Unit: Circuitry and Sensory Substitution Devices

Lesson 3: Engineering the Circuit

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CENTER *for* NEUROTECHNOLOGY
a National Science Foundation Engineering Research Center

LESSON OVERVIEW

Activity Time:
One 90 minute and two 45 minute class periods

Lesson Plan Summary:
In this lesson, students will design their sensory substitution circuit (prototype of their sensory substitution device), build and test it, and make any necessary changes after the test.

STUDENT UNDERSTANDINGS

Big Idea & Enduring Understanding:

- Models of simplified sensory substitution devices can be designed, built, and tested using electronic input, processing, and output components.

Engineering Design Challenge:

- To build, design, test, and optimize a model of a sensory substitution device using circuits and electronic components in order to build an assistive device for someone who has a lost or impaired sense (i.e., vision, hearing, touch).

Driving Question:

- What are the steps in engineering a simplified sensory substitution device?

Learning Objectives:
Students will know…

- The steps in the engineering design process: asking questions, identifying a problem, brainstorming solutions, designing a prototype, testing and redesigning, evaluating the solution, and communicating the final design.

Students will be able to…

- Identify a sensory substitution device design which will meet a specific end-user need
- Draw a circuit diagram incorporating one or more input sensors, processors, and output components
- Evaluate multiple circuit designs to assess which best meets the criteria and constraints
- Build, test., troubleshoot, and iteratively improve a circuit prototype
- Design and create a scientific poster to communicate the final circuit prototype

Next Generation Science Standards:

This lesson builds toward the following bundle of Performance Expectations (PEs) and their integrated three dimensions of learning. Additional dimensions not part of these PEs are denoted with an asterisk (*).

High School Performance Expectations		
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. (Grades 9-12). **HS-ETS1-2:** Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering. (Grades 9-12).		
Science and Engineering Practices (SEPs)	**Disciplinary Core Idea(s)**	**Crosscutting Concepts (CCCs)**
Constructing Explanations and Designing Solutions *Asking Questions and Defining Problems *Developing and using models *Planning and Carrying out Investigations *Analyzing and Interpreting Data *Constructing Explanations and Designing Solutions	PS3.A: Definitions of Energy ETS1.A: Defining and Delimiting an Engineering Problem ETS1.C: Optimizing the Design Solution	Energy and Matter *Structure and Function * Cause and Effect *Stability and Change *Scale, Proportion, and Quantity *Systems and System Models *Connections to Engineering, Technology, and Applications of Science* Influence of Science, Engineering, and Technology on Society and the Natural World *Scientific Investigations Use a Variety of Methods

Common Core State Standards:

- **CCSS.ELA-Literacy.RST.9-10.7:** Translate between forms
- **CCSS.ELA-Literacy.W.9-10.1:** Write arguments
- **CCSS.ELA-Literacy.W.9-10.2:** Write explanatory texts

- **CCSS.ELA-Literacy.W.9-10.3:** Write narratives

IGCSE Physics Standards:

- **AO1-3**: Demonstrate knowledge and understanding of scientific instruments and apparatus
- **AO2-3**: In words or using other written forms of presentation, manipulate numeric & other data
- **AO2-6**: In words or using other written forms of presentation, make predictions and hypotheses.
- **AO3-1**: Demonstrate knowledge of how to safely use techniques, apparatus, and materials.
- **AO3-2**: Plan experiments and investigations
- **AO3-3**: Make and record observations and measurements
- **AO3-4**: Interpret and evaluate observations and data.

TEACHER PREPARATION

Materials:

Note: There are three sets of materials students can use to build their circuit prototypes, depending on school supplies and teacher expertise. General materials are listed first, then the materials specific to each option.

Material	Description	Quantity
Classroom Supplies	Small whiteboards and whiteboard markers for the brainstorming; butcher or poster paper, markers and colored pencils, rulers, printer, glue sticks	1-2 sets per group
Documents	Student Handout 3.1 and Student Handout 3.2	1 per person
Circuit Components	Tilt Sensor: $2 @ https://www.sparkfun.com/products/10289 Flex Sensor: $8 @ https://www.sparkfun.com/products/10264 Vibration Motor: $4 @ https://www.sparkfun.com/products/8449 Rotary Motor:$2 @ https://www.sparkfun.com/products/11696	1 per group

Option 1 - SnapCircuits: Use the SnapCircuit kits and components listed in Lesson 2 along with the general materials above. The advantage of this option is that you already have the correct SnapCircuit components from Lesson 2, and that the components are large and easy to see and connect for students. The disadvantage however is that it is quite challenging for students to know which resistors to use with the sensors, and building these circuits with transistors or relays can lead to an overwhelming amount of connectors.

Option 2 - Elenco Electronic Playgrounds: Use the 130-in-1 kits and the general components listed above. The advantage of this option is that the majority of the components students need are already in place on the board, and students just need to wire them together. The disadvantage is that there are a great many components students will not need and which can confuse them, there are still a great many resistors to choose from, and accidental miswiring can results in burned out components.

Material	Description	Quantity
Elenco Electronic Playground 130 kits	$26 from https://www.amazon.com/Elenco-Electronic-Playground-Learning-Center/dp/B0035XSZDI/ref=sr_1_1?ie=UTF8&qid=1502329981&sr=8-1&keywords=elenco+130+in+1+playground	1 kit per group
External Components	Minibreadboards: $3.95 from https://www.sparkfun.com/products/12043	1 per group

Option 3 - Individualized Circuit Boards: Design your own circuit boards with specifically adapted to the components students need to learn in a particular curriculum. This option requires extensive preparation and basic soldering skills, but the advantage is that by limiting the number of attachments for each input, processor, and output, as well as including the specific resistors needed for your sensors in an order that makes sense, students can work much more independently on their prototypes. The boards can be organized so that inexpensive components are easily replaceable, and students can manage the full engineering design process without the need for teacher-directed trouble-shooting. Board design depends on your particular requirements; materials for the boards used in this lesson are listed below. See Teacher Resource 3.2 for sample boards.

