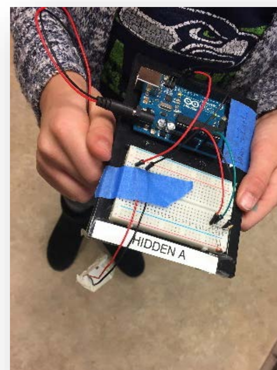
Lesson Nine: Designing a Sensory Substitution Device
Center for Sensorimotor Neural Engineering
Lesson Plan Author: Phelana Pang

LESSON OVERVIEW

Activity Time: Three+ 50 minute periods.

Lesson Plan Summary:
In this lesson, students will discuss engineering practices, identify criteria and constraints in a project, recognize that the steps involved in designing a solution is not necessarily linear and that optimizing a solution requires rounds of testing, feedback, and modification. Students will design and program their sensory substitution devices.



STUDENT UNDERSTANDINGS

Big Idea & Enduring Understanding:

- Engineering is a non-linear, iterative process which involves coming up with a design to solve a problem, considering the criteria and constraints, asking questions, testing the design, modifying the design, and seeking feedback to help with optimizing the design.

Essential Question:

- How can a model of a sensory substitution device be designed and tested to meet the needs of the end-user?

Learning Objectives:

Students will know…

- Criteria and constraints for a design project must be identified, with special attention to the person (end-user)'s needs.
- Designs can be improved through iterative testing and modifications, and through the incorporation of feedback from peers.

Students will be able to…

- List criteria and constraints for their design project.
- Document the engineering process in their design notebook.
- Test and modify their design to create a functional model.
- Seek and incorporate feedback into their design.

Vocabulary:

- **Criteria**: requirements of the design (ex: serving a certain function, size).
- **Constraint**: limitations for the design (ex: budget, materials, time).
- **End-User**: the person the product is designed for (patient, doctor).

Standards Alignment: This lesson addresses the following middle school Next Generation Science Standards (NGSS) Disciplinary Core Ideas (DCIs):

NGSS Disciplinary Core Ideas

- **MS-ETS1.A Defining and Delimiting Engineering Problems:** The more precisely a design task's criteria and constraints can be defined, the more likely it is that the designed solution will be successful. Specifications of constraints includes consideration of scientific principles and other relevant knowledge that are likely to limit possible solutions.
- **MS-ETS1.B Developing Possible Solutions:** There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of the problem.
- **MS-ETS1.C Optimizing the Design Solution:** Although one design may not perform the best across all tests, identifying the characteristics of the design that performed the best in each test can provide useful information for the redesign process—that is, some of those characteristics may be incorporated into the new design.

NGSS Cross-Cutting Concepts

- **Systems and System Models**
- **Cause and Effect**
- **Influence of SET on Society and Natural World**

NGSS Science & Engineering Practices

- **SEP:** Asking Questions and Defining Problems
- **SEP:** Constructing Explanations and Designing Solutions
- **SEP:** Developing and Using Models
- **SEP:** Engaging in Argument from Evidence
- **NoS:** Science is a Human Endeavor
- **NoS:** Science Addresses Questions about the Natural and Material World

MATERIALS

Material	Description	Quantity
Student Handout 9.1: Engineering Design Sketchpad	Notebook used for students to document their design process	1 copy per student
Student Handout 9.2: Making it Real (optional)	An optional extension activity	1 copy per student
Teacher Resource 9.1: Engineering Design Process Cards	To be laminated and cut as a puzzle to discuss design process	1 set per group
All Arduino, breadboard, and circuit component materials from *Lesson 8*		1 of each per group/pair
Teacher Resource 8.1: Sample Arduino Sketches from *Lesson 8*	If needed, make available for students electronically so they can cut and paste the code, and then modify it	

TEACHER PREPARATION

1. Make copies of *Student Handout 9.1: Engineering Design* Sketchpad for each student.

2. Copy, laminate (optional), and cut the *Engineering Design Process Card*s to make one set per group.

3. If needed, make *Teacher Resource 8.1: Sample Arduino Sketches* available for students electronically (can be posted on class website or shared through email or Google Doc) so that students can cut, paste, and modify the code.

