Circuitry and Sensory Substitution

A Curriculum Unit for High School Physics
and Cambridge IGCSE Physics courses
April 2019

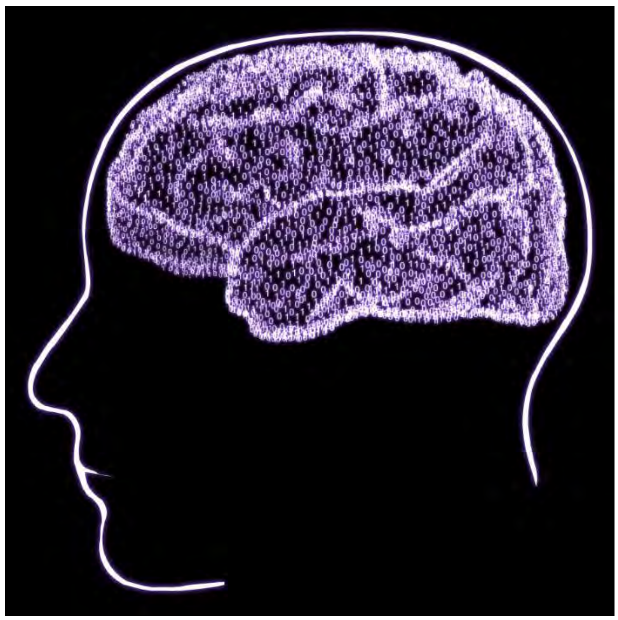

Image: Outline of the human head with the shape of the brain created out of purple 1s and 0s.
Source: 2003, Nicolas P. Rougier, Wikimedia Commons.

Research Experience for Teachers (RET) Program

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

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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 Handout 3.1: Engineering Design Process

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In this lesson, students will evaluate their sensory substitution circuit both in terms of engineering and ethics by taking part in a scientific poster session.

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About the RET Program & the CNT

About the Research Experience for Teachers (RET) Program

The Research Experience for Teachers (RET) program is a seven week research experience for middle and high school STEM teachers, hosted by the Center for Neurotechnology (CNT) on the University of Washington's Seattle campus. Each summer cohort is selected through a competitive application process. Accepted teachers apprentice in a CNT lab alongside a team of researchers conducting cutting-edge neural engineering research. They enhance their understanding of lab safety, bioethics, engineering education, and curriculum design. Together, the teachers work to develop innovative neural engineering curriculum materials, which are then pilot-tested in their own classrooms the following academic year. More information about the RET program is available here.

About the Center for Neurotechnology (CNT)

The Center for Neurotechnology (CNT) is revolutionizing the treatment of spinal cord injury, stroke, and other debilitating neurological conditions by discovering principles of engineered neuroplasticity and developing neural devices that will assist, improve, and restore sensory and motor functions. Engineered neuroplasticity is a new form of rehabilitation that uses engineered devices to restore lost or injured connections in the brain, spinal cord, and other areas of the nervous system. Learn more about the center here.

Neural Engineering Skill Sets

The CNT has identified the following skill sets as essential for students to achieve neural engineering competency. All education activities supported by the CNT are designed to teach one or more of these skills.

1. **Fundamentals of neuroscience, neural engineering, and neuroethics research:** Knowledge of core concepts in neuroscience and neural engineering, designing and conducting experiments, analysis and interpretation of results, problem solving, understanding primary scientific literature, building scientific knowledge, and ethical and responsible conduct of research.
2. **Neural engineering best practices:** Oral and written communication of neural engineering knowledge and research, confidence, working independently, working on a team, participating in a learning community, innovation, and persistence.
3. **Connections to neural engineering industry and careers:** Awareness of career options in neural engineering and pathways

Funding

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Contact Information & Credits

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Target Grade Level: Grade 10 (9-12)

Time Required: 405 minutes (two weeks with 45 minute classes each day)

Unit Description

In this two week unit, students extend their knowledge of basic electric circuits by studying the function and use of more complex components (e.g., thermistors, LDRs, logic gates, LEDs, etc.) in the context of a neural engineering design project. Students are introduced to basic neuroscience principles (e.g., the brain, neurons, motor cortex, brain-computer interfaces, etc.) and use these concepts to design, build, optimize, evaluate, and present a sensory-substitution device, modeled as an assistive device on circuit boards (the anchoring design problem).

Neural engineering is an interdisciplinary branch of science and engineering which ties together aspects of biomedical and electrical engineering with neuroscience. Biomedical engineers work to understand what types of devices are needed, electrical engineers support in the creation of these devices, and neuroscientists work to understand how they are performing in individuals with neurological illnesses or disabilities.

In Lesson 1, students are introduced to the similarities and differences between the brain and computers and how they are connected through use of an EMG-controlled gripper claw. They learn about and discuss some of the practical and ethical considerations in neuroscience and specifically of sensory substitution devices. In Lesson 2, students explore more complex circuit components through the use of SnapCircuits, and practice problem-solving with complex circuit diagrams. In Lesson 3, students engage in the practices of engineering design as they work in teams to design, build, and iterate on their model sensory substitution devices. In Lesson 4, students will evaluate their prototypes and the unit will culminate in a scientific poster session in which students present and evaluate their final models.

- Lesson 1 - Brain and Computer Connections (45 min)
- Lesson 2: Sensor and Logic Circuits (180 min)
- Lesson 3: Engineering the Circuit (180 min)
- Lesson 4: Evaluating the Prototypes (45 min)

Classroom Testing

This curriculum was implemented in February 2017 and February 2018 at Juanita High School, in Kirkland, WA. Implementation occurred with two sections of 10th grade Physics students each year, for 113 students in total.

Alignment to National Learning Standards

This unit is aligned to the Next Generation Science Standards (NGSS).

This unit is also aligned to the International Technology Education Association (ITEA) Standards for Technological Literacy.

Next Generation Science Standards: Performance Expectations

This unit builds toward the following bundle of high school Performance Expectations (PEs). Alignment to the three dimensions of science and engineering education (Disciplinary Core Ideas, Crosscutting Concepts, and Practices) are outlined in the table below. Hyperlinks direct to relevant sections of the Next Generation Science Standards and *A Framework for K-12 Science Education*.

High School Performance Expectations		
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). **HS-ETS1-3:** Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts. (Grades 9-12). **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).		
Science and Engineering Practices (SEPs)	**Disciplinary Core Idea(s)**	**Crosscutting Concepts (CCCs)**
Constructing Explanations and Designing Solutions	ETS1.A: Defining and Delimiting an Engineering Problem ETS1.B: Developing Possible Solutions ETS1.C: Optimizing the Design Solution PS3.A: Definitions of Energy	Energy and Matter *Connections to Engineering, Technology, and Applications of Science* Influence of Science, Engineering, and Technology on Society and the Natural World

NGSS Lead States. (2013). *Next Generation Science Standards: For States, By States*. Achieve, Inc. on behalf of the twenty-six states and partners that collaborated on the NGSS.

International Technology Education Association (ITEA) Standards for Technological Literacy

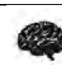
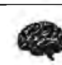
This unit builds toward the following high school ITEA Standards. Hyperlinks direct to relevant sections of the *Standards for Technological Literacy*.

ITEEA 2000, grades 9-12, 3.H	**3. Students will develop an understanding of the relationships among technologies and the connections between technology and other fields of study.** H. Technological innovation often results when ideas, knowledge, or skills are shared within a technology, among technologies, or across other fields.
ITEEA 2000, grades 9-12, 4.I	**4. Students will develop an understanding of the cultural, social, economic, and political effects of technology.** I. Making decisions about the use of technology involves weighing the trade-offs between positive and negative effects.
ITEEA 2000, grades 9-12, 8.H	**8. Students will develop an understanding of the attributes of design.** H. The design process includes defining a problem, brainstorming, researching and generating ideas, identifying criteria and specifying constraints, exploring possibilities, selecting an approach, developing a design proposal, making a model or prototype, testing and evaluating the design using specifications, refining the design, creating or making it, and communicating processes and results.

ITEA and its Technology for All Americans Project. (2006*). Standards for Technological Literacy: Content for the Study of Technology*, 3rd Ed. International Technology Education Association: Reston, Virginia.

IGCSE Physics Standards

This unit builds toward the following high school Cambridge IGCSE Physics standards.

Standards	**Lesson 1**	**Lesson 2**	**Lesson 3**	**Lesson 4**
AO1-2. Demonstrate knowledge and understanding of scientific vocabulary and conventions				
AO1-3: Demonstrate knowledge and understanding of scientific instruments and apparatus				
AO1-4: Demonstrate knowledge and understanding of scientific and technological applications with their social, economic, and environmental implications.				
AO2-3: In words or using other written forms of presentation, manipulate numeric & other data				
AO2-5: In words or using other written forms of presentation, present reasoned explanations for phenomena, patterns and relationships.				
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.				
AO3-5: Evaluate methods and suggest possible improvements.				
AO4-3: Action and use of circuit components				
AO4-4: Digital electronics				

Cambridge International Examinations (2016*). Syllabus: Cambridge IGCSE Physics.* Available https://www.cambridgeinternational.org/Images/167041-2016-2018-syllabus.pdf.

Unit: Circuitry and Sensory Substitution Devices

Lesson 1: Brain and Computer Connection

Author: Alexandra Pike

CENTER for NEUROTECHNOLOGY
a National Science Foundation Engineering Research Center

LESSON OVERVIEW

Activity Time:
One 45 minute class period (+)

Lesson Plan Summary:
In this lesson, students will make connections between what they have learned about basic and complex circuits in the previous weeks to neuroscience applications (assistive devices and sensory substitution). They will compare and contrast the brain and circuitry, and brainstorm about types of senses/sensors (inputs) and types of outputs.

STUDENT UNDERSTANDINGS

Big Idea & Enduring Understanding:

- **The brain**: The brain can be thought of similarly to an electric circuit, where sensory neurons receive input, the brain processes this, and motor neurons instigate a response.
- **Sensorimotor neural engineering**: Sensorimotor neural engineering is a field of study that aims to understand how to capitalize on the sensorimotor loop to design devices, treatments, and therapies to help people with neurological, sensory, and motor disorders. Neural engineering connects the nervous system and computers to restore and enhance normal human function. Sensorimotor neural engineering is focused on the loop between sensory information received by the brain, information that the central nervous system (CNS) sends out, and devices (computers, implants, prosthetics, etc.) that receive inputs and produce outputs that feed back into the CNS.

- **Sensory substitution**: Sensory substitution is when one sense is substituted with another. Usually this occurs through a non-invasive device which takes one input (which the body can no longer sense) and converts it to a different input (which the body can sense, process, and react to). This relies heavily on brain plasticity, the brain's ability to repair and enhance existing neural pathways.

Investigative Phenomenon: How does a robotic gripper hand work to translate biosignals from the human body to a simple machine?

Driving Question:

- What are similarities and differences between our brains and electric circuits, and how is that useful in neuroscience applications?

Learning Objectives:

Students will know…

- That there are similarities between electrical and biological systems including inputs (human senses and electrical sensors), processors (the nervous system and logic gates, transistors, and relays), and outputs (movement etc., and motors, LEDs etc.), as well as differences - digital vs analogue, scale and complexity, etc.
- That the purpose of sensory substitution device is to enable a person with a sensory disability to use a working sense to replace a damaged or lost sense (i.e., a retinal implant, a cochlear implant, etc.).