Material	Description
Eagle	Free: https://www.autodesk.com/products/eagle/overview
PCBs	Print from:
General Components	Resistors: https://www.sparkfun.com/products/10969 Switches: https://www.sparkfun.com/products/9276 LEDs: https://www.sparkfun.com/products/12062 Battery holder: https://www.sparkfun.com/products/9547

	Capacitors: https://www.sparkfun.com/products/13698 Long M/M: https://www.sparkfun.com/products/9387 Short M/M: https://www.sparkfun.com/products/8431 F Headers: Digikey PPPC021LFBN-RC/S7035-ND/810174
Equipment	Soldering iron, solder, multimeter
Input Components	Thermistor: https://www.sparkfun.com/products/10988 LDR: https://www.sparkfun.com/products/9088 Pressure: https://www.sparkfun.com/products/9375 Tilt Sensor:https://www.sparkfun.com/products/10289 Flex Sensor: https://www.sparkfun.com/products/10264 Potentiometer: https://www.sparkfun.com/products/9939
Processing Components	Transistors: https://www.sparkfun.com/products/521 AND Gates: Digikey SN74LS08N/296-1633-5-ND/277279 OR Gates: Digikey SN74LS32N/296-1658-5-ND/277304 NOT Gates: DigikeySN74LS04N/296-1629-5-ND/277275 Button Switch: https://www.sparkfun.com/products/10302 SPDT Switch: https://www.sparkfun.com/products/102 Relay: https://www.sparkfun.com/products/100
Output Components	Vibrating Motors: https://www.sparkfun.com/products/8449 Rotary Motors: https://www.sparkfun.com/products/11696 Multi LEDs: https://www.sparkfun.com/products/12062 Buzzer: https://www.sparkfun.com/products/7950 Spring Terminal: https://www.sparkfun.com/products/8073

Preparation:

1. Teacher should have an idea of the possible circuits students might design, as well as the necessary resistor to protect the components.
2. Photocopy Student Handout 3.1 and Student Handout 3.2 for students.

PROCEDURE

Engage: (10 min)

1. Discuss engineering survey results briefly, if assigned, or simply engage students in a discussion about what they think engineering is, as compared to "traditional" science
2. Go over Student Handout 3.1 (designed to be taped into interactive journals). Suggest that students think as they work about how their work over the next few days aligns with the engineering process, and make sure to highlight that it isn't a "procedure" to be followed step by step.

Explore, Explain, and Elaborate: (35 + 45 + 45 min)

3. Distribute Student Handout 3.2 for students to use as they work through their circuit design and testing. Monitor as they work, providing support and encouragement but not problem-solving for them.
   a) In remaining 35 min, Qs 1-3 (planning for end-use and suggesting designs).
   b) In next 45 min, Qs 4 and 6 (choosing a design and building the prototype). Assign Q5 as homework (typing up a full explanation for the design choice)
   c) In final 45 min, Q 6-7 (final testing), start 9 (making the poster). Assign Q8 (criteria for the Pugh Chart) and finishing Q9 as homework. Some groups may need to come in before/after school or during a tutorial session.

Evaluate:

1. As students work, assess their understanding of their decision-making process (why did they choose this particular design?), their understanding of circuit design (why is a transistor or relay necessary here?), and their understanding of what trade-offs they are making (how would you scale this to actually help someone accomplish something?).
2. Continue evaluating their design choices as they work on Q9, getting their posters ready.
3. Principal model evaluation occurs in Lesson 4.

STUDENT ASSESSMENT

Assessment Opportunities:

- No summative assessments, although Q5 could be read for a comments and a grade.

Student Metacognition:

- Students will be reflecting as they work - why they are choosing one design over another, why their circuit is not working as it should, how this activity aligns with the engineering process, etc.
- Students can also reflect on their group dynamics as they work - how all ideas are being heard or incorporated, what ways they are contributing to the design and supporting each other with problem-solving

Scoring Guide:

- Success is students actively collaborate to design, build, and test their circuit. Success is not necessarily have their circuit fully functioning the way they want by the end of the lesson, assuming they can explain what is not working and propose possible solutions.

EXTENSION ACTIVITIES

Extension Activities:

- Students could expand their circuit design to incorporate even more input sensors - provide students with extra components that they can use either on their breadboards or suggest additional choices from SnapCircuits or Electronic Playgrounds.
- Students could write up a scientific paper in addition to designing their poster presentation - they could use sample peer-reviewed journal articles from engineering journals to guide their work.
- Students could do more independent research to determine a cost-benefit analysis of their design, particularly with regards to the cost of the components they have used vs the benefit of having that particular design, and with regards to the cost of having something like this implanted in someone vs the benefit of their particular design.

Adaptations:

- **For groups who are struggling**: provide a more limited list of suggested components, possibly on index cards that students need to rearrange and build in the correct order. Be prepared to suggest which sensors are easier to work with (the force sensor is much easier than the thermistor, for example), and which outputs require simpler circuitry (the buzzer usually requires a relay, for example, whereas the LEDs do not).
- **For groups who are advanced**: rather than using any of the existing circuit kits, provide a breadboard and all of the loose electronic components they would need to build their circuit, and challenge them to get it to work on a breadboard.
- **For classes with extra time**: after students have drawn their circuits on whiteboards and chosen their particular design, have them create an electronic simulation of their proposed circuit before they actually build it with physical components. This is the way most electrical engineering is done - both a computer and a physical model are built and compared to each other before production. Students can use free online software (Eagle) to design and test their boards, and then they can build the physical model and see how it compares to the computer model.