4. Assign students to design teams of 3 or 4 students per team. You can assign roles which rotate between team members each day to facilitate engagement. Roles might include:
   - Electrical engineer (in charge of circuit and components)
   - Computer scientist (in charge of Arduino program)
   - End-user (ensures design meets criteria)
   - Project manager (supervises process and manages time and materials).

PROCEDURE

Engage: Engineering Design Process (20 minutes)

1. Pass out *Student Handout 9.1: Engineering Design Sketchpad.*

2. Discuss engineering practices through a group brainstorm using some of the following questions to elicit students' ideas. Have students record their ideas on the first page of the Sketchpad.
   - What does an engineer do?
   - Who does the engineer serve (who are stakeholders)?
   - What aspects of design have to be considered?

3. Pass out *Engineering Design Process Cards* to each group, and have students try to put them in order. Take away message: There is not necessarily a set order…engineering design is an iterative, interconnected process!

4. You can also show the video The Engineering Design Process: A Taco Party from PBS (3:37 minutes). The video doesn't emphasize that steps can take place "out of order" so you may have to discuss that with your class.
   - https://kcts9.pbslearningmedia.org/resource/tacoparty/tacoparty/

5. Students can write down the steps of the design process and draw a web of their interconnectedness in their Sketchpad.

Explore, Explain, & Elaborate: Design, Prototype, Test, and Share (120+ minutes)

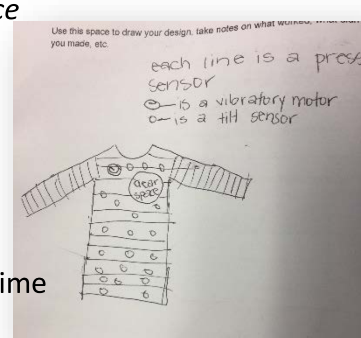
6. Allow students to look over the layout of the Sketchpad and tell students this is where they will document their thinking process and design work.

7. Introduce students to the materials they have available to them to design their device: inputs (sensors: light, temperature, pressure, tilt, distance, flex, push button) and outputs (motors, LEDs, buzzers). You will have a lot of small components so it is important to be organized.

8. Students will work in their teams to design their sensory substitution device. Each student is accountable for documenting their teamwork in the design Sketchpad. Work through the Sketchpad at the pace that is appropriate for your students. Remind students to consider the end-user:
   - Would an LED output help someone who is visually impaired? Why or why not?

- Is there a reason why two inputs would be helpful? For example, when would it be helpful to have two pressure sensors instead of one? Or when might it be helpful to have a pressure sensor and a temperature sensor?
- Is it helpful to have a switch? Why or why not?

9. Brainstorm pathways… "If… then." See *Teacher Resource 9.2* for examples of circuit possibilities.

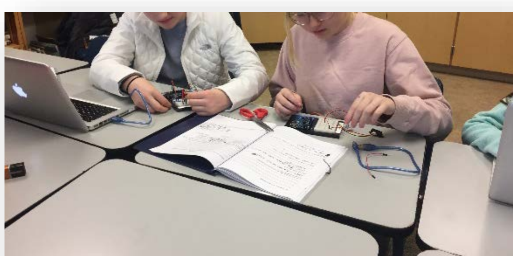


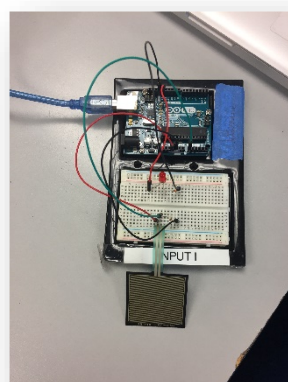
10. Be sure that students draw a diagram of their chosen circuit in their Sketchpads. Stress the importance of documenting their design process.

11. Once students have completed their design work, it is time to build their prototypes. They can grab their Arduinos, breadboards, and other components needed to construct their input and output circuits

12. Allow ample time for students to program and construct their circuits based on their designs. As they work, encourage students to independently solve problems and to use appropriate resources—including peers with expertise—to seek help when needed, rather than always coming to the teacher for help.