Students will be able to…

- Explain the principal similarities and differences between electric circuits and the brain
- Define and give examples of sensory substitution devices

Vocabulary:

- **Sensorimotor neural engineering**: the process of engineering devices to restore or augment the body's capabilities for sensation and movement
- **Sensory and motor neurons**: sensory neurons convert external stimuli from the organism's environment into internal electrical impulses, while motor neurons conduct an impulse that causes movement
- **Sensory substitution device**: a device which enables one sense to replace the use of another sense
- **Assistive device:** any device that helps someone do something that they might not otherwise be able to do well or at all

- **Neural plasticity**: the brain's ability to reorganize itself by forming new neural connections throughout life

Next Generation Science Standards:

This lesson builds toward the following Performance Expectation (PE) and its integrated three dimensions of learning. Additional dimensions 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).		
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 *Obtaining, evaluating, and communicating information	ETS1.A: Defining and Delimiting an Engineering Problem PS3.A: Definitions of Energy	Energy and Matter *Structure and Function *Connections to Engineering, Technology, and Applications of Science* Influence of Science, Engineering, and Technology on Society and the Natural World *Science is a Human Endeavor *Science Addresses Questions about the Natural and Material World

Common Core State Standards:

- **CCSS.ELA-Literacy.RST.11-12.1:** Cite evidence to support analysis
- **CCSS.ELA-Literacy.RST.11-12.7:** Integrate and evaluate information in diverse formats
- **CCSS.ELA-Literacy.RST.11-12.9:** Synthesize information
- **CCSS.ELA-Literacy.SL.9-10.1:** Initiate and collaborate in discussions

IGCSE Physics standards:

- **AO1-4**. Demonstrate knowledge and understanding of scientific and technological applications with their social, economic and environmental implications.

TEACHER PREPARATION

Materials

Note: In place of the pieces below, Backyard Brains now carries a kit which eliminates the need for actually building the gripper arm: https://backyardbrains.com/products/clawBundle .

Material	Description	Quantity
Arduino Uno R3	From Amazon.com or Sparkfun.com	1 per class
EMG SpikerShield	Works with Arduino to harness electrical activity of the muscles. $75 from BackyardBrains.com	1 per class
Gripper hand	$10 from www.sparkfun.com/products/13174	1 per class
Gripper servo motor, HiTech HS-422	$10 from www.sparkfun.com/products/11884	1 per class
USB portable power bank 2200 mAh	$10 from Amazon.com	1 per class
USB cable A to B	$4 from https://www.sparkfun.com/products/512	1 per class
Male header pin	$1 from https://www.sparkfun.com/products/12693	1 per class
Jumper wire M/M	$4 from https://www.sparkfun.com/products/8431	1 per class
ECG electrodes	$29 https://backyardbrains.com/products/emglargeelectrodes	3 per stdt
Supplies	Large whiteboards and whiteboard markers	1 set per lab group
Documents	Student Handouts 1.1a-d and 2.1 Teacher Resources 1.1 and 1.2	1 per stdt

Preparation

1. Build and test Gripper Hand (or purchase the assembled kit from Backyard Brains):

   a. Instructions are at: https://www.backyardbrains.com/experiments/gripperhand. Note: The assembly includes making a custom USB cable, described at https://www.backyardbrains.com/experiments/files/USB_Cable_Gripper.pdf.
   b. Connect the gripper hand to the Arduino and SpikerShield, and test its action using the EMG patches to make sure if works reliably.
2. Access the four articles that will make up Student Handouts 1.1a-d. Print copies or have students read online.
   a. **Handout 1.1a: *Blind Sight: The Next Generation of Sensory Substitution Technology***
      Dana Smith, *The Crux* (2014). Reading level: High School.
      http://blogs.discovermagazine.com/crux/2014/04/28/blind-sight-the-next-generation-of-sensory-substitution-technology/#.XLjOiJhKiUk
   b. **Handout 1.1b: *Sensory Substitution***
      Timothy Gower, *Proto* (2015). Reading level: High School.
      http://protomag.com/articles/sensory-substitution
   c. **Handout 1.1c*: Sensory Substitution: Closing the Gap between Basic Research and Widespread Practical Visual Rehabilitation***
      Shachar Maidenbaum, Sami Abboud, and Amir Amedi, *Neuroscience & Biobehavioral Reviews* (2014). Reading level: High School-College.
      https://www.sciencedirect.com/science/article/pii/S0149763413002765?via%3Dihub
   d. **Handout 1.1d: *Tactile Substitution for Vision***
      Yael Zilbershtain-Kra, Amos Arieli, and Ehud Ahissar, *Scholarpedia* (2015). Reading level: High School.
      http://www.scholarpedia.org/article/Tactile_Substitution_for_Vision

3. Photocopy exit tickets (Student Handout 1.2) so they are ready to distribute.
4. Open and test the David Eagleman VEST video clip: https://www.youtube.com/watch?v=kbKzF8gKxT4

PROCEDURE

Engage: (10 min)

1. Show students and demonstrate the gripper hand (the investigative phenomenon).
   a. Briefly brainstorm or pair-share: When/where have you seen something like this before? What makes the gripper hand work? In what situations might this be useful? Encourage students to try the gripper hand themselves, and test the effects of different muscles and actions.
   b. Initial Explanation: Have students work in lab groups on large whiteboards to sketch the gripper hand system (arm to hand) and label what they think is

happening as the hand works. There is no correct answer at this point, but push students to commit to their ideas in writing

c. Transition: What connection does the gripper hand have to what you have learned in the previous weeks?

Explore: (10 min)

2. What are similarities between electric circuits and your brain/body? Have students work together to brainstorm a list of similarities and differences, as well as questions they have. They should/might need help to come up with ideas including
    a. Similarities: senses compared to inputs (i.e., vision and light-dependent resistors), both rely on electricity to communicate, both have outputs, both are fast, etc.
    b. Differences: brains can learn/think more organically than computers at this point, circuits have sensors in only certain places instead of all over the skin, etc.
3. Why might these similarities be useful? ...we can use circuits to assist humans to replace lost senses, or even use other senses to substitute for lost senses

Explain: (15 min)

4. Tell students: We are going to be applying what you have learned about circuits to a field called "sensorimotor neural engineering" - the process of engineering devices which aim to replace or enhance damaged neural and motor capabilities. You will be designing "sensory substitution" device - a circuit designed to interface with the nervous system in order to replace one sense with input from a different sense.
5. Show VEST by David Eagleman and discuss. Possible questions are included below.
    a. Shorter Option: https://www.youtube.com/watch?v=kbKzF8gKxT4 (3:13 min)
    b. Longer Option: http://eaglemanlab.net/sensory-substitution (20 min)
    c. What are the senses involved in the VEST? What is the input of the VEST? What is used to process the information? What is the output? Explain how this is an example of a sensory substitution device. Why is a potato head a good model?
    d. What are the advantages of this device over the cochlear implant? What disadvantages can you imagine? Can you think of other sensory substitution devices that could be designed to do similar things? Can you think of other senses for which you can design a sensory substitution device?

Elaborate: (5 min)

6. Pass out one of each homework article (Student Handouts 1a-d) to lab groups (or post online). Have students decide how to jigsaw the articles (1.1c is longer).
    a. Handout 1.1a - *Blind Sight: The Next Generation of Sensory Substitution Technology*, (Smith, 2014)

   b. Handout 1.1b - *Sensory Substitution*, (Gower, 2015)
   c. Handout 1.1c - *Sensory Substitution: closing the gap between basic research and widespread practical visual rehabilitation* (Maidenbaum, Abboud, & Amedi, 2014)
   d. Handout 1.1d - *Tactile Substitution for Vision* (Zilbershtain-Kra, Arieli, & Ahissar, 2015)
7. Explain how students should interact with the article. Suggestions include
   a. Read and highlight 10-15 most important sentences. Come prepared with 3 principal points or questions to share with the class.
   b. Answer the included questionnaire based on your understanding of the article
   c. In your lab journal, summarize the principal points of the article in 5 sentences or less. Come prepared with 2 questions you have about the article.

Evaluate: (5 min)

8. Distribute the Exit Ticket (Student Handout 1.2) for students to complete, and collect these as they leave. Students should hopefully respond with answers such as….
   a. to substitute one sense for another – i.e., substitute loss of hearing with tactile
   b. input is a push switch vs pressure feeling in hand, battery is the supply of power in both, and output is a light bulb vs a visual indicator of pressure.

STUDENT ASSESSMENT

Assessment Opportunities:

- Students will be assessed on their recognition of similarities and differences between the brain and electric circuits and why those similarities might be useful informally through conversation throughout the unit
- Students will be assessed on their understanding of connections on the exit ticket
- Students can also be assessed on their understanding of the homework article
- In preparation for the engineering design project, assign a SurveyMonkey or GoogleDoc quiz on attitudes towards STEM and Engineering in preparation for the next few lessons. See Teacher Resource 1.1 and 1.2 for ideas. Note that Teacher Resource 1.1 is an adaptation of the Student Attitudes toward STEM Survey (S-STEM). Learn more here: https://miso.ncsu.edu/articles/s-stem-survey.

Student Metacognition:

- Students will have informal notes in their lab journals about their initial ideas about connections between the brain and electric circuits, which they will add to and modify based on the class share-out.

- Students will reflect on their learning when they complete the exit ticket

Scoring Guide:

- Success is all students participating throughout and having thoughtful exit ticket answers

EXTENSION ACTIVITIES

Extension Activities:

- Students could be assigned more specific articles to read about sensory substitution devices - see resources (for example, *Sensory Substitution and the human-machine interface*, by Bach-y-Rita and Kercel)
- Students could watch additional video clips that could be discussed the next day
- Students could be asked to find more articles about sensory-substitution devices of interest to them to share with the class.

Adaptations:

- A structured handout for the initial gripper-hand explanation could be provided for students who struggle to get down abstract, unformed ideas.
- For teachers with more time, the initial discussion pieces could be much more elaborate - sharing out via whiteboards for example, or many more video clips/articles could be incorporated.

TEACHER BACKGROUND & RESOURCES

Background Information:

- Review similarities and differences in Brains vs Computers from Neuroscience for Kids: https://faculty.washington.edu/chudler/bvc.html
- More about similarities and differences between brains and computers: http://scienceblogs.com/developingintelligence/2007/03/27/why-the-brain-is-not-like-a-co/

Resources:

- A gripper hand (built by the teacher beforehand with a robot gripper, Arduino shield, and specialized cables) along with EMG patches. Will be used initially by the teacher but students will want to try it as well.
- Sensory substitution video clips: VEST by David Eagleman (also a longer TED talk)
- Sensory substitution articles:

- Alternative 1: *Sensory substitution and the human-machine interface*, Paul Bach-y-Rita and Stephen W. Kercel (*Trends in Cognitive Science* Vol 7 No. 12, Dec 2003).
- Alternative 2: *Brain plasticity: 'visual' acuity of blind persons via the tongue*, Eliana Sampaio, Stephane Maris, Paul Bach-y-Rita (*Brain Research* 908, May 2001)

- Brain vs Computer:
    - http://theconversation.com/to-understand-the-brain-you-need-electronic-engineers-too-26104
    - http://news.mit.edu/2000/circuit-0712
- Neuroscience:
    - http://www.nobelprize.org/educational/medicine/nerve_signaling/game/nerve_signaling.html#/plot1

Student Handout 1.2: Exit Ticket

Name: ______________________________ P: _____

1. What is the purpose of sensory substitution devices?

2. State the connection between sensory substitution devices and a simple electric circuit with a battery, push switch, and light bulb.