TEACHER BACKGROUND & RESOURCES

Background Information:

- Make sure to build a few example circuits beforehand, because students will likely need support troubleshooting while they build their prototypes. This is particularly important if using the SnapCircuits or Electronic Playgrounds, because there are so many more issues students might run into when choosing resistors and completing the wiring.

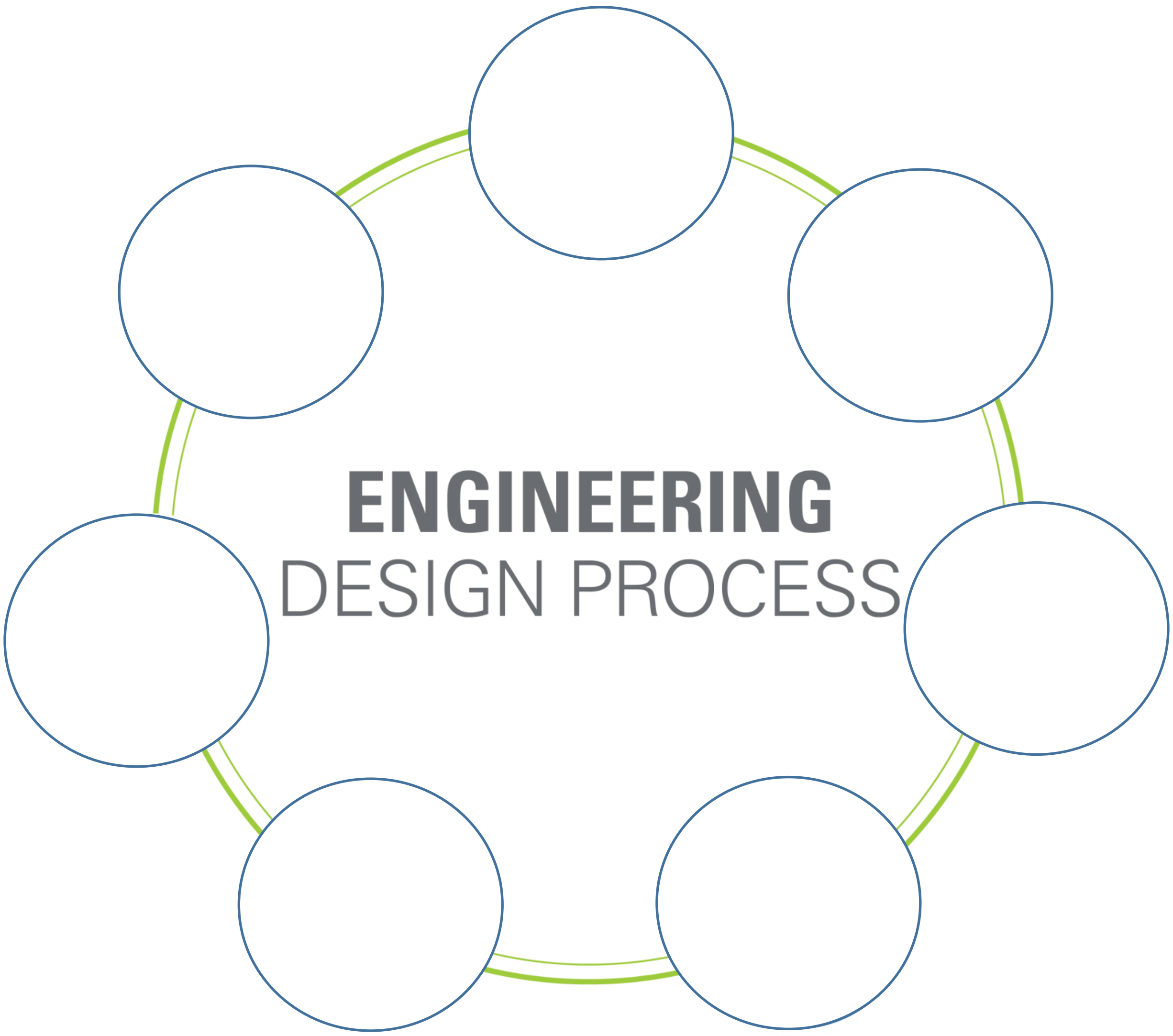
Resources:

Science and Engineering Practices

- https://gasstationwithoutpumps.wordpress.com/2010/06/10/engineering-vs-science/
- https://helix.northwestern.edu/blog/2013/12/what-difference-between-science-and-engineering

Unit: Circuitry and Sensory Substitution Devices
Student Handout 3.1: Engineering Design Process