13. It is important to allow plenty of time for students to test, modify, and evaluate their model sensory substitution devices. The testing phase of the engineering design process is imperative, but it often gets skipped in classroom instruction due to time constraints.





14. Ask each student group to show their device to another pair/group of students so that they can collect peer feedback and modify their designs. Encourage students to document feedback and modifications in the design Sketchpad.

15. As students work through the design process, they may become frustrated. Here are some resources to help you set the tone for supporting your students.
    - Managing Student Frustration During Engineering Design Projects
        - http://stemteachingtools.org/brief/36
    - How to Focus Students' Engineering Design Projects on Science Learning
        - http://stemteachingtools.org/brief/45

16. In *Lesson 10*, students will prepare a poster or slideshow as a way to present their design to others.

STUDENT ASSESSMENT

Assessment Opportunities: Student knowledge, skills, and concepts for this lesson will be assessed in a number of ways.

- Each teacher will need to decide if they will focus assessment on the design process, documentation of the design process, and/or the designed product. See the Scoring Guide section below. Addition criteria may be added depending on each teacher's preferences.
- The design Sketchpad should reflect students' growing understanding and problem-solving skills. The teacher may develop a scoring key to assign points for the thoroughness of documentation within the Sketchpad.

Student Metacognition:

- Students can continuously reflect as they troubleshoot their design. Guide students to asking themselves questions such as: What are you trying to make happen? What components are needed? What needs to happen first? Would drawing a circuit diagram help with your understanding?
- Students can reflect on the design process on the last page of their Sketchpad.

Scoring Guide:

- A rubric can be created to see if students can (1) independently solve problems, (2) use appropriate resources to seek help when needed, (3) document changes made to the model and the resulting output, and (4) addressed the needs of the end-user and criteria of the design challenge. See sample below:

Criteria	4	3	2	1
Statement of problem and consideration of end-user	Design challenge is clear with extensive list of criteria and constraints that are driven by the needs and wants of the end-user	Design challenge is stated, with list of criteria and constraints that are driven by the needs of the end-user	Design challenge is somewhat unclear, many criteria and constraints are missing, or the criteria do not completely match the needs of the end-user	Design challenge is not stated or is incorrect, and no criteria or constraints are listed
Documentation of modifications and resulting output	All modifications are noted with details of effects of changes made	Most modifications included with explanation of result of modification	Some modifications included with inconsistent explanation of results	No modifications indicated, and no explanations are provided
Critical thinking and problem solving	Consistently attempts to solve problems independently or with group and uses appropriate resources to seek help	Often attempts to solve problems independently or with group and uses resources to seek help	Solves problems with teacher guidance or relies often on classmates, uses resources with guidance	Seeks help from teacher immediately before troubleshooting on own, does not use resources

EXTENSION ACTIVITIES

Extension Activities:

- Students who have a working prototype on their first attempt should be challenged to make a more advanced model of their device. They can add more components, program more intricate parameters/instructions, or identify and document additional applications for their device.
- Students can further explore other relevant topics in designing their sensory substitution device. Use the optional *Student Handout 9.2: Making it Real* to guide their research.

TEACHER BACKGROUND & RESOURCES

Resources:

- To support students in developing their Arduino sketches and designing their circuits, refer to *Teacher Resource 8.1: Sample Sketches for Varying Outputs* and *Teacher Resource 9.2: Circuit Possibilities.* These other Arduino code resources are also helpful:
    - Force Sensor Resistor Arduino Code:
        - https://learn.adafruit.com/force-sensitive-resistor-fsr/using-an-fsr
    - Analog Input Varying Length of LED Blink:
        - https://www.arduino.cc/en/Tutorial/AnalogInput
    - Analog Input/Output Dimming LED:
        - https://www.arduino.cc/en/Tutorial/AnalogInOutSerial
    - Boolean Operators (and, or, not):
        - https://www.arduino.cc/en/Reference/Boolean
    - Flex Sensor Tutorial (Sparkfun):
        - https://learn.sparkfun.com/tutorials/flex-sensor-hookup-guide