Student Handout 1.2: Exit Ticket

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Name: ______________________________ P: _____

1. What is the purpose of sensory substitution devices?

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Survey 1
Views about Engineering

Adapted from the Student Attitudes toward STEM Survey (S-STEM)

https://miso.ncsu.edu/articles/s-stem-survey

1. Science: Fill in the circle that best describes how much you agree or disagree with the following statements.

	Strongly disagree	Disagree	Agree	Strongly agree
I am good at science	○	○	○	○
I would consider choosing a career that uses science.	○	○	○	○
I get good grades in science.	○	○	○	○
I am sure I could do advanced work in science.	○	○	○	○
Knowing science will help me earn a living.	○	○	○	○

2. Math: Fill in the circle that best describes how much you agree or disagree with the following statements.

	Strongly disagree	Disagree	Agree	Strongly agree
I am good at math.	○	○	○	○
I would consider choosing a career that uses math.	○	○	○	○
I get good grades in math.	○	○	○	○
I am sure I could do advanced work in math.	○	○	○	○
Knowing math will help me earn a living.	○	○	○	○

3. Engineering: Fill in the circle that best describes how much you agree or disagree with the following statements.

	Strongly disagree	Disagree	Agree	Strongly agree
I like to imagine creating new products.	○	○	○	○
If I learn engineering, then I can improve things that people use every day.	○	○	○	○
I am good at building and fixing things.	○	○	○	○
I am interested in what makes machines work.	○	○	○	○
Designing products or structures will be important for my future work.	○	○	○	○
I am curious about how electronics work.	○	○	○	○
I would like to use creativity and innovation in my future work.	○	○	○	○
Knowing how to use math and science together will allow me to invent useful things.	○	○	○	○
I believe I can be successful in engineering.	○	○	○	○

4. 21st Century: Fill in the circle that best describes how much you agree or disagree with the following statements.

	Strongly disagree	Disagree	Agree	Strongly agree
I am confident I can lead others to accomplish a goal.	○	○	○	○
I am confident I can encourage others to do their best.	○	○	○	○
I am confident I can produce high quality work.	○	○	○	○
I am confident I can respect the differences of my peers.	○	○	○	○
I am confident I can help my peers.	○	○	○	○
I am confident I can make changes when things do not go as planned.	○	○	○	○
I am confident I can manage my time wisely when working on my own.	○	○	○	○
I am confident that I can figure out how to start on large challenging projects.	○	○	○	○

5. Thinking about your friends and family...

	Yes	No	Not sure
Do you know any adults who work as scientists?	◯	◯	◯
Do you know any adults who work as engineers?	◯	◯	◯
Do you know any adults who work as mathematicians?	◯	◯	◯
Do you think you know what engineers do for work?	◯	◯	◯
Do you think you know what scientists do for work?	◯	◯	◯

6. Are the following myth or reality?

	Myth	Reality
Engineers do not need strong soft skills (writing, speaking, leadership)	◯	◯
Engineers must love math	◯	◯
Engineers must be good problem solvers	◯	◯
Engineering involves finding solutions to the world's problems.	◯	◯
Engineering involves improving people's lives.	◯	◯
Women are not as successful in engineering as men.	◯	◯
An engineer and a scientist have totally different jobs.	◯	◯
Engineers more often work alone.	◯	◯
Engineers spend much of their time trying to improve existing designs rather than designing new ones.	◯	◯
Engineers have to spend a lot of time at their desks in front of computers.	◯	◯
Engineers must love science	◯	◯
Engineering can have an direct impact on people's lives.	◯	◯
Engineers work in the private sector, not the public or academia.	◯	◯

7. Which of the following might be job descriptions for an engineer, and which might be a job description for a scientist? Select all that apply; some titles might apply to both.

	Scientist	Engineer
aviation engineer	☐	☐
lab technician	☐	☐
astronomer	☐	☐
statistician	☐	☐
nurse	☐	☐
geologist	☐	☐
weather forecaster	☐	☐
software engineer	☐	☐
computer programmer	☐	☐
chemist	☐	☐
nuclear physicist	☐	☐
pharmacologist	☐	☐
systems analyst	☐	☐
electrical technician	☐	☐
civil engineer	☐	☐
welder	☐	☐
professor	☐	☐

8. How confident are you in your understanding of what is involved in the following tasks, and your ability to carry them out?

	Very confident	Somewhat confident	Somewhat uncertain	Very uncertain
Ask a testable question	○	○	○	○
Define a solvable problem	○	○	○	○
Identify experimental variables	○	○	○	○
Identify engineering constraints	○	○	○	○
Use observational evidence to develop a model	○	○	○	○
Model a phenomenon in multiple ways	○	○	○	○
Plan and conduct an investigation resulting in relevant data	○	○	○	○
Build and test a prototype resulting in relevant data	○	○	○	○
Analyse data using scientific and mathematical tools to develop a conclusion	○	○	○	○
Consider the limitations of resulting data	○	○	○	○
Analyse data using scientific and mathematical tools to optimise a design	○	○	○	○

Consider the limitations of resulting data	○	○	○	○
Analyse data using scientific and mathematical tools to optimise a design	○	○	○	○
Construct an explanation using gathered evidence	○	○	○	○
Develop an improved design using gathered evidence	○	○	○	○
Compare and evaluate given explanations for observable phenomena based on scientific principles	○	○	○	○
Compare and evaluate given designs for real-world problems based on scientific principles and relevant factors and constraints	○	○	○	○
Have fun doing engineering	○	○	○	○
Have fun doing science	○	○	○	○

Survey 2
The Engineering Process

1. On a scale of 1 to 5, how confident are you that you understand the engineering design process?

0 (no confidence) | 5 (total confidence)

2. On a scale of 1 to 5, how much overlap do you think there is between the engineering process and the scientific method?

0 (no overlap) | 5 (complete overlap)

3. On a scale of 1 to 5, how confident are you that you have the understanding and skills to be successful in a future engineering project, class, or summer program (whether you intend to or not)?

0 (no confidence) | 5 (total confidence)

4. Which activity would an engineer do, but not a scientist?

- ◯ record measurements
- ◯ make observations
- ◯ draw conclusions
- ◯ build prototypes
- ◯ ask questions

5. During the design process, engineers often do the following in what order?

- [ ] Identify a need
- [ ] Research a problem
- [ ] Develop possible solutions
- [ ] Construct a prototype
- [ ] Test and evaluate a design

6. An engineer notices that a transistor-operated heat lamp circuit has a flaw in its design - it turns the heat lamp on when it is still hot outside. What step should the engineer take next to improve the design?

- ○ draw a schematic for several new circuits
- ○ identify design constraints for heat lamp circuits
- ○ build models of several new circuits
- ○ gather information about heat lamp circuits

7. When finding a solution to an engineering design problem, there is/are usually

- ○ only one possible correct solution
- ○ a very limited number of possible correct solutions
- ○ many possible correct solutions

8. The engineering design process is iterative. This allows engineers to

- ◯ become proficient at many different engineering software applications
- ◯ find the most optimal solution to a design problem
- ◯ incorporate both math and science concepts into a design problem

9. When following the engineering design process, the different stages can occur in what order?

- ◯ clockwise
- ◯ either clockwise or counterclockwise
- ◯ in any direction, including shortcuts
- ◯ there are no distinct stages int he engineering design process

10. Both engineers and scientists work towards a purpose using the methods at their disposal. What tools/methods do each use, and towards what purpose?

Scientist purpose and methods:

Engineer purpose and methods:

Unit: Circuitry and Sensory Substitution Devices

Lesson 2: Sensor and Logic Circuits

Author: Alexandra Pike

LESSON OVERVIEW

Activity Time:
One 90 minute class period and one 45 minute class period

Lesson Plan Summary:
In this lesson, students will explore what types of sensors and logic gates are commonly used in electronic circuits and how they function.

STUDENT UNDERSTANDINGS

Big Idea & Enduring Understanding:

- **Electric sensors:** these take a specific input (light, heat, force, etc.) and convert that into an electronic signal (voltage) which is then read, displayed, stored, or used to control some other quantity.
- **Logic gates:** these take one or two input voltages, and convert that into one output voltage. Logic gates are binary: they have high/1 and low/0 states. The working of logic gates is represented through Boolean logic and truth tables.

Investigative Phenomenon: An electrical circuit can be used to light a LED, give power to a motor, switch on/off a specific component, or receive information from a sensor by the flow of electrons through the electrical components and wires.

Driving Question:

- What and how are common electric sensors and logic gates used in circuits?

Learning Objectives:

Students will know…

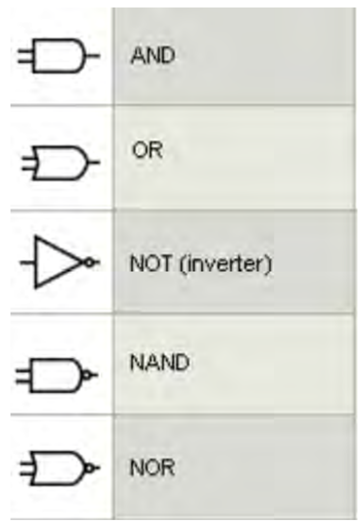
- That an LDR's resistance decreases as light increases, that a thermistor's resistance decreases as temperature increases, that a pressure sensor's resistance decreases as pressure is increased, that a flex sensor's resistance decreases as it is bent, and that a tilt sensor has no resistance when tilted upside down.
- That an AND gate gives a high output when both inputs are high, that an OR gate gives a high output when one or both inputs are high, and that a NOT gate gives a high output when the input is low, and that the logic of this can be represented using truth tables.

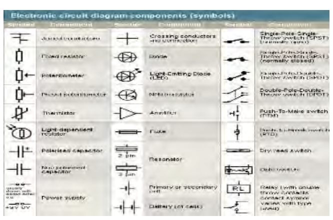
Students will be able to…

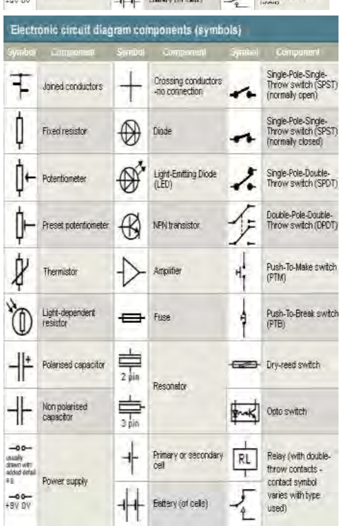
- Draw circuits which incorporate sensors, and explain the function of those circuits
- Draw circuits which incorporate logic gates, and explain the function of those circuits

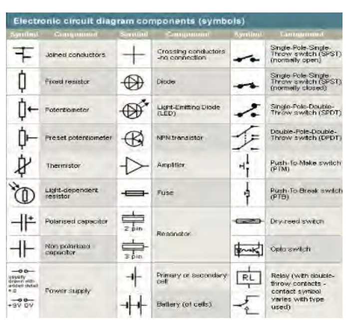
Vocabulary:

- **Sensors:** LDR, Thermistor, Force Sensor, Flex Sensor, Tilt Sensor
- **Other components:** Variable resistor, Transistor, Relay, Diode, LED
- **Logic Gates:** AND, OR, NOT, NAND, NOR and their truth tables









Next Generation Science Standards:

This lesson does not build toward a specific Performance Expectation (PE) but does support engagement in the following three dimensions.