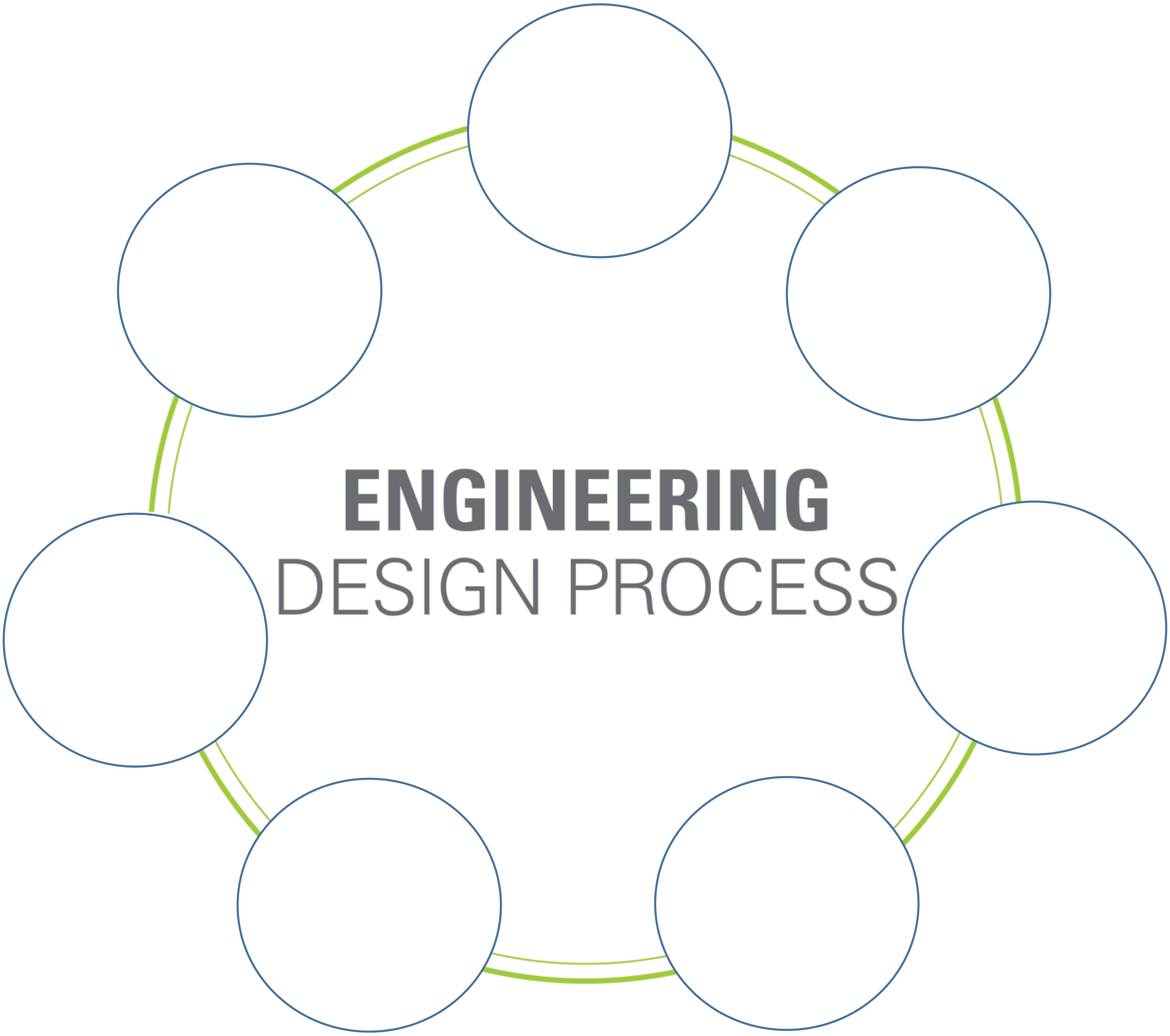
Name:____ Date:______________________ Period:______



Science vs Engineering

Differences:

Similarities:



Science vs Engineering

Differences:

Similarities:

Unit: Circuitry and Sensory Substitution Devices
Student Handout 3.2: Activity—Sensor Circuit Engineering

Name:____ Date:______________________ Period:______

Directions: Answer the following questions in your lab journal unless otherwise stated. Explain your thinking clearly.

Elicitation Question

Asking questions and identifying needs and constraints

(1) As you think about a potential sensory substitution device (SSD), identify…

- what are some needs a SSD could address? who are your end users?
- in what way could an SSD meet those needs? do any have particular advantages?
- what are the constraints your SSD must operate within? think both in terms of practical considerations (materials available) and theoretical (end user requirements)
- is there anything else you need to learn or find out in order to start designing a potential SSD?

Exploration Questions

The design process: engineering your device

(2) Create a table with three columns: inputs, processors, outputs. Generate a list of the available components in each category.

(3) With your group, discuss and make note of the following decisions:

a. which need will you address and substitute for (and therefore which input sensor will you use?)
b. which output(s) will you use that with that input sensor? Why is that output a good choice for a user who needs to substitute for a lost sense?
c. how will you know if your SSD will meet the need you identified? what will you look for?

(4) Sketch four possible circuit diagrams for your SSD on four small whiteboards.

- You must use the same principal input component for all four design possibilities, but can change the secondary inputs as well as the processors and outputs
- You must use at least two different processors in your proposed circuits (extra kudos if you design a circuit with two processors in the single circuit!)
- Each circuit design must include at least two "if…then" sentences for your input and output choices, based on changing input conditions. Write these on the whiteboards.
- Before you erase your whiteboards, take a picture of each to tape into your journal

(5) As a group, decide which of your four circuits best addresses the sensory substitution scenario you have chosen. Write (or type and tape in) a paragraph or two in which you address the following ….

- the need for your chosen SSD,
- why this design is the best choice in your constraints to meet this need
- what advantages and disadvantages it will potentially have
- what you expect should happen when your SSD is put to work (in terms of current, voltage, etc)
- how you will judge whether it is effective or not

(6) Build and test your chosen circuit. As you work, make a note of what changes were necessary as you built and tested your circuit and why these changes were necessary. Also make a note of any changes that were not necessary, but which you thought might optimize your SSD design.

(7) When you have successfully built, tested, and optimized your SSD, evaluate how effectively it meets your identified need, fits your criteria and constraints, and any unresolved issues.

Conclusion Questions

Evaluate your solution in relation to other proposals

(8) Generate a list of 5-8 criteria you would use to evaluate similar proposed SSD. Some examples might include how well it follows design regulations, how easy the proposed final form is for an end-user, how much energy it uses, etc.

(9) Design a poster presentation for your SSD. It should follow the general academic poster format below and be easily readable on poster paper. You will be working in pairs to present your device and evaluate others', so make sure you are prepared for questions and have a working prototype! Take a picture of your completed poster and tape it into your lab journal.

Name of your SSD

Your names

Introduction - what need does your SSD seek to address? - how does your SSD address this need? - ?	Draw your final SSD circuit Explain in words how your circuit functions. Be specific but brief.	**Conclusion** - what are some of the more important changes you made as you worked, and why? - what would be your next steps or improvements now? - ?

(10) In pairs, present your poster and then evaluate others' using your Pugh chart. Tape your completed Pugh chart into your lab journal.