- Teaching engineering design in the science classroom can be daunting if this is your first time. The resources from STEM Teaching Tools offer helpful tips on making engineering design meaningful, authentic, and equitable in the science classroom.
    - Failing Forward: Managing Student Frustration During Engineering Design Projects
        - http://stemteachingtools.org/brief/36
    - How to Focus Students' Engineering Design Projects on Science Learning
        - http://stemteachingtools.org/brief/45
    - Learning STEM through Design: Students Benefit from Expanding What Counts as "Engineering"
        - http://stemteachingtools.org/brief/7
    - How Can Students' Everyday Experiences Support Science Learning through Engineering Design?
        - http://stemteachingtools.org/brief/39

Citations:

Photographs by Kristen Bergsman.

Student Handout 9.1: Engineering Design Sketchpad

Name:_________________________________ Date:__________________ Period:__________

Brainstorm

What is engineering? What do engineers do?

Diagram of Engineering Practices

Designing a Sensory Substitution Device - Making a Plan

Big Ideas - Dreams/Things I wish could exist

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Flip your big ideas into possible design challenges.
How might we…..

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What are the end goals? What will I work to produce?

- ____
- ____
- ____
- ____

How will I know if it's successful? What measures and indicators will inform me of success of design?

- ____

□ ____

□ ____

□ ____

What constraints will I need to manage?

□ ____

□ ____

□ ____

□ ____

Define your end-users. Who will you be building this design for?
Who will be your primary users?

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Who might be other end-users?

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What do you already know/understand in starting your design?

□ _____________________________________ □ ____________________________________

□ _____________________________________ □ ____________________________________

□ ____

□ ____

What else do you need to know/understand to start your design? How might you acquire this knowledge?

□ _____________________________________ □ ____________________________________

□ _____________________________________ □ ____________________________________

□ ____

Design Sketchpad

Write out as many "If… then..." statements for your sensory substitution device as possible.

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Sketch out your basic ideas for what how you might connect different parts of the circuit for your sensory substitution device.

Basic Components:
- ❑ Sensory/Input
- ❑ Motor/Output
- ❑ Power supply

Which types of Arduino sketches might you use to copy and paste portions of the code?

Initial Design

Use this space to draw your design, take notes on what worked, what didn't work, what changes you made, etc.

Sketchpad 2

Expand your "If… then..." statements for your sensory substitution device to include the use of logic gates (AND, OR, NOT). For example, you can write statements such as "If not…. and… then…." or "If…. or….. then…." or "If…. then…. and …."

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Sketch out more ideas for what how you might connect different parts of the circuit for your sensory substitution device to include at least one logic gate.

Basic Components:

- ❏ Sensory/Input
- ❏ Motor/Output
- ❏ Power supply

Additional Component(s):

- ❏ Switch
- ❏ Additional sensor
- ❏ Additional output
- ❏ AND gate
- ❏ OR gate
- ❏ NOT gate

Which types of sketches might you use to copy and paste portions of the code?

Modified Design

Use this space to draw your design, take notes on what worked, what didn't work, what changes you made, etc.

Review your design plan. What else do you need to consider and incorporate?

Prototyping & Testing: Design Notebook

Use this page to document the things you tried, what worked, what didn't work, what you modified, and the feedback you received.

Design Reflection

What are you most proud of in designing your sensory substitution device?

What was one of the biggest challenges you encountered? Why was it challenging? How did you feel initially?

How did you overcome your challenges? What resources did you seek to help you through your challenges?

How did you and your teammate(s) work together? What interactions were you proud of? What interactions would you like to improve?

What tips would you give to a student who will be learning the same things you did to design your sensory substitution device?