NGSS Alignment		
Science and Engineering Practices (SEPs)	**Disciplinary Core Idea(s)**	**Crosscutting Concepts (CCCs)**
Asking Questions and Defining Problems Obtaining, evaluating, and communicating information	PS2.C Stability and Instability in Physical Systems PS4.C Information Technologies and Instrumentation	Cause and Effect Stability and Change

Common Core State Standards:

- **CCSS.ELA-Literacy.RST.9-10.4:** Determine the meaning of domain-specific terms and symbols

IGCSE Physics Standards:

- **AO1-2**. Demonstrate knowledge and understanding of scientific vocabulary and conventions
- **AO2-5**. Present reasoned explanations for phenomena, patterns and relationships.
- **AO4.3.** Action and use of circuit components
- **AO44.4.** Digital electronics

TEACHER PREPARATION

Materials:

Material	Description	Quantity
SnapCircuit 500 kit*,**	$48 from Amazon.com	1 per group
SnapCircuit Logic Gates (NOT, AND, OR)	$10 each from http://www.snap-circuits.com/phpstore/catalog/SNAP-CIRCUITS-6SCU15-CMOS-Inverter-Gate-4069-259.html http://www.snap-circuits.com/phpstore/catalog/SNAP-CIRCUITS-6SCU16-CMOS-AND-Gate-4081-261.html http://www.snap-circuits.com/phpstore/catalog/SNAP-CIRCUITS-6SCU17-CMOS-OR-Gate-4071-260.html	1 of each per group
SnapCircuit Two-spring sockets	$3 from http://www.snap-circuits.com/phpstore/index.php?l=product_detail&p=101	2 per group
Alligator Clip 10 pack	$2.75 from https://www.sparkfun.com/products/12978	1 per group
Sensors (Temperature, Light, Pressure)	$1.50 from https://www.sparkfun.com/products/10988 $1.50 from https://www.sparkfun.com/products/9088 $7 from https://www.sparkfun.com/products/9375	1 of each group
Student Handouts	Entrance ticket, Sensor Circuits (Notes, Practice & Homework), Logic Circuits (Notes, Practice & Homework)	1 per student

Preparation:

1. If you are unfamiliar with them, review how the sensors and logic gates work, so you are prepared with what resistors students should use to protect the devices.
2. Photocopy a class set of the necessary materials
   a. Student Handout 2.1 (Activity instructions, can also just project overhead)
   b. Student Handouts 2.2-2.4 (Sensor Circuit Notes/Practice/Homework)
   c. Student Handouts 2.5-2.7 (Logic Gates Notes/Practice/Homework)
   d. Student Handouts 2.8-2.10 (Formative/Self/Post Assessment)
3. Set-up each lab group with a different sensor (Day 1) and logic gate (Day 2), so that at least one of each is ready. On Day 1, also be prepared with flashlights and beakers of hot water for the LDR and Thermistors.

PROCEDURE

Activity Procedure Day 1:

Engage: (25 min)

1. Discuss the homework articles in small groups, then as a whole class
    a. Review the definition and purpose of a sensory substitution devices, and give some examples. Ensure that students understand the (sliding) difference between sensory substitution and assistive devices
2. Introduce the circuit project
    a. We will be engineering a simplified sensory substitution circuit that could be used to help someone who has lost the function of one of their senses.
    b. What components go into a sensory substitution device? (input-processor-output)
    c. So, the next step is to understand what components we will be using

Explore: (20 min)

3. Assign each group a sensor and have them use their SnapCircuits kit to determine its function. Once they have a conclusion, have a class share-out of all the sensors.
    a. **For more structure:** tell students to use batteries, the sensor, a 100 ohm resistor (to protect the sensor) and the analogue meter to test their component.
    b. **For less structure:** warn students to always have a resistor in series with the sensor, but let them decide how to test the component's function.
    c. **With more time:** have students test multiple components, and make a table of their function.

Explain: (10 min)

4. Review, clarify, and explain as necessary the sensor circuit components using Student Handout 2.2. The note sheet is designed to be taped into interactive journals and completed together as a class.

Elaborate: (35 min)

5. Students should work on Student Handout 2.3 individually, in pairs, or in groups as the teacher prefers. Circulate and provide assistance as necessary; also providing an answer key can be helpful.

Evaluate: (at home)

6. Send students home with Student Handout 2.4. This assignment is designed to be used as an individual homework assignment after students are comfortable with the practice; students should still be free to revisit and improve their work.

Activity Procedure Day 2:

7. Repeat same exploration as yesterday but with logic gates this time; repeat the same type of note taking as yesterday but using Student Handout 2.5; repeat the same type of practice as yesterday but using Student Handout 2.6; and then send students home with Student Handout 2.7.

STUDENT ASSESSMENT

Assessment Opportunities:
Students will be assessed on their understanding of neural engineering and sensory substitution through the initial review discussion about the jigsawed homework articles.

- If no engineering survey is given, students should be assessed at some point during the activity portion about their initial understanding of the engineering process.
- Students will be assessed on sensors and logic gates through the practices, when the teacher can listen and help as groups work together on the problems, as well as through the associated homework (all designed as fully aligned formative assessments).
- Also provided are a formative, self, and post assessment on sensor and logic circuits (Student Handouts 2.8-2.10). This set can be used to assess student understanding more formally, particularly their written reasoning.

Student Metacognition:

- Students will try the practice in groups in class when they can ask questions, and check their work to see what they initially misunderstood or didn't understand.
- Students will work on the homework individually to see how well they understand the material on their own, and receive feedback with the opportunity for corrections.

Scoring Guide:
See example practice and homework keys.

EXTENSION ACTIVITIES

Extension Activities:

- Significant time could be spent allowing students to develop their understanding of how the sensors and logic gates work via the SnapCircuits, as long as they are cautioned about protecting the components with resistors.
- Questions similar to the practice and homework problems could be done via Kahoot, whiteboards, or in an online practice assignment.

Adaptations:

- A copy of the filled-in notes can be provided for students who struggle to track teacher instruction
- Practice questions can be broken down into easier pieces if necessary, and explanation questions can be reformatted to give students sentence starters.

TEACHER BACKGROUND & RESOURCES

Background Information:

Different types of sensors have variable resistance, which affects the current in the circuit. If students understand and are aware of the resistance, then they can understand the circuit. SnapCircuits allows students to play around with the components and learn their function through trial and error, but all-class verification and review is helpful before students actually begin their own circuit designs - some of the resources below have good explanations about the sensors and processors (especially transistors).

Resources:

- BBC Bitesize
  - http://www.bbc.co.uk/schools/gcsebitesize/design/electronics/logicrev1.shtml
  - http://www.bbc.co.uk/schools/gcsebitesize/design/electronics/componentsrev1.shtml
  - http://www.bbc.co.uk/schools/gcsebitesize/design/electronics/switchesrev1.shtml
- Explain that Stuff on Logic Gates: http://www.explainthatstuff.com/logicgates.html
- Lady Ada on Sensors: https://learn.adafruit.com/category/sensors (scroll down easier)

Activity 1 – Sensor Circuit Components

- Using the SnapCircuit components in front of you, determine the purpose of each.
- In your lab journal, sketch the symbol for each component you test, and describe its purpose or function. Try to word your description in the form of "if this happens, then this will happen"

Student Handout 2.2: Notes—Sensor Circuits

Name:____ Date:______________________ Period:______

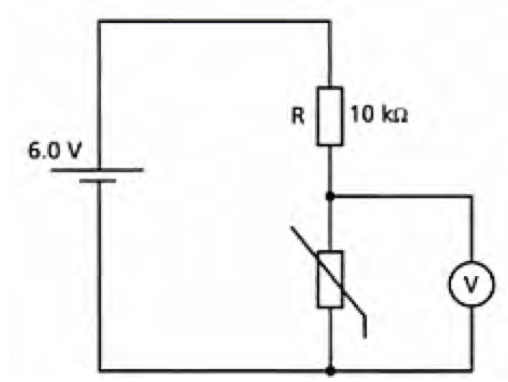
Name	Symbol	Function

Unit: Circuitry and Sensory Substitution Devices

Student Handout 2.3: Practice 1—Sensor Circuits

Name: ____ Date: _____________________________________ Period: ______

Directions: Answer the following questions in the space provided. Take time to really understand these challenging circuits!



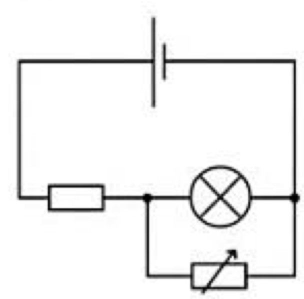
(1) a. The diagram shows a potential divider circuit. Identify each component in the circuit by name.

b. The voltmeter reads 2.0 V when the thermistor's temperature is 20 °C. Calculate the resistance of the thermistor at this temperature.

c. A second 10 kΩ resistor is connected in parallel with R. Calculate the voltmeter reading with this second resistor in the circuit when the thermistor is at the same temperature.

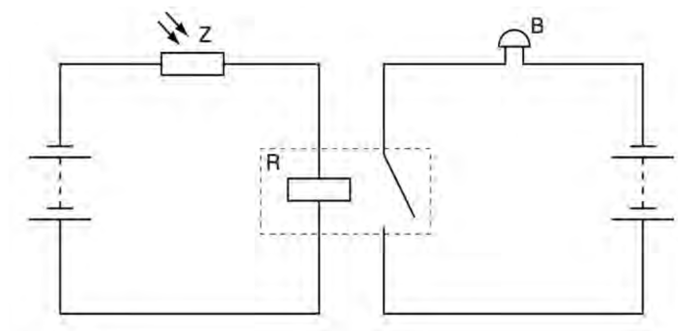
d. Describe and explain how the voltmeter reading would change if the temperature of the thermistor were increased.

(2) a. The following circuit is set-up. Describe how the brightness of the light bulb changes as the resistance of the variable resistor is increased from zero.



b. Explain why it is possible to reduce the bulb current to zero by adjusting the variable resistor.

(3) A warning bell is fitted in a photographic dark room. In the dark, the bell is silent but in bright light, it rings. Two circuits linked by a relay R control the bell B.

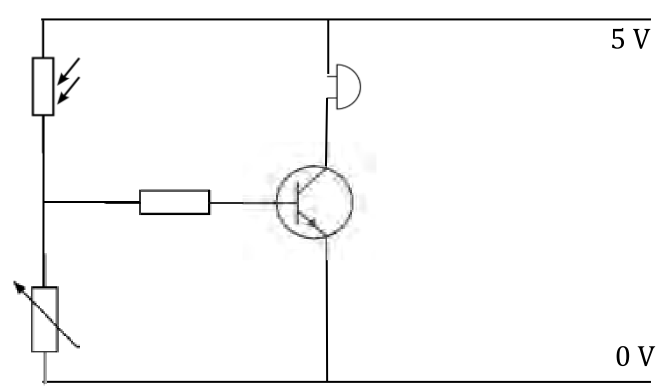


a. State the name of component Z: ______________________

b. Explain why B rings in bright light.

c. A change is made to one of the circuits so that B starts to ring when the temperature in the room rises. State and explain the change made.

(4) a. Explain the relationships between the current and voltage through each of the components in the circuit at right.



b. Identify the similarities between this circuit and the circuit in Q3.

c. i. Identify the differences between this circuit and the circuit in Q3.

ii. What is the advantage in the first circuit?

iii. What is the advantage in the second circuit?

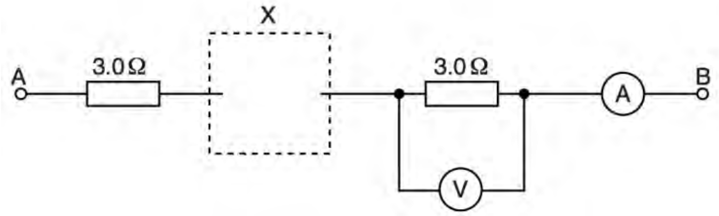
Unit: Circuitry and Sensory Substitution Devices

Student Handout 2.4: Homework 1—Sensor Circuits

Name:____ Date:_______________________ Period:______

Directions: Answer the following questions in the space provided, working alone.