Tactile Substitution for Vision Article 1/30/17

Sensory Substitution

on-tongue
- sensor that senses info by substituted modality.
- coupler to process this and drive actuator.
- actuator activates receptors
- normally sight is what this substitutes, using touch and hearing.

Feasibility
VT sensub
- depends on flexibility of perception system
- receptors scan environment (2D)
- receptors can use sound too.
- touch and vision are related.
- using a combination didn't work due to overload.

Limits
VT sensub
- visual space to tactile space, visual luminance to tactile vibrations.
- uses pins on the skin, but there aren't enough to get as detailed information.
- hard to find an unused skin space.

A sensub
- uses motor-sensory relations
- can use a camera on the forehead.
- person has to be trained.
- when sensor and actuator are on the same organ.

Challenges
VT sensub
- finances
- less foveal and peripheral

S Sensor Circuits 1/30/17

Sensor circuits respond to outside change they have a potential divider a lot of the time.

A potential divider consists of two or more resistors in series.

Pd is shared between the resistors.

Voltage depends on resistance, as they have the same current in a series.

Investigating the potential divider
- sum of pds is the same as the battery pd.
- with a variable resistor, the pd in the other changes so that it is still equal to the pd in the battery.

Potentiometer is a variable potential divider with fixed contact ends and sliding contact on the track which is straight when linear and circular in a rotary potentiometer.
- sliding contact up, voltage is higher
- sliding contact down, voltage is lower.

A sensor circuit uses changes externally to change the

Notes- Intro to SMNE

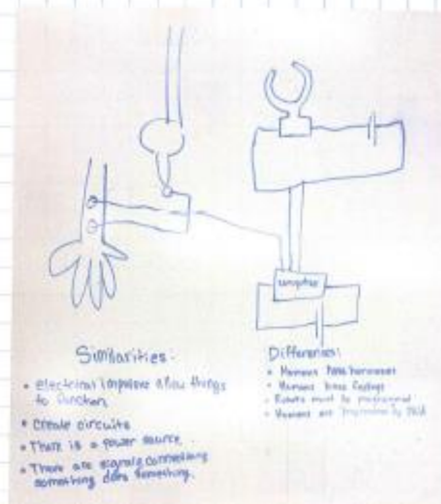
1. Examples of using sensors:
   - snakes have infra-red.
   - machines in hospitals for x-rays.
   - machines in cars for radio waves.
   - flies pick up heat and odor
   - bats pick up compression waves.

2. Brain:
   - sees electrochemical signals - doesn't know where these come from.
   - uses all information.

3. Potato Head:
   - our senses are plug-ins on the outside.
   - They are periferals.
   - sensory substitution using different senses to send information to your brain to take the place of a different sense.

4. VEST:
   - Sound goes to tablet which goes to vest vibrations.

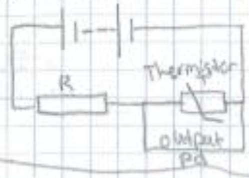
5. Pros/Cons:
   - gain an extra sense (pro)
   - overwhelming (con)
   - can be expensive (con)



...e voltage to power something. (can be called an input transducer)
...hermistors are resistors that depend on temperature.
- temp. increases, resistance decreases, so pd decreases
- symbol: [thermistor symbol]
- output pd increases.

...DRs are resistors that depend on light.
- light increases, resistance decreases, output pd increases

...riable Resistors can be adjusted.

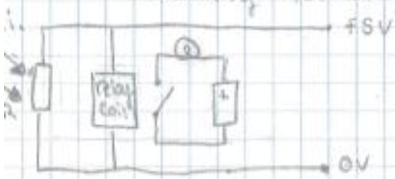


...6 Switching Circuits 1/30/17

...elays turn machines on and off
- current goes through electromagnet to attract iron armature which pivots to close the switch gap.
- small current turns on bigger current.

Rectifier circuits use diodes to turn alternating current to direct current.
- pd has to be forward to get through pd, so the diode "rectifies" it.

...emperature-operated Fan
- variable resistor has relay just off.
- when temp. increases thermistor resistance decreases, as does the pd, so the pd on the coil increases, switching the relay to make the fan go.



...7 Logic Circuits 2/2/17

...igital circuits have a low voltage of zero or high voltage of a ...rtain number, nothing in between.
- sequence of pulses
- new technology of silicon chip with switching circuits using transistors allows this.

...efore digital, analogue was used where voltage can vary between two points.

...nalogue signal

Article 1
- sound lets them recognize objects
- gloves vibrate letting people drive, along with pads on chair to show speed, and a [illegible] plate for a map.
- people could not be comfortable with people driving.
- how would this be certified.

Article 2
- sound lets people see
- sunglasses with camera, which goes to computer to change it to sound which comes out headphones.
- not good with color and depth perception.
- cheap

Article 4
- putting in camera to connect directly (are invasive and expensive)
- substitution of one sense for another ie hearing and touch.
- brail is an example
- not much training for SSD so it isn't used as much.
- scientific report (selling)
- hard to see complex shapes
- brain doesn't lose how to process the information.
- There is online training.

