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Engineering and Testing a Soil Moisture Sensor

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Introduction

During the summer of 2019, on a road trip from Santa Clara to Los Angeles, I couldn't ignore the billboards displayed along the roadside, asking people to conserve water, and the water shortages that the state of California is constantly facing. Farmers and the State had various messages displayed on their billboards to educate people about the need to conserve water. California's agricultural abundance includes more than 400 commodities. Over a third of the country's vegetables and two-thirds of the country's fruits and nuts are grown in California. California is the leading US state for cash farm receipts, accounting for over 13 percent of the nation's total agricultural value.[1] Agriculture is a major user of ground and surface water in the United States, accounting for approximately 80 percent of the Nation's consumptive water use, and over 90 percent in many Western States. Efficient irrigation systems, and water management practices can help maintain farm profitability in an era of increasingly limited, and more costly water supplies.

Rationale

The Franklin-McKinley School District in partnership with East Side Union High School District, Evergreen Valley College, and San Jose State University opened College Connection Academy (CCA), a Partnership School, grades 7 – 12/13 in the fall of 2008. CCA has the same autonomy and freedom to deal with curriculum, teaching and learning to meet individual students' needs. The four partners have combined and integrated their resources to make the Academy successful. CCA is located on Yerba Buena High School Campus, which allows students to take high school elective classes while in eighth grade. CCA students can earn up to one year's worth of college credits by the time they graduate from Yerba Buena High School.

The population of students is made up of 210 students for the academic year 2018-2019, of which 97 are seventh-grade students, and 113 are eighth-grade students. About 40% of the students are considered socioeconomically disadvantaged. The student demographics are the following: Black or African American 1%, Asian 62.9%, Filipino 3.8%, Hispanic or Latino 30.5%, White 1%, Two or more races 1%, English Learner's 9.5%, and Students with Disabilities 0.5%. This unit is developed for approximately 100 seventh grade general education students. All the students attending CCA are required to participate in the School District Science Fair. Prior to attending CCA, most of the students did not participate in any Science Fairs and did not have the opportunity to work with electronic components or engage in solving an Environmental Problem using Engineering. This unit is designed to align with the *Next Generation Science Standards*, which have been adopted by the state of California for use in Science education.

The beginning of this unit is designed to build background knowledge on the importance of conserving freshwater. The students targeted in this unit have limited knowledge of Earth's water and it's physical location, which includes above the earth in the air and clouds, on the surface of the earth, and inside the earth as groundwater.[2] Humans need food for survival, and in order to produce food, water is a necessity. Water shortages can lead to higher food prices. This unit is geared towards creating a hands-on learning experience for most of my students, who will be engaging in building a device for the first time with teammates.

The availability of water-saving gadgets is definitely creating awareness in people on ways they could save water. The ECO shower drop is a device that measures the amount of water, your shower uses and lets you know when it is time for you to get out.[3] The meter is designed to tell exactly how much water was used. A bathwater diverter is a fast and budget-friendly kit that is fitted to the outer waste pipe of your house. It diverts bathwater straight out of the house where it can be reused to water plants and grass. This water can be reused to water plants and grass. A part-sink part-toilet is useful to reduce water consumption. After flushing, fresh cold water is directed through the faucet for handwashing and that water drains into the tank to be used for the next flush. The toilet sink is highly efficient and uses just 1.28 liters per use. Aerators are small and quiet devices that save water by mixing air into the stream of the faucet. It has three settings, 0.5, 1.0, and 1.5 gallons per minute for washing, soaping, and rinsing.

Attending Science professional development workshops and engaging in activities with other teachers, allowed me to learn from my peers how a given problem can be solved in more than one way. This practice inspired me to create a similar experience for my students. A discussion on the characteristics of good team members will help students to learn the benefits of working as a team.[4] Students will work in teams, where there will be a heterogeneous mix of students with varied learning abilities, and each team having a maximum of four students. The soil moisture sensor is a device that will help solve the problem of not overwatering the soil on a farm or in gardens, while the soil is already moist.

Objectives

The main goal for creating this unit is to teach students the importance of water, and the need to conserve it. In an effort towards conserving water, students will learn to work as teams to build a soil moisture sensor by following the engineering design process. Students will also learn the importance of recycling the materials used in electronic devices in an environmentally responsible and resource efficient manner. Later, students should be able to use the engineering design process for future science fair projects.

Unit Content

What do we use water for?

We use large amounts of water each day, as water serves many different purposes. We use water to drink, to do the dishes, to take a shower, to flush the toilet, to cook food and for many other purposes. But water is not only used for domestic purposes, humans also use water in the industries and in agriculture. In agriculture, water is mainly used to water crops, but in the industries, it serves many different purposes. It can serve as an ingredient of a product we produce, but it can also be a part of the whole production process. Water can be used to cool substances in the production process, for transportation and conditioning of raw materials. [5]

How much water does a person use each day?