(1) A student carries out an experiment with the circuit shown in the figure at right. The component in the dashed box labelled X is a diode.

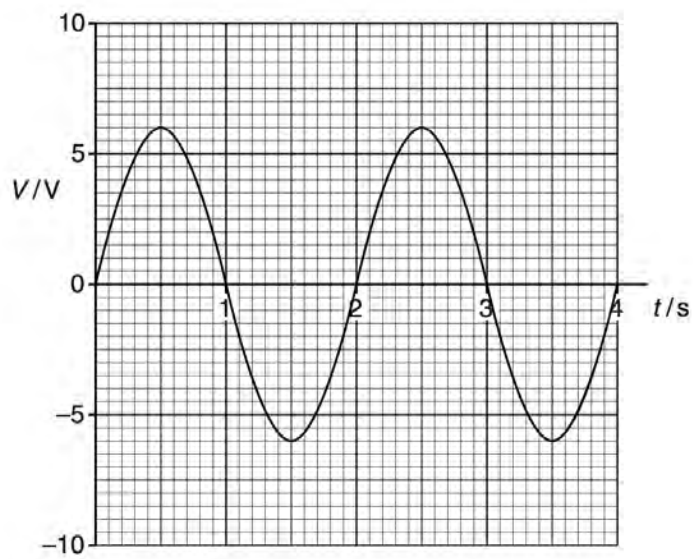


a. Draw the correct symbol for a diode, connected either way round, in the dashed box labelled X.

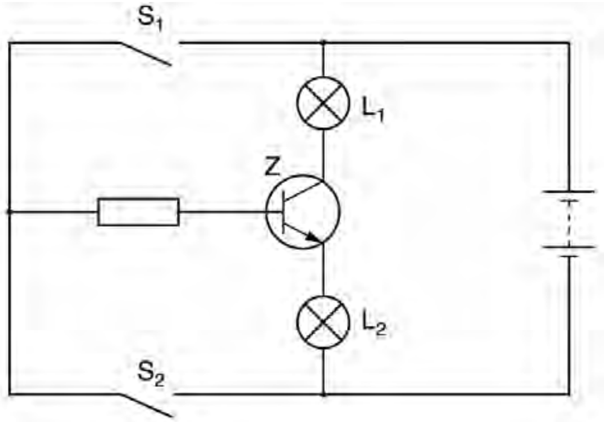
b. +6.0V is applied to point A, 0V to point B. State and explain what the student observes on the ammeter.

c. –6.0V is applied to point A, 0V to point B. State and explain what the student observes on the ammeter.

d. The voltage shown is applied to the point A of the circuit. Point B is kept at 0V. On the graph below, draw a graph of the readings indicated by the voltmeter.

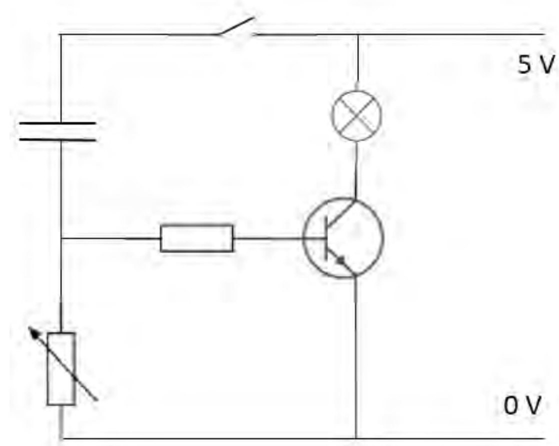


e. The circuit below contains two switches and two indicator lamps. Complete the table to state whether the lamps are on or off with the switches in the positions stated.



switch S_1	switch S_2	lamp L_1	lamp L_2
open	closed		
closed	open		

(2) a. Identify the components and their function in the time-delay circuit at right.



b. State and explain the effect on the operation of the circuit of increasing the resistance in the variable resistor.

c. Design a circuit to activate an alarm circuit a short time after closing a switch. Include suitable components to switch the alarm circuit on via a transistor-operated relay. Draw the circuit diagram for your design.

d. State and explain another use of a time-delay circuit.

Unit: Circuitry and Sensory Substitution Devices

Student Handout 2.5: Truth Table

Name:____ Date:_______________________ Period:______

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

In	Out

In		Out

In		Out

In		Out

In		Out

Unit: Circuitry and Sensory Substitution Devices
Student Handout 2.6: Practice 2—Logic Circuits

Name:____ Date:_______________________ Period:______

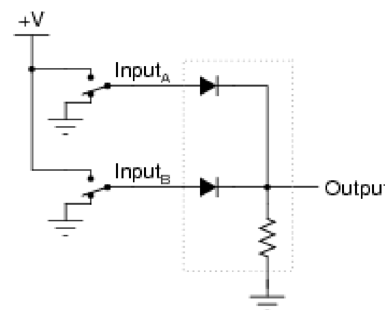
(1) One way to think of logic gate types is to consider what input states guarantee a certain output state. For example, we could describe the function of an AND gate as such: Any low input guarantees a low output. Identify what type of gate is represented by each of the following phrases:

a. Any high input guarantees a low output. ______________________________

b. Any low input guarantees a high output. ______________________________

c. Any low input guarantees a low output. _______________________________

(2) Crude logic gates circuits may be constructed out of nothing but diodes and resistors. Identify what type of logic function is represented by this gate circuits, and explain.



<u>Directions</u>: In the following situations, a combination of sensors and logic gates must be used in order to achieve the desired outcome. Sketch the appropriate circuit.

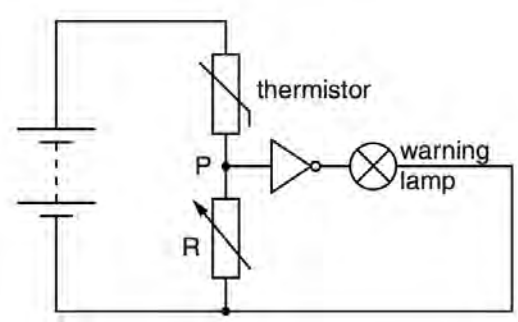
(3) In hospitals, babies sometimes need to be kept warm in incubators for a period of time after birth. Design a system that will sound an alarm if the incubator gets too cold.

(4) Some hospital rooms get very warm in the summer. We need an automatic fan to cool the patients. The fan should also be able to be turned on manually. Design this fan control system.

(5) A photographer needs to use a remote camera shutter release that will be activated when the birds land on a feeding table. Design a circuit that ensures that the camera only works during daylight hours.

(6) Design a system that will turn on the A/C system when the temperature rises above a thermostat setting. A manual control switch should also be included for continuous operation of the system.

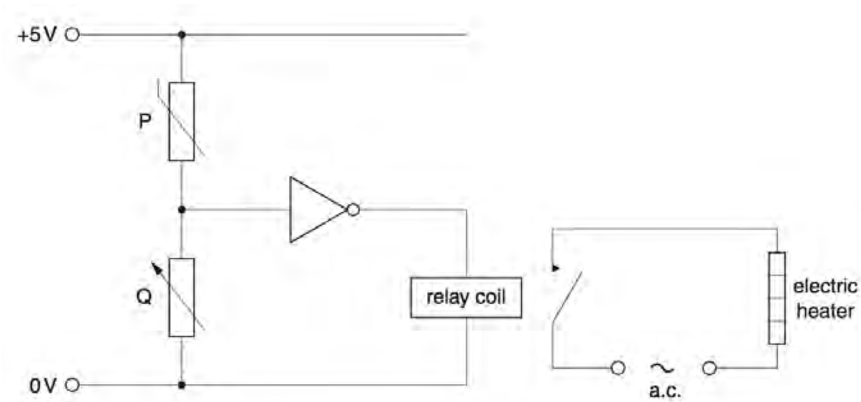
(7) The figure at right shows a circuit that switches on a warning lamp when the temperature in an oven falls below a set value.



a. Explain, with reference to the components in the circuit and point P, why the warning lamp is on when the temperature in the oven is below the set value.

b. Explain effect of changing the resistance of R.

(8) The figure below shows an electronic circuit controlling an electric heater.



a. State what happens to P when its temperature falls.

b. For the relay to operate, the output of the gate must be high (logic 1). What must be the input of the gate for the relay to operate? Explain your response.

c. State what the resistance of P must be, compared with that of Q, in order to give this input: ____________

d. Under what conditions will P have this resistance?

e. Suggest why component Q is a variable resistor, rather than one with a fixed value.

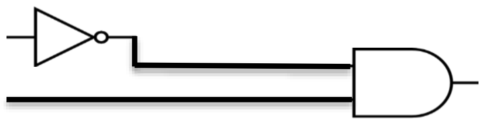
f. Suggest a practical use for this circuit.

Student Handout 2.7: Homework 2—Logic Circuits

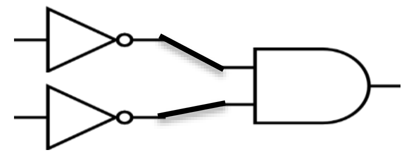
Name:____ Date:______________________ Period:______

Directions: Answer the following questions on your own, in the space provided. For Q 1, complete the truth table for each logic gate combination.

(1)



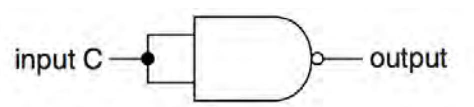
Inputs A	B	Output
0	0	
1	0	
0	1	
1	1	



Inputs A	B	Output
0	0	
1	0	
0	1	
1	1	

(2) Design a "babysitting" circuit that warns parents with a bell when their child turns on a lamp or when the temperature falls below a certain limit. Explain briefly and include a truth table.

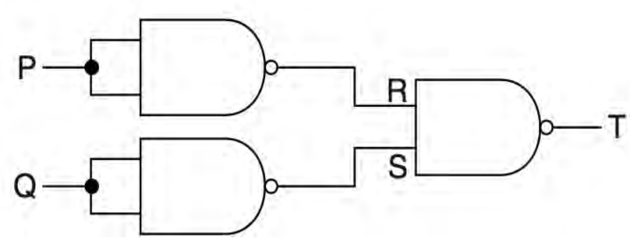
(3) The two inputs of the NAND gate are joined together and connected to an input C.



a. Determine the output of this NAND gate when input C is set to 0 and when it is set to 1.

b. State the logic gate that behaves in the same way as the NAND gate above: __________________________

c. A circuit combines three NAND gates. The inputs to the circuit are P and Q, as shown. Points R, S and T in the circuit are labeled. Input P is set to 0 and input Q is set to 1. Determine the logic states of points R, S and T.



R = _____________ S = _____________ T = _________

(4) Answer question 2 on page 199 in your book (you'll probably need to go onto the back).

Unit: Circuitry and Sensory Substitution Devices

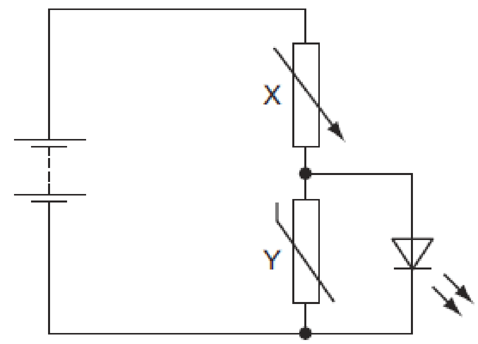
Student Handout 2.8: Formative Assessment—Complex Circuitry (IGCSE Physics)

Name:____ Date:______________________ Period:______

Directions: Answer the following questions in the space provided. Explain your thinking clearly.