Article 4

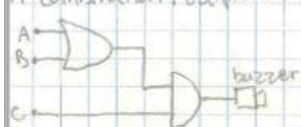
[redacted]

Digital signal

Logic is output depending on input
Logic gates have switches, one or more inputs and one output (digital circuit)

Gate	Symbol	Function (High voltage=1, Low voltage=0)	Truth Table Inputs A	B	Output
OR	A, B → output	output=1 if A or B=1	0	0	0
			0	1	1
			1	0	1
			1	1	1
AND	A, B → output	Output=1 if A and B=1	0	0	0
			0	1	0
			1	0	0
			1	1	1
NOR	A, B → output	Output=0 if A or B=1	0	0	1
			0	1	0
			1	0	0
			1	1	0
NAND	A, B → output	Output=0 if A and B=1	0	0	1
			0	1	1
			1	0	1
			1	1	0
NOT	input → output	output=1 if input=0	0		1
		output=0 if input=1	1		0

A combination: "output=1 if input A or input B=1 and input C=1"



2/2/17

9 Logic Circuits in Control

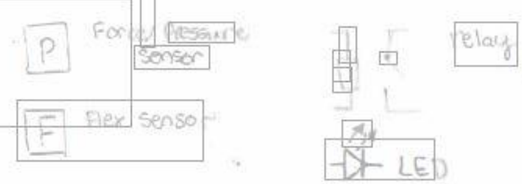
A control system usually has input sensors, then a control circuit, then an output device.
Sensors send electrical signals depending on a variable changing.
Using thermistor and variable resistor, or a light-dependent

Notes - Sensor Components
* sensors, inputs, outputs

4

Notes - Sensor Components

Name	Symbol	Function
Potential divider "potentiometer"		2 or more resistors in series that divide the potential.
Thermistor (sensor)		resistance decreases as temperature increases.
LDR (sensor)		resistance decreases as brightness increases.
Relay (proc.)		"a special switch" used when want 2 diff. power sources or choices.
transistor (proc.)	B, C, E	"a special switch" current into the base controls the current through the emitter.
capacitor		battery charges the plates then the plates store the potential for later use.
diode		allows current to flow in one direction.



resistor and a variable resistor to make a potential divider we can use a logic gate to make th output pd turn into a digital signal, using th variable resistor to change th temperature or light that th output changes at.

- when temp. increases, thermistor resistance and pd decreases so output pd increases, to a point where th output switches.

r pressure switch could also be used as a sensor.

symbols:

emperature light pressure

ogic circuits can tell us when something is too high or low.

High-temperature indicator.

- light turns on when th test switch is closed or when th temperature is too high using a temperature sensor and an OR gate.

Night-time rain alarm

- buzzer goes off if it is dark, as a light sensor gives a 0 to th NOT gate, thus making it a 1 and it is wet as th moisture sensor gives a 1 also to th AND gate.

A logic indicator can be an LED and resistor and so th light lights up when th voltage is high, thus showing th voltage in a digital circuit.

Notes - Logic Gates

Gate + Symbol | **Truth Table** | **Description/Application**

NOT

In	Out
0	1
1	0

Inverts th input
Changes low to high

AND

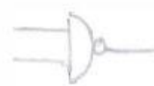
In		Out
0	0	0
1	0	0
0	1	0
1	1	1

Both inputs must be high/on(1) for th output to be high.

OR

In		Out
0	0	0
1	0	1
0	1	1
1	1	1

one or th other input must be high for th output to be high.



NAND

In		Out
0	0	1
1	0	1
0	1	1
1	1	0

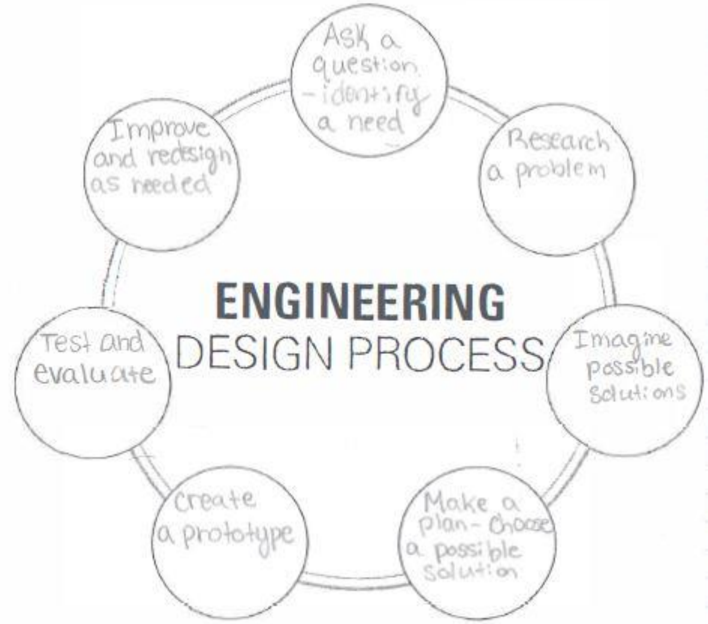
AND and NOT
- both inputs must be high for th output to be low.

NOR

In		Out
0	0	1
1	0	0
0	1	0
1	1	0

OR and NOT
- If either of th inputs is high, th output is low.

Digital (on-off)
not analogue (continuous)



Science vs Engineering very similar

Differences:

- Engineering results in a design/product
- Engineering tries to solve existing problems not just understand

Similarities:

- Both have a process
- Iterative
- Both rely on results

Activity - Sensor Circuit Engineering

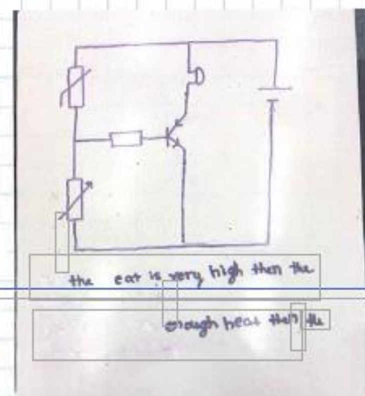
1. An SSD could address a loss of sight, hearing, and touch. Blind people, deaf people, and people without a sense of touch. An SSD could replace one sense using another. They can be cheaper than other ways and you can just use the senses that they have. Constraints are that people have to learn to use it, it takes time to get used to, and in our lab, we only have certain sensors and not very many, and we have limited power. We need to figure out how to connect the sensors to the board and how to use them.