Information about water use can be presented in many different ways. One basic but very useful indicator is per capita water use.[6] Per capita water use is a metric representing an individual's share of a community's average daily water needs. Sometimes it's referred to as GPCD, shorthand for Gallons Per Capita per Day. Per capita water use is calculated by dividing the total volume of public water produced daily by the number of people being served. For example, in Santa Cruz, CA it takes an average of almost 9 million gallons of water every day to serve the regional population of about 93,000 people. That works out to 95 gallons per person per day. Surprised? It sounds like a lot of water – 95 gallons! That's because it includes not only the water we use in our homes and for irrigating lawns and gardens, but also water used at businesses including restaurants, hotels, and office buildings; at community facilities like schools, parks, swimming pools and hospitals; and for miscellaneous uses like fighting fires. Most of it, about two thirds, or 61 gallons per person per day, is used at home. Figure 1 shows a typical breakdown of the residential water use. Toilets, clothes washers, faucets, and showers make up the majority of indoor water use. About one-quarter of this amount goes to water landscapes and gardens.

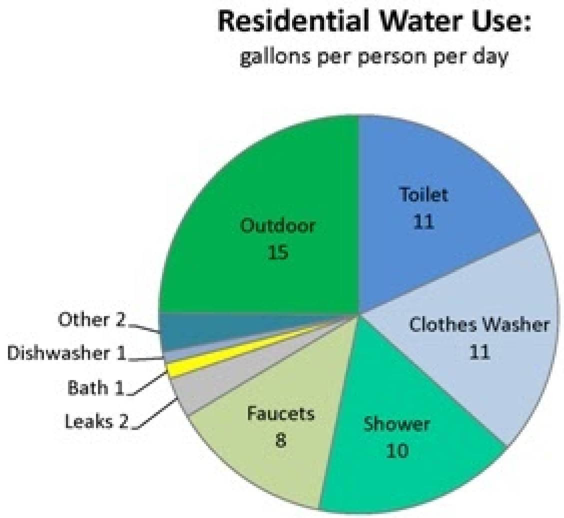

Figure 1. Residential water use for Santa Cruz, CA, USA. Source: City of Santa Cruz Water Department.

Monthly Water Tracker

It is interesting to learn about how the Santa Clara Valley Water District keeps track of its water usage each month. I wish to share this information with students to raise an awareness that water is a resource and its usage is monitored. The monthly water tracker gives information about the weather, local reservoirs, groundwater, imported water, treated water, conserved water, and recycled water for each month. As of July 1, 2020, Monthly Water Tracker, Santa Clara Valley began the calendar year 2020 with groundwater storage well within Stage 1 (Normal) of the Water Shortage Contingency Plan of Valley Water. Despite being well below-normal local rainfall and statewide snowpack, end of the year groundwater storage for 2020 is projected to be well within Stage 1. [7] The rainfall year is calculated from July 1 to June 30. The Board continues its call for a 20% reduction and a limit of three days per week for irrigation of ornamental landscape with potable water.

Future Widespread Water shortage likely in the United States

Based on the information from Harvard University's," Science in The News" Blog, by 2071, nearly half of the 204 freshwater basins in the United States may not be able to meet the monthly water demand. These model projections, recently published in the journal Earth's Future, are just one preliminary component of the upcoming Resources Planning Act (RPA) Assessment expected to be published next year. In 1974, congress required that this assessment of US renewable resources be published every 10 years.[8]

The water supply itself is also expected to decrease. Projected climate change affects both rain patterns and temperatures. While rainfall is expected to increase in some parts of the U.S, the southern Great Plains and parts of the South will see decreases in precipitation. The water basins rely on rainfall to feed the rivers and tributaries that flow into them. Separately, more water will evaporate from reservoirs and streams as the climate gets warmer, further chipping away at the water supply. Around 50 years from now, many U.S. regions may see water supplies reduced by a third of their current size, while demand continues to increase. The water shortages may especially impact U.S. agriculture. Irrigated agriculture often accounts for around 75% of the annual consumption of water from these storage reservoirs. The authors point out, though, that this also makes agriculture a clear area for reducing water use. Up to 96 freshwater storage reservoirs are projected to face shortages. Reducing water use for irrigation by just 2% could prevent shortages in a third of these storage reservoirs. The agricultural sector is likely to face serious challenges. Accordingly, the findings raise concerns about both future water security and food security in the U.S.

Drought's Effect on the Economy and You

A drought is a reduction in precipitation over an extended period. This creates a water shortage that damages crops, livestock, and the environment. Since droughts adversely impact agriculture, those that depend on the commodities from the industry suffer as well. Food becomes scarcer and demand exceeds supply. Prices go up, and the commodities markets waiver. If the economy is already in a state of depression or recession, a drought can increase that state. Climate change can also amplify the effects of a drought. A drought can further cause damage by increasing the risk of large-scale wildfires and can cause populations to begin tapping into their emergency reserves of water - the aquifers that collect water underground.[9] It helps to understand how droughts can deepen the effects of a changing climate, and how they have played a part in environmental and human circumstances in the recent past—so that one day, humans can move past destroying fragile ecosystems and still survive in comfort on the planet.