(1) The fuel for an engine needs to be warm in order for the engine to work. If the temperature of the fuel is below the working temperature T_W, an LED emits light.

a. Label each of the four elements in the circuit, and identify their purpose.



i. ____

ii. ____

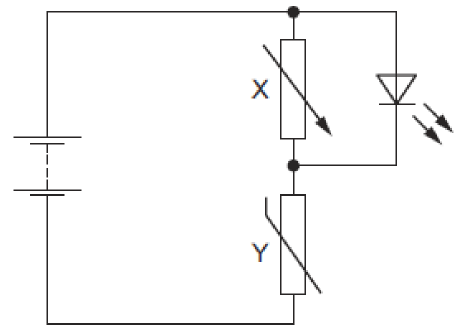
iii. ____

iv. ____

b. Describe the relationships between the current and voltage through each of the four elements. Explain.

(2) Currently the fuel is too cold and the LED is emitting light. State and explain what happens in the above circuit as the temperature of the fuel increases to a value above T_W.

(3) The circuit is modified as shown. Predict and explain what happens in this circuit, and suggest a practical use.



Unit: Circuitry and Sensory Substitution Devices

Student Handout 2.9: Self-assessment—Complex Circuitry (IGCSE Physics)

Name:____ Date:______________________ Period:______

Brain Check: Below are our unit learning goals. Based on your work so far, how confident are you feeling about each? Rank from 1 to 5 (1 = most confident).

You should be able to…	BFA	AFA	BSA
• Draw and interpret circuit diagrams containing sources, switches, resistors (fixed and variable), heaters, thermistors, light-dependent resistors, lamps, ammeters, voltmeters, galvanometers, magnetizing coils, transformers, bells, fuses, relays, and diodes			
• Describe the action of a variable potential divider (potentiometer)			
• Describe the action of thermistors and light dependent resistors and show understanding of their use as input transducers			
• Describe the action of a relay and show understanding of its use in switching circuits.			
• Describe the action of a diode and show understanding of its use as a rectifier			
• Show understanding of circuits operating as light sensitive switches and temperature-operated alarms (to include a relay)			

Directions: Review your answers to the formative assessment and shade in the answers/reasoning that you included. Then comment on your misconceptions and what you don't yet understand, as well has how you are going to improve before the next assessment.

Question	**Answer**	**Description/Reasoning**			
1a	Batt, var. resistor, thermistor, LED	*provide power*	*control current*	*Hotter = less resistance*	*Light up*
1b	I: Batt = X = Y + LED V: Batt = X + Y/LED	*X alone gets all current, Y and LED split unevenly*	*Each loop adds to volt. of batt, so X + Y = X + LED = batt*		
Issues and improvements?					

Question	**Answer**	**Description/Reasoning**		
2	LED goes off	*R of thermistor decreases so I increases*	*More current through thermistor than LED*	*V across LED decreases*
Issues and improvements?				

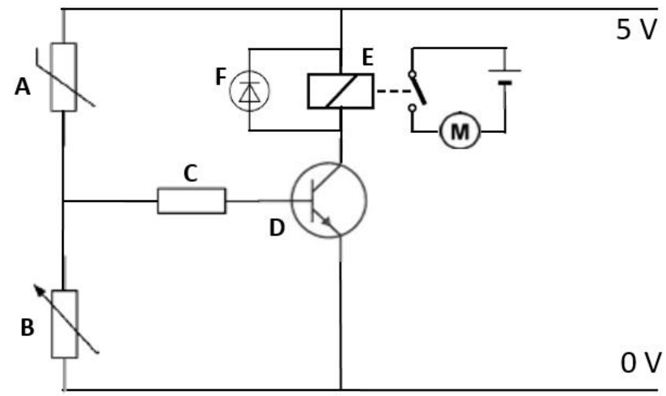
Question	**Answer**	**Description/Reasoning**	
3	LED lights as hotter Warning if overheat	*If hot, low resist. in thermistor so high current in circuit*	*More current/voltage through LED so lights*
Issues and improvements?			

Student Handout 2.10: Post Assessment—Complex Circuitry (IGCSE Physics)

Name:____ Date:______________________ Period:______

Directions: Answer the following questions in the space provided. Explain your thinking clearly.

An IGCSE student designs the circuit at right.



(1) Identify each of the lettered components, and briefly describe their function **in this circuit**.

A: ____

____

B: ____

____

C: ____

D: ____

E: ____

F: ____

M: ____

(2) Explain the functioning of this circuit, and suggest a possible practical use for it.

(3) Three students are arguing about the best way to modify the circuit so that the motor turns on the heat when the temperature is too low.

> *Student 1: The best way to modify the circuit is to add a NOT gate in front of the thermistor. This way the entire purpose of the circuit will be inverted.*
>
> *Student 2: No, I think the best way to modify the circuit is to switch the placements of the thermistor and the variable resistor. This will work better.*
>
> *Student 3: I think the best way is to replace the variable resistor with another thermistor. This way the heat will turn on when it is twice as cold.*

Which student, if either, do you agree with? Explain your reasoning.

Unit: Circuitry and Sensory Substitution Devices

Lesson 3: Engineering the Circuit

Author: Alexandra Pike

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.

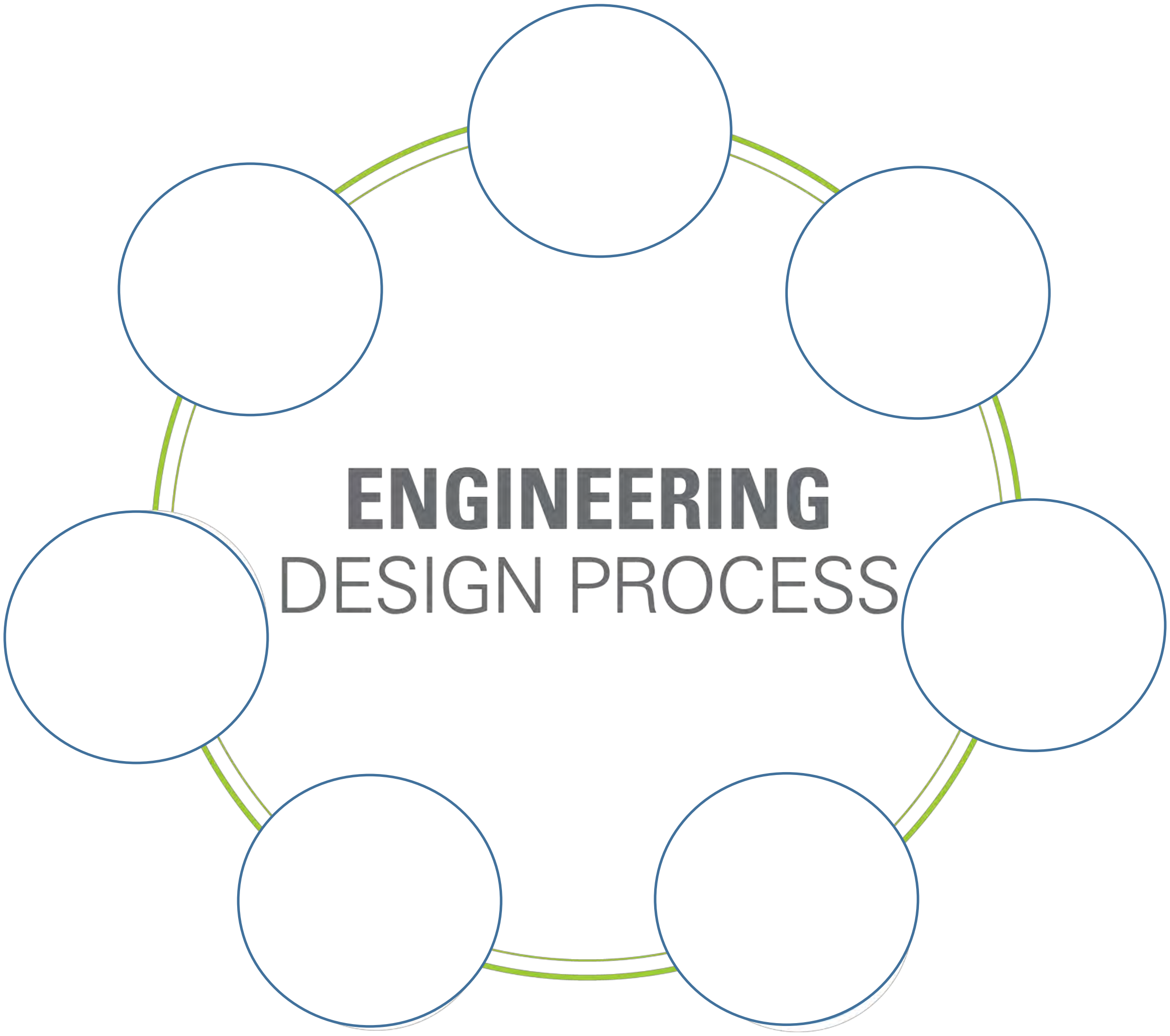
Resources:

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

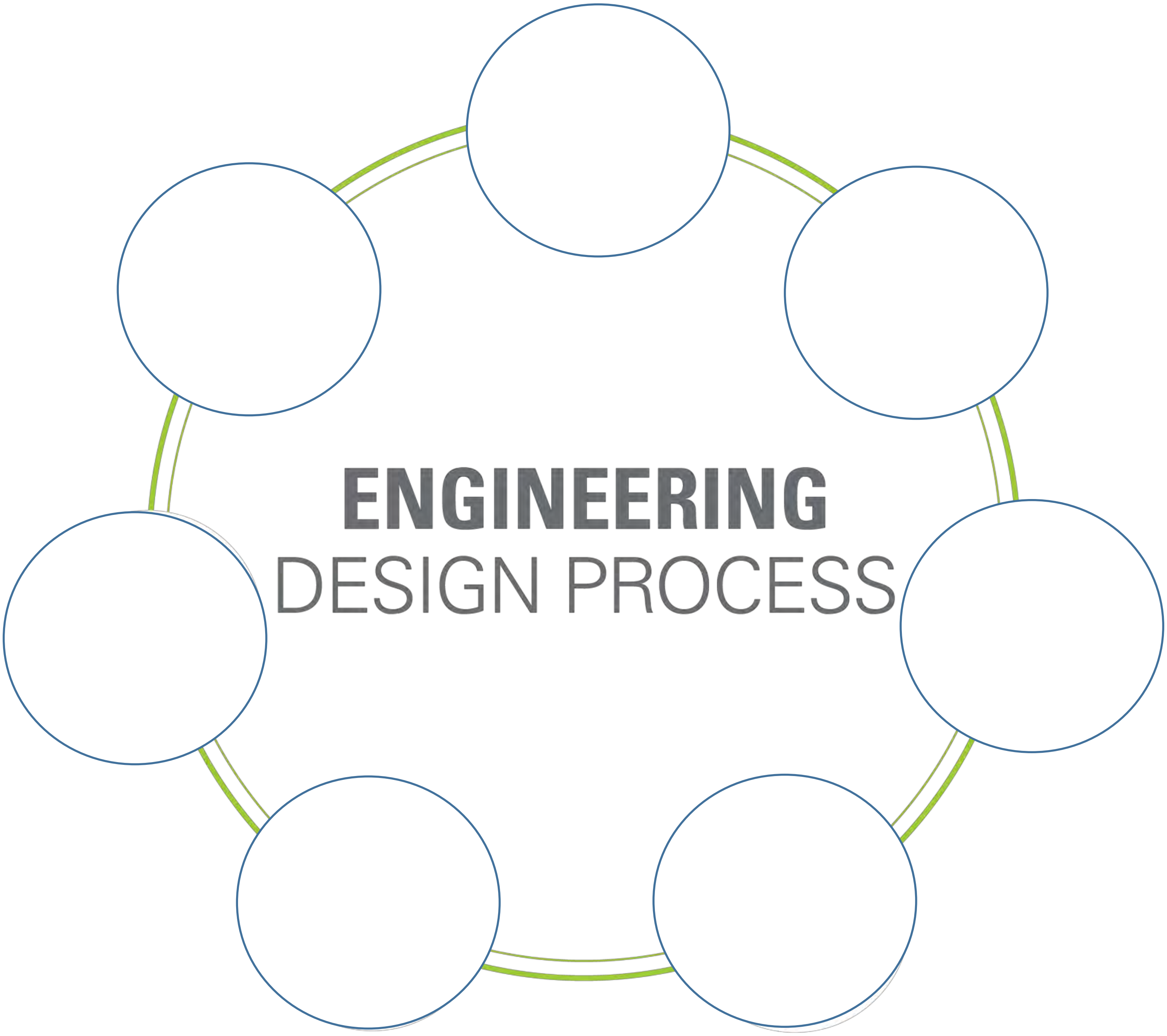
Name:____ Date:______________________ Period:______



Science vs Engineering

Differences:

Similarities:



<u>Science vs Engineering</u>

Differences:

Similarities:

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		**Conclusion**
- 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.	- 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

Brain-tongue
- sensor that senses info by substituted modality.
- coupled to processors and drive actuators.
- actuator activates receptors
- normally sight is what this substitutes, using touch and hearing.