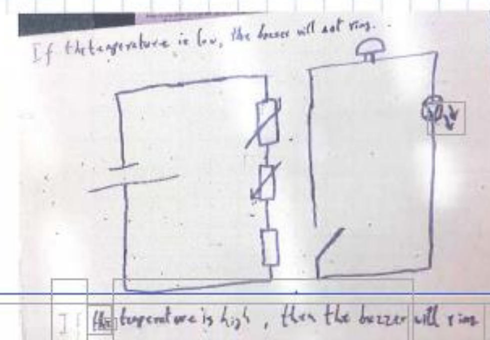
2.

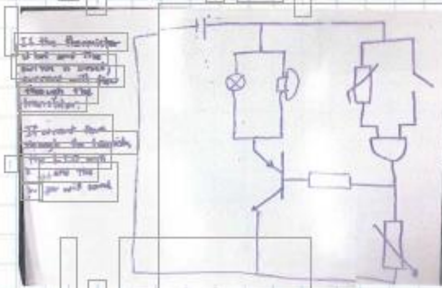
inputs	processors	outputs
-flick switches	-transistor	-LED
-push switches	-relay	-buzzer
-thermistor	-OR gate	-light bulb
-LDR	-AND gate	
-battery	-NOT gate	
-flex sensor		
-force sensor		

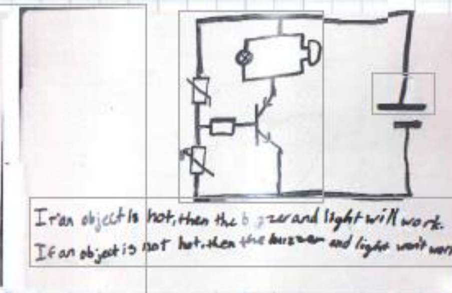
3a. We will address the loss of touch and substitute it for sight and hearing by using a thermistor.
b. The output is the LED and the buzzer which are good choices because they are easy to sense, and they are common and are cheap.
c. If our SSD meets our need we will look for the LED to light and the buzzer to sound.
* We will put the design in a glove.

4.









5. ~~There is a need to~~ substitute touch for sight and hearing as there are people who can't feel. The design we chose is the best choice because it only includes the necessary components, but has two outputs to ensure that it works, along with having a switch so that it can also be switched on manually. The advantages of this design are that it has two outputs, it can be switched on and off manually, the transistor allows the bulb to be brighter and the buzzer to be louder, the variable resistor lets you control the amount of heat needed to light the bulb and make the buzzer buzz. The disadvantages of this design are that the transistor can only sense a certain amount of heat, you have to adjust the variable resistor many times, and we aren't positive that it will work yet. The current in the circuit will go to the thermistor, and depending on where the variable resistor is set, the more heat there is, the less resistance so there will be more current which will then flow into the base of the transistor, then letting current flow through the buzzer and the light bulb. So the current in the battery is equal to the current going through the thermistor which is also equal to the current going through the buzzer and light bulb combined, as the current is split between the buzzer and the light bulb. The voltage in the battery is equal to the voltage in the buzzer, the light bulb, and the thermistor combined. This is what makes the buzzer buzz and the light bulb light. We will judge whether it is effective or not by bringing warm objects and cold objects near the thermistor, and if the buzzer buzzes and the light bulb lights when the warm object is by it, and neither of them work when the cold object is by it, then we will see if it is effective.

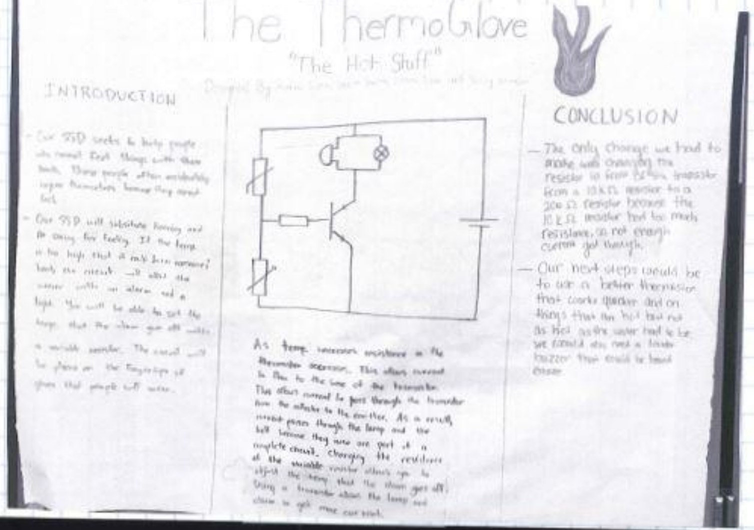
the circuit connected and was complete.

- We had to change the resistor in front of the transistor from a 10k Ω resistor to a 200 Ω resistor because the 10k Ω resistor had too much resistance so not enough current got through.

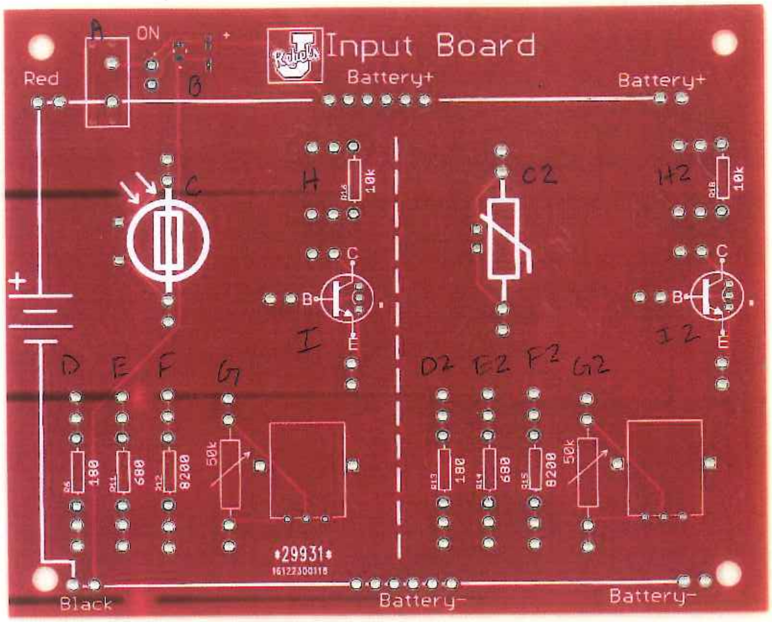
7. Our SSD met our needs pretty well. When the thermistor came in contact with boiling water the light bulb lit up and the buzzer went off. Taking into account that we had only certain materials to work with it does fit the criteria. Although, if it were going to be used for a real SSD, it would need to be more transportable. The only unresolved issues were with the buzzer. The thermistor had to be held in the boiling water for a while until the buzzer went off, and when it did, it wasn't very loud and the thermistor was close to being damaged from being in the boiling water for too long. We would need to use a better thermistor that works quicker and on things that are still hot but not as hot as the water had to be for it to work, and a louder buzzer so that it could be heard better. But, due to our limited materials and constraints, our SSD fit the criteria well. We would put this all in a glove to be transported easier.