Student Handout 9.2: Making it Real

Name:________________________________ Date:__________________ Period:__________

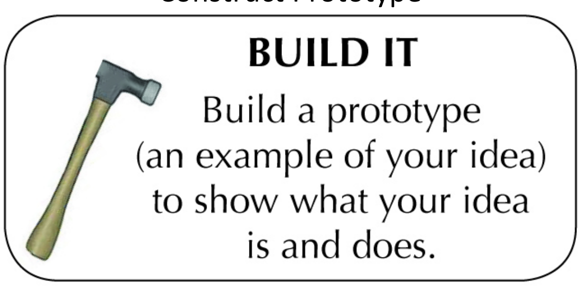
Pick one or two of the following areas to explore further for your sensory substitution device.

- What are the requirements of testing this device on users before making it available for public use?
- What materials should be used to build/encase the device?
- What aesthetic considerations should you take into account so that someone wants to use it?
- How can you scale down/up the device so it is more convenient for the user?
- What is the budget for making a complete prototype?
- How fast can a single device be produced?
- What safety concerns might be involved in using this device?
- Do any devices like this already exist? If so, how is yours alike or different?
- If you were to patent your design, what steps do you need to take?
- Who would you market the device to? Who would be selling this device?
- What's the history of the development of devices like yours?
- If you needed a battery to power your device, what type of battery is best? How long would your battery last before you needed to change it?
- Anything else you can think of?

Find a creative way to present your sensory substitution device, along with your one or two "Making It Real" ideas.

Teacher Resource 9 .1: Engineering Design Process Cards

Print and cut the following cards (one set per pair/group). Have students come up with an order for these cards. Discuss afterwards about the non-linearity of the engineering design process. Steps in engineering design process acquired from [Tch Teaching Channel].

Identify Need or Problem 	Research Criteria/Constraints 
Brainstorm Possible Solutions 	Select Best Solution 
Construct Prototype 	Test 
Present Results 	 Redesign

Teacher Resource 9.2: Circuit Possibilities

Light Sensor

If it is bright, then the resistance in the LDR (light dependent resistor) will decrease, which will decrease the total circuit resistance, which increases the current, which will turn the motor/bell/buzzer on.

If it is dark, then the resistance in the LDR will increase, which will increase the total circuit resistance, which decreases the current, which will prevent the motor/bell/buzzer from being turned on.

With NOT gate: If it is dark, then the resistance in the LDR will increase, which will decrease the total circuit resistance. The NOT gate inverts the low input to a high output, which increases the current, which will turn the motor/bell/buzzer on.

With AND gate: If it is bright AND the switch is closed, then the current will flow into both inputs of the AND gate, and current will flow through the output as well, turning on the motor/bell/buzzer.

Examples: If you want to turn "off" the ability to sense light like closing your eyes.

With OR gate: If it is bright through one LDR OR if it is bright through the other LDR, then one of these inputs will have current, the current will flow into the OR gate, and current will flow through the output, turning on the motor/bell/buzzer.

Pressure Sensor

If pressure is high, then the resistance in the sensor will decrease, which will decrease the total circuit resistance, which increases the current, which will turn on the motor/bell/buzzer/light.

The harder you press, the more current.
Example: For prosthetic arm, if pushed too hard, turn on light or move arm away. If push hard and it's hot, then move arm away.
If you pushed just one pressure sensor, only one LED comes on. If both pushed, then different motor or buzzing sound comes on.

With NOT gate: If pressure is low, then resistance will be high, then NOT gate will invert and produce high output current, and motor will run.
(helps move closer to desired object or location until pressure is sensed)

Tilt Sensor

Tilt sensor with low power on prothestic leg will relay information to muscle that moves the leg. Give voltage to leg (with switch).

If tilt sensor is tilted, then no current is flowing into NOT gate, which produces output current to relay. If there's current through relay AND switch on muscle is closed, then current will be delivered to the muscle to activate movement.

For Arduino

If light sensor 1 receives light over certain threshold, then vibration motor 1 turns on.
If light sensor 2 receives light over certain threshold, then vibration motor 2 turns on.

If pressure sensor 1 AND pressure sensor 2 are pushed passed certain threshold, then LED turn on.

If pressure sensor is over certain threshold, then LED 1 turns on.
If pressure sensor is over even higher threshold, then LED 1 and 2 turn on.