Feasibility of VT sensub
- depends on flexibility of perceptual system
- receptors scan environment (2D)
- receptors can use sound too.
- touch and vision are related.
- using a combination doesn'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 [illegible] enough to get us 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

.5 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 [illegible] to change the

Notes - Intro to SMNE 2

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.

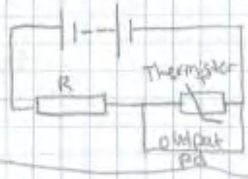
2. Brain:
   - sees electrochemical signals - doesn't know where these come from.
   - uses all information.

3. Potato Head:
   - our senses are plug-ins on the outside.
   - They are peripherals.
   - 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)

...voltage to power something. (can be called an input transducer)
Thermistors are resistors that depend on temperature.
- temp. increases, resistance decreases, so pd decreases
- symbol:
- output pd increases.
LDRs are resistors that depend on light.
- light increases, resistance decreases, output pd increases
Variable Resistors can be adjusted.



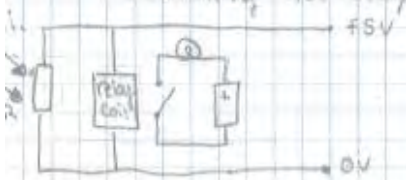
...6 Switching Circuits

1/30/17

Relays 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.

Temperature-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

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

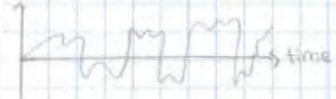
Before digital, analogue was used where voltage can vary between two points.
Analogue signal

Article 1
- sound lets them recognize objects
- gives vibrating telling people drive, along with pads on chair to show speed, and a [illegible] place 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 [illegible]
- hard to see complex shapes
- brain doesn't lose how to process the information
- time to do the training.

Article 4
[redacted]

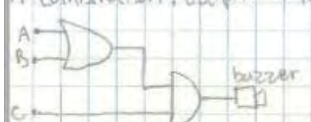


Digital signal

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	Truth Table Inputs 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



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.8 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		resistance decreases as temperature increases.
LDR		resistance decreases as brightness increases.
Relay		"a special switch" used when want 2 diff. power sources or choices.
transistor	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

sensor
sensor
proc.
proc.

P Force/Pressure Sensor
F Flex Sensor
Relay
LED

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

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

r pressure switch could also be used as a sensor.

symbols:

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

High-temperature indicator.

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

Night-time rain alarm

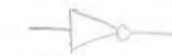
- buzzer goes off if it is dark, as a light sensor gives a 0 to the NOT gate, thus making it a 1 and it is wet as the moisture sensor gives a 1 also to the AND gate.

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

Notes - Logic Gates

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

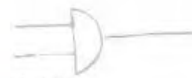
NOT



In	Out
0	1
1	0

Inverts the input
changes low to high

AND



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

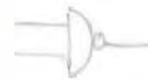
Both inputs must be high/on for the output to be high.

OR

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

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

NAND



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

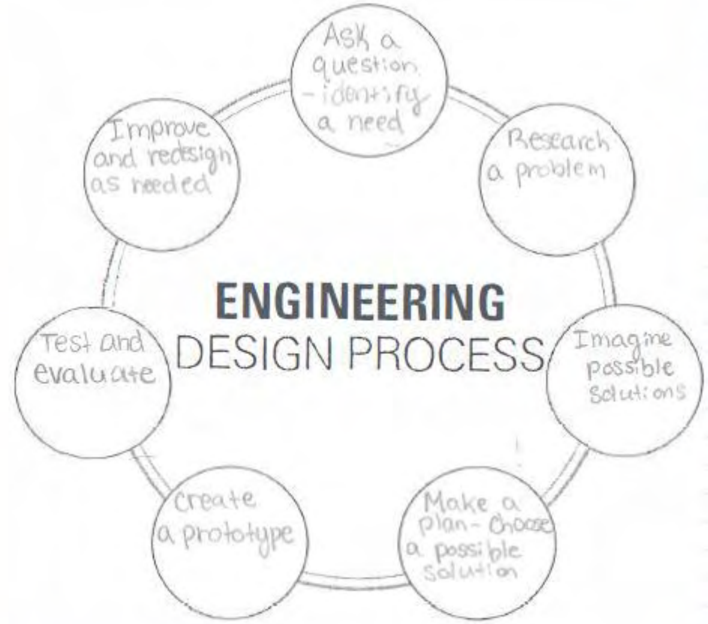
AND and NOT
- both inputs must be high for the output to be low.

NOR

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

OR and NOT
- If either of the inputs is high, the 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

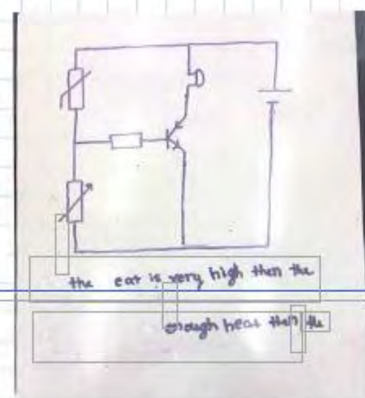
1. An SSD could address a loss of sight, hearing, and touch. Blind people, deaf people, and people without a sense of touch. An SSD could replace one sense using another. They can be cheaper than other ways and you can just use the senses that they have. Constraints are that people have to learn to use 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.

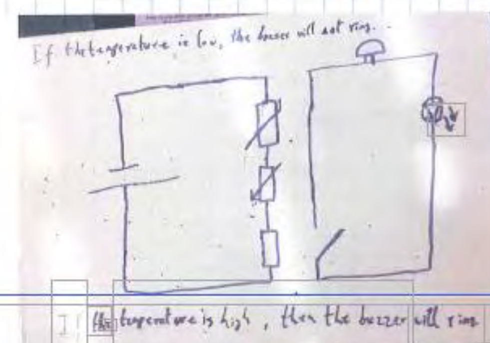
2.

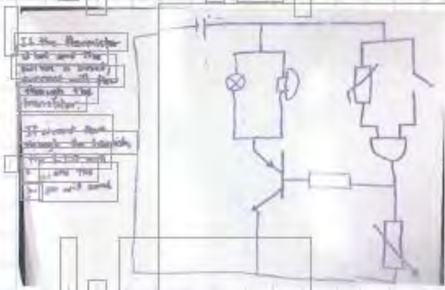
inputs	processors	outputs
-flick switches	-transistor	-LED
-push switches	-relay	-buzzer
-thermistor	-OR gate	-light bulb
-LDR	-AND gate	
-battery	-NOT gate	
-flex sensor		
-force sensor		

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.

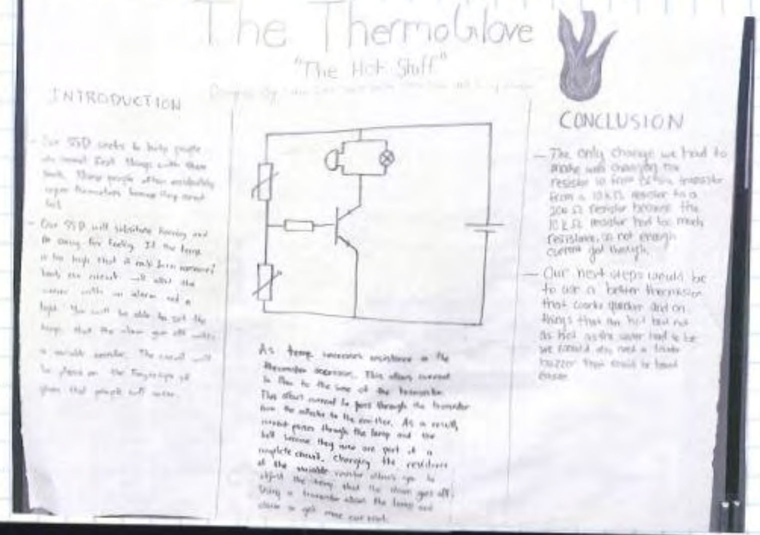
the circuit connected and was complete.

- 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.

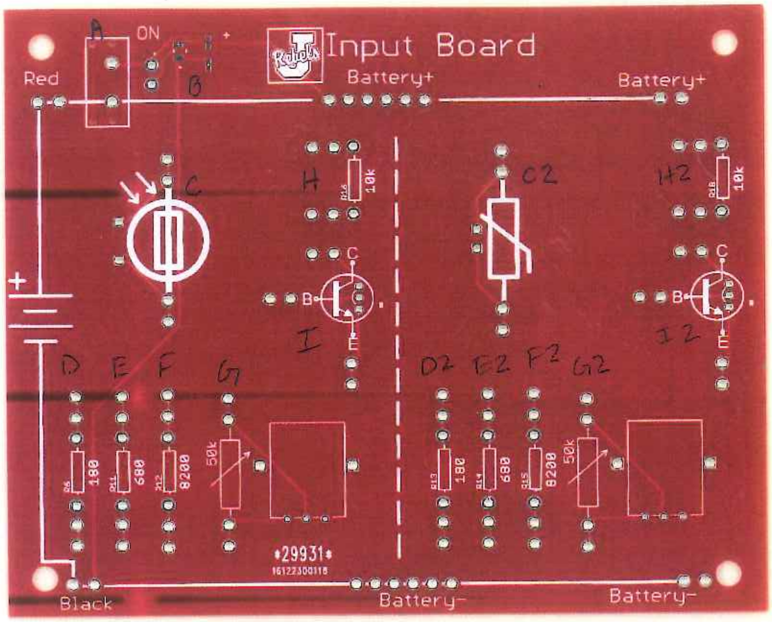
7. Our SSD met our needs pretty well. When the thermistor came in contact with boiling water the light bulb lit up and the buzzer went off. Taking into account that we had only certain materials to work with it does fit the criteria. Although, if it were going to be used for a real SSD, it would need 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.