8.
- Does it work?
- Does the circuit have unessacary components?
- Is is easy to use?
- Is it easy to reproduce?
- Is it practical, would people use it?
- Is it reliable?

9.

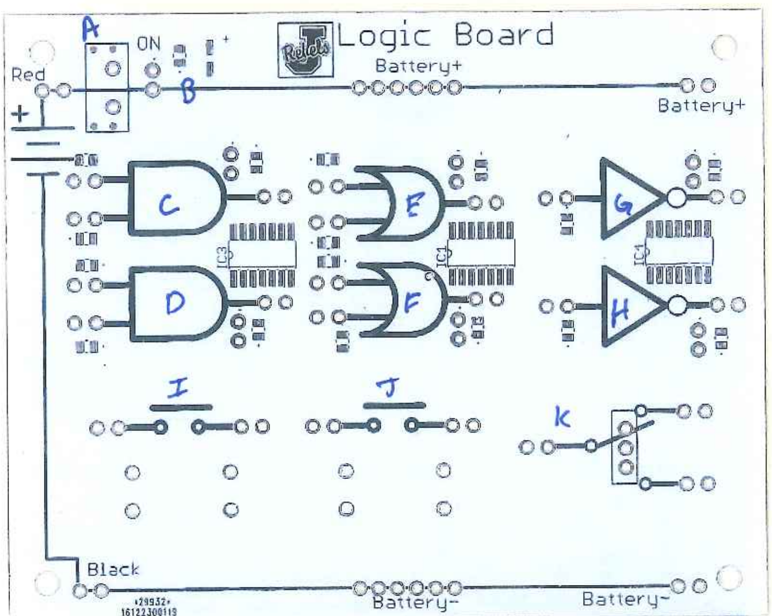


Criteria	Brightness Tester	Sensor for the Paralyzed	Touch Augmentation Device	Sensor Suit	Silent Doorbell	Thermodetector	Buzzy Buzzer
Efficiency in Function /3	2	3	3	3	3	3	3
Functionality - does it work? /5	5	5	5	3	5	3	5
Practical to use - is it important? /5	5	5	5	5	5	5	5
Ease of use/design /4	3	3	3	4	4	4	4
Reliability /4	4	4	4	2	4	2	3
Durability /5	5	5	5	5	5	5	5
Follows constraints /5	5	5	5	5	5	5	5
Total	29	30	30	27	31	27	30



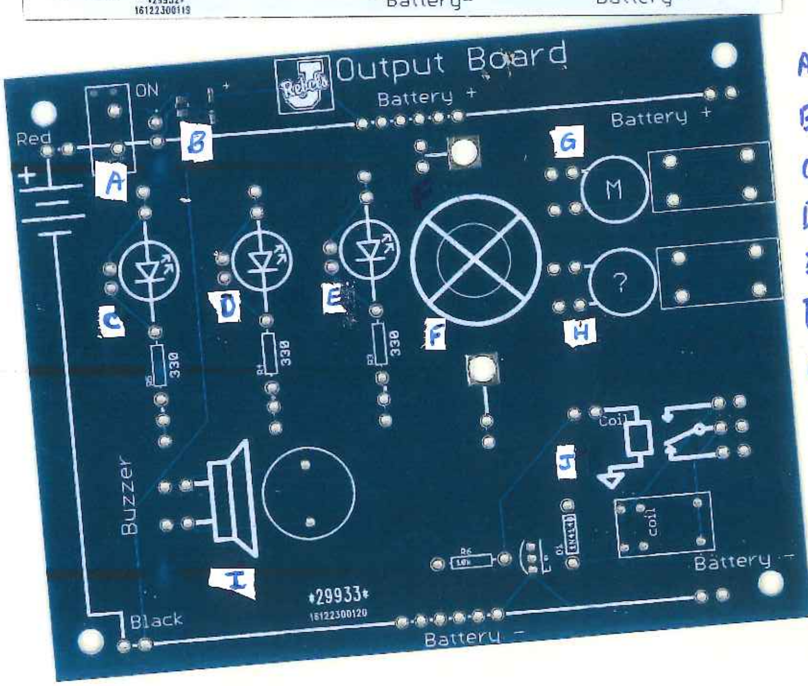
A - switch
B - capaciter
C - sensor [LDR, pressure, flex, thermistor)
D - R1
E - R2
F - R3
G - Variable Resister
H - R for transister
I - transistor

Red



A- switch
B- capaciter
C- AND 1
D- AND 2
E- ~~AN~~ OR 1
F- OR 2
G- NOT 1
H- NOT 2
I- switch 1
J- switch 2
K- switch 3

White



A - switch
B - capaciter
C - LED 1
D - LED 2
E - LED 3
F - Bulb
G - Motor 1
H - Motor 2
I - buzzer
J - relay

Blue