to explore the sensor measurement, data operations, sound and loop blocks to figure out how to scale the measurement and play a range of tones. Then have groups present their solutions. This can help the class build collective knowledge of how to solve this problem.

When introducing sensors, give real world examples: 10 minutes

- Explain to students that this activity will mimic the engineering used in the following devices
  - Submarine sonar (ultrasonic sensor)
  - Smoke detector (light sensor)
  - Video game controllers, airplanes (gyroscope)
- All of those devices use sensor data to create an output/reaction.
- Ask students for other examples of devices that use sensor inputs to generate an output/reaction.

POSSIBLE EXTENSIONS

Different sensors

- After students have completed the activity with one sensor, ask them: how can they achieve the same objective using different sensors?
- Have students design the same instrument with different sensors.

More than one sensor

- Have students create a musical instrument that uses more than one sensor.
- Ask students - how can they utilize two sensors to make a more complex musical instrument?
- Have students brainstorm ideas with their group, share their ideas with the class then create a new musical instrument or modify their first design

EXAMPLE SOLUTIONS

Color Sensor as Input

Ultrasonic Sensor as Input

Calculations for an ultrasonic sensor

In the example solution below, the program waits until the ultrasonic sensor detects an object within 30 cm of the sensor. The program takes the distance measurement from the ultrasonic sensor and scales the value. The EV3 plays a tone with the scaled value as its frequency.

Chosen distance range: 0 cm – 30 cm

Chosen frequency range: 300 Hz – 800 Hz

Two-variable Linear Equation:

$$y = mx + b$$

$$m = \frac{y_2 - y_1}{x_2 - x_1} = \frac{800 - 300}{30 - 0} = 16.67$$

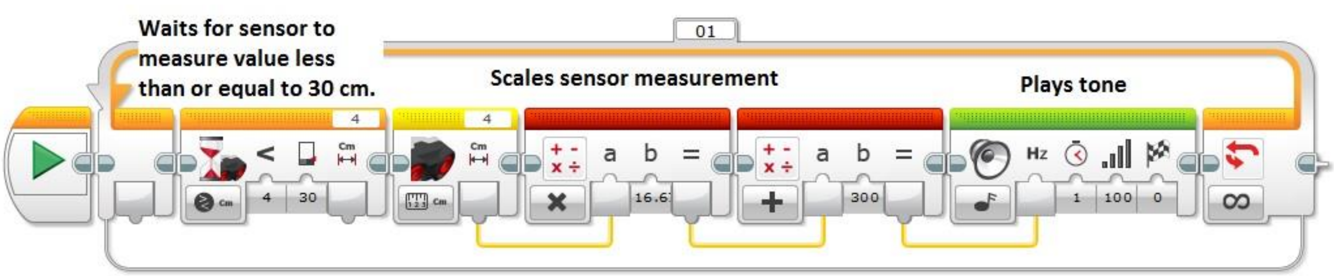
$$y_1 = mx_1 + b$$

$$300 = (16.67)(0) + b$$

$$b = 300$$

$$y = 16.67x + 300$$

Ultrasonic sensor is plugged into port 4 (as indicated on the ultrasonic measurement block)