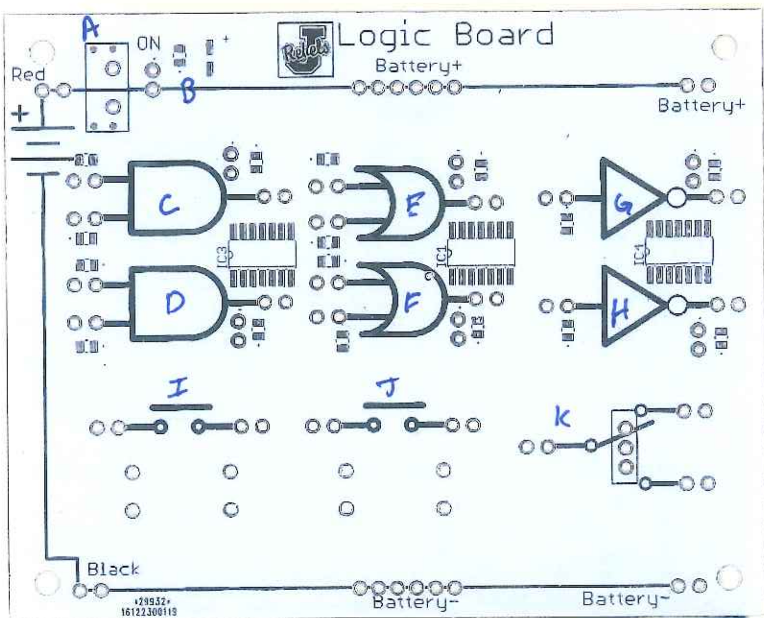


Criteria	Brightness Tester	Sensor for the Paralyzed	Touch Augmentation Device	Sensor Suit	Silent Doorbell	Thermodetector	Buzzy Buzzer
Efficiency in Function /3	2	3	3	3	3	3	3
Functionality - does it work? /5	5	5	5	3	5	3	5
Practical to use - is it important? /5	5	5	5	5	5	5	5
Ease of use/design /4	3	3	3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



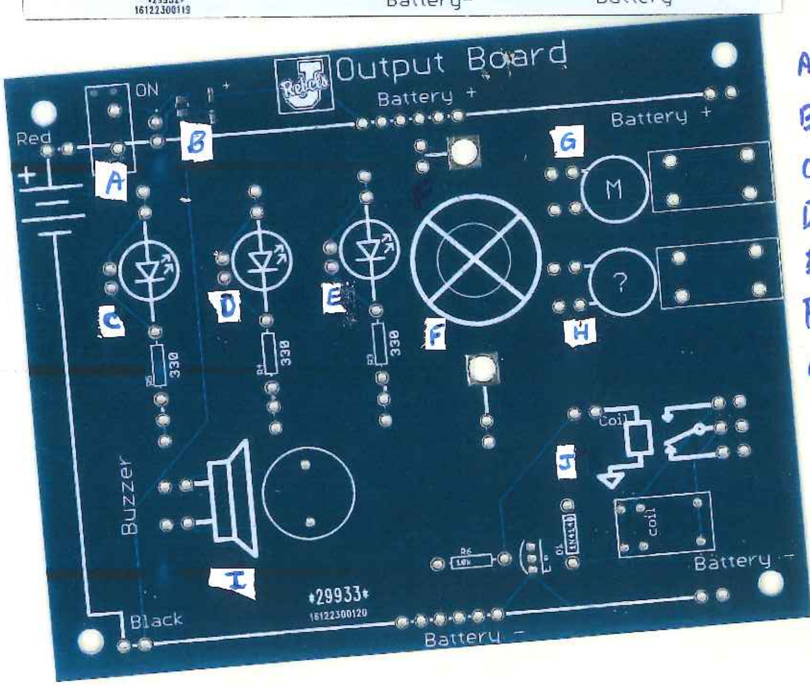
Red

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



White

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



Blue

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

Unit: Circuitry and Sensory Substitution Devices

Lesson 4: Evaluating the Prototypes

Author: Alexandra Pike

LESSON OVERVIEW

Activity Time:
One 45 minute class period

Lesson Plan Summary:
In this lesson, students will evaluate their sensory substitution circuit both in terms of engineering and ethics by taking part in a scientific poster session.

STUDENT UNDERSTANDINGS

Big Idea & Enduring Understanding:

- Scientists and engineers communicate their research publicly in order to share their new discoveries and understandings, and to receive constructive criticism and questions about their work. In this way, professionals can build off the work of each other and effectively collaborate on larger projects.
- Tools such as Pugh Charts enable scientists and engineers to evaluate the multiple dimensions of a design and take into account the importance of different priorities.

Design Problem:
Teams will evaluate and present their design solutions in the form of models of sensory substitution devices that have the potential to assist a person who has a lost or impaired sense.

Driving Question:

- How do scientists and engineers share and evaluate their discoveries and designs with the wider scientific and engineering communities?

Learning Objectives:

Students will know…

- The purpose of a Pugh Chart is to numerically assess engineering designs and prototypes in order to make an evidence-based evaluation of its effectiveness
- That scientific poster sessions are an informal but important method of sharing and learning from other scientists and engineers

Students will be able to…

- Speak knowledgeably to different groups of people about their engineering designs
- Evaluate a variety of sensor circuit designs based on relevant and ranked criteria and constraints

Vocabulary:

- **Pugh Chart:** A matrix tool used to facilitate a disciplined, team-based process for concept generation and selection.

Next Generation Science Standards:

This unit builds toward the following high school Performance Expectation (PE). Alignment to the three dimensions of science and engineering education (Disciplinary Core Ideas, Crosscutting Concepts, and Practices) are outlined in the table below. Hyperlinks direct to relevant sections of the Next Generation Science Standards and *A Framework for K-12 Science Education*.

High School Performance Expectations		
HS-ETS1-3: Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts. (Grades 9-12).		
Science and Engineering Practices (SEPs)	**Disciplinary Core Idea(s)**	**Crosscutting Concepts (CCCs)**
Constructing Explanations and Designing Solutions *Obtaining, evaluating, and communicating information *Engaging in Argument from Evidence	ETS1.B: Developing Possible Solutions	Energy and Matter *Stability and Change *Scale, Proportion, and Quantity *Systems and System Models *Structure and Function *Connections to Engineering, Technology, and Applications of Science* Influence of Science, Engineering, and Technology on Society and the Natural World

Common Core State Standards:

- **CCSS.ELA-Literacy.RST.9-10.6:** Analyze the author's purpose
- **CCSS.ELA-Literacy.RST.9-10.8:** Assess reasoning and evidence
- **CCSS.ELA-Literacy.RST.9-10.9:** Compare and contrast findings
- **CCSS.ELA-Literacy.W.9-10.2:** Write explanatory texts
- **CCSS.ELA-Literacy.SL.9-10.1:** Initiate and collaborate in discussions
- **CCSS.ELA-Literacy.SL.9-10.3:** Evaluate speaker's point of view
- **CCSS.ELA-Literacy.SL.9-10.4:** Present information clearly

- **CCSS.ELA-Literacy.SL.9-10.6:** Adapt speech to context

IGCSE Physics Standards:

- **AO1-4**: Demonstrate knowledge and understanding of scientific and technological applications with their social, economic, and environmental implications.
- **AO2-5**: In words or using other written forms of presentation, present reasoned explanations for phenomena, patterns and relationships.
- **AO3-5**: Evaluate methods and suggest possible improvements.

TEACHER PREPARATION

Materials:

Materials	Description	Quantity
Documents	Student Handout 4.1	1 per student

Preparation:

1. Ensure there is space in the room for groups to hang their completed posters.
2. Invite wider community members to participate in the poster session, so that students have the experience of talking with a wider variety of audiences. Invite parents, admin and other staff, and if possible, even science and engineering undergraduates or postgraduates who would be willing to help model a true poster session.
3. Photocopy Student Handout 4.1 for each student.

PROCEDURE

Explain: (10 min, or do the day before)

1. Pass out the Pugh Chart template and discuss as a class how the circuit designs and prototypes should be assessed (Q8).
2. Explain that they will be participating in a scientific poster session, exactly as scientists often share their work with colleagues. Two group members will stay with the poster and the prototype, and talk with other pairs who walk around asking questions and assessing based on the Pugh Chart. After half of the class period, the pairs will switch.

Evaluate (20 min and 20 min):

1. Use about half the class period for one pair to stay with the poster and circuit prototype, answering questions. The other pair should circulate, each with their Pugh Chart, evaluating the other designs. After 20-25 minutes, swap pairs.
2. Either at the end of the poster session or through discussion the next day, ask students to tally up their Pugh Charts and discuss why certain circuit prototypes scored higher

and others lower, why science and engineering discoveries are shared this way, what worked and what didn't during the design process etc. This is an opportunity to have a rich and thorough discussion both about sensorimotor neural engineering and ethics, as well as the engineering process.

STUDENT ASSESSMENT

Assessment Opportunities:

- As students present, probe their understanding of how their circuit functions, how it aligns to an actual device, what criteria and constraints and ethical considerations they focused on, and how well they understand the engineering process they went through.
- Additional assessment can take place during the discussion afterwards (#2 above)
- A survey can be given about the engineering process again, to compare with students' initial responses (see Teacher Resource 4.1).
- At the end of the unit, a content test can also be given, to assess students' ability to explain in writing how different sensor circuits function (see Teacher Resources 4.2 and 4.3 for a test review and test).

Student Metacognition:

- During the presentations, students can be asked about the poster session they are engaging in. They can be asked to assess their own work in addition to the other groups'
- The final engineering survey can also ask students to reflect on their confidence in the engineering process as well as other tasks - presenting in front of others, troubleshooting with their groups

Scoring Guide:

- Success looks like every group having a functioning circuit and an appropriate poster to share with their peers and others.

EXTENSION ACTIVITIES

Extension Activities:

- As suggested in Lesson 3, students could write an engineering journal article about their circuit design, modeling the journal publishing process.
- Another extension activity would be to really model a scientific conference, and have students both give short individual presentations about one particular aspect of their circuit to begin with, and then transition to the poster session later. In this case, having more community members would be important in order to keep up the interest.

Adaptations:

- Having a pair present each poster at a time to only those pairs and individuals who happen to be walking around should alleviate many of the issues students face when giving presentations, and having the poster and the circuit to refer to should aid students who struggle with vocabulary and memory. If the informality of a poster session is still too much however, individuals could present their poster with just the teacher or one group.
- If completing a Pugh Chart is too much individually, these charts could be completed in pairs. Provide clipboards if students need, and use simple criteria for younger students or more complex weighted criteria for older students.
- If students struggle with the poster design itself, more guidance can be given about what kinds of information need to be included, or physical templates could be printed for them

TEACHER BACKGROUND & RESOURCES

Background Information:

- Hopefully teachers will have experienced a poster session themselves as an undergraduate. If not, it would be very helpful to find an example video online, or to attend one at a local conference or university - either science or engineering focused, or education focused.

Resources:

Some Information about Poster Sessions:

- https://www.nature.com/scitable/nated/topicpage/poster-presentations-13907939
- https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1876493/
- http://guides.nyu.edu/posters
- https://nau.edu/undergraduate-research/poster-presentation-tips

Background about Pugh Charts

- http://ngss.nsta.org/Resource.aspx?ResourceID=218
- http://www.businessnewsdaily.com/6146-decision-matrix.html
- https://www.sciencebuddies.org/engineering-design-process/best-solution.shtml#keyinfo

Student Handout 4.1: Pugh Chart

Name:____ Date:______________________ Period:______

Criteria								
Total								

Student Handout 4.1: Pugh Chart

Name:____ Date:______________________ Period:______