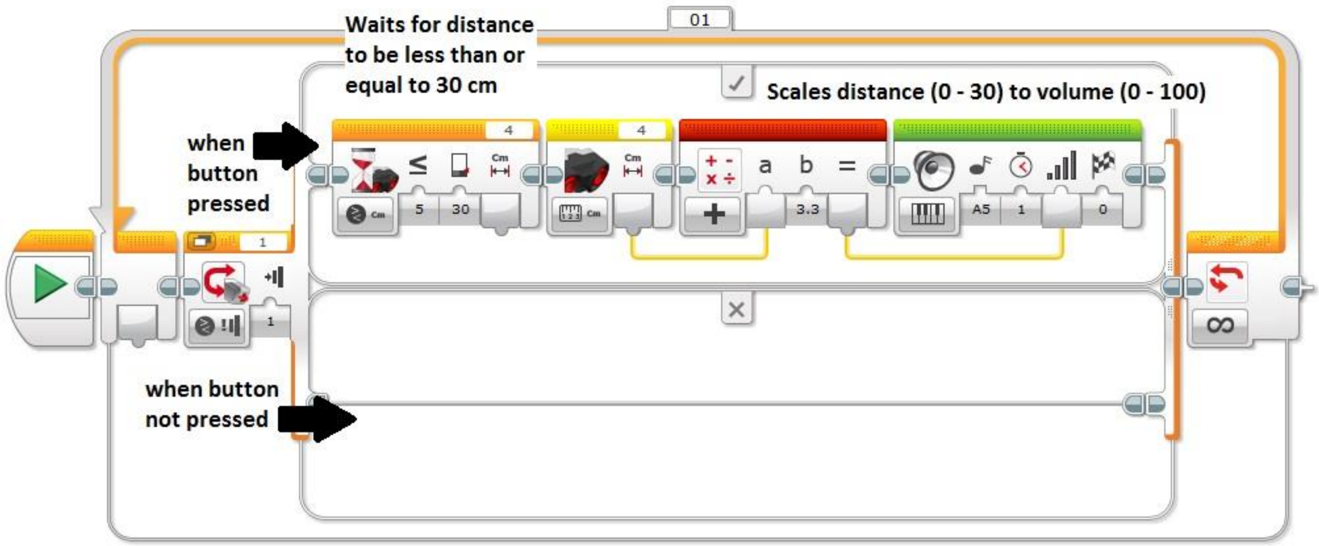


EXAMPLE SOLUTION FOR MORE THAN ONE SENSOR

The solution below uses a touch and ultrasonic sensor. When the touch sensor is pressed, and an object (such as a hand) is within 30 cm of the ultrasonic sensor a note plays. The note's volume can be controlled by moving the hand closer or farther away from the ultrasonic sensor while to touch sensor is being pressed.

Touch sensor - plugged into port 1 (as indicated on the touch sensor switch block)

Ultrasonic sensor - plugged into port 4 (as indicated on the ultrasonic sensor wait for and measurement blocks)



REFERENCE

Units and Ranges

EV3 sound frequency range: 250 Hz – 10,000 Hz

Ultrasonic sensor: measures distance in centimeters (0 - 255 cm)

Light sensor: measures ambient or reflective light in arbitrary intensity units (0 – 100)

Gyroscope: measures angle of rotation (positive and negative) in degrees

Motor: measures angle of rotation (positive and negative) in degrees

Units and Ranges for Additional Challenge

Light - also detect color

Touch sensor - measures/compares state (pressed, released, bumped)

Connecting to the EV3

The motor plugs into ports A, B, C, or D on the EV3 brick

The other sensors plug into ports 1, 2, 3 or 4 on the EV3 brick

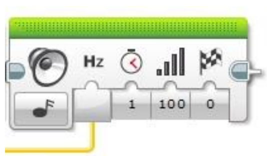
Program Support

Flow control tab: Consider using a **wait for** or **switch** block to control the maximum and minimum tone range.

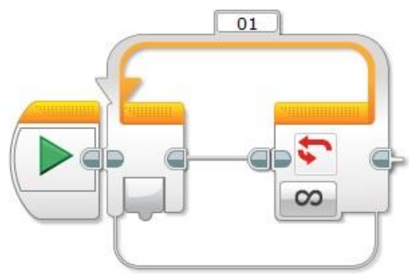
Switch block: program chooses between cases based on input

Wait for block: program waits until condition is met

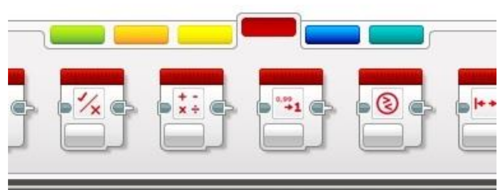
Sensor tab: use to take measurement from sensor data



Sound block: use to play scaled measurement as frequency



Loop: blocks inside are repeated



Data Operations tab: use to scale sensor measurements for the sound block frequency