The U.S Drought Monitor (USDM) is a map that shows the location and intensity of drought across the country each week. As per this week's report, 11,339,000 residents are in drought, and 2,754,000 more residents are in abnormally dry areas. This accounts for 30% of the state of California's population, and 8% more in abnormally dry areas respectively. Figure 2 demonstrates the Percent Area of California that has been in a state of drought between 2000 and 2020. Based on the United States Drought Monitor which started in 2000, the longest duration of drought (D1-D4) in California lasted 376 weeks beginning on December 27, 2011 and ending on March 5th, 2019. The most intensive period of drought occurred the week of July 29, 2014 where D4 affected 58.4%of California land. [10] On the Drought Monitor, D0 indicates Abnormally Dry, D1 indicates Moderate Dry, D2 indicates Severe Drought, and D3 indicates Extreme Drought, and D4 indicates Exceptional Drought. All of this information is sufficient reason to conserve water.

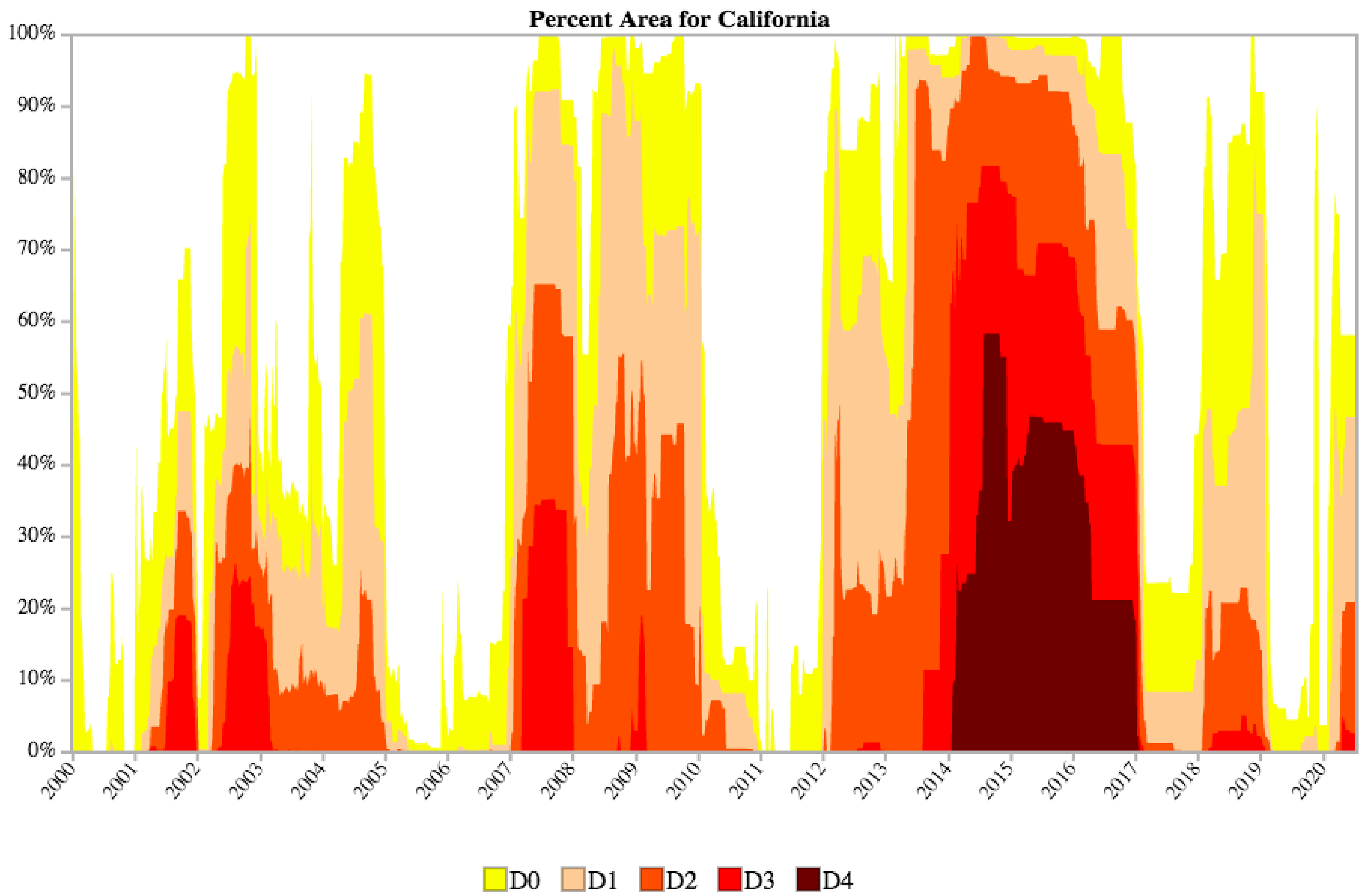

Figure 2: Percent Area of California, USA that has been in a state of drought between 2000 and 2020. Source: Drought.gov - U.S. Drought Portal.

Overview of The Engineering Design Process

The goal of this unit is to design, build and test a device for monitoring soil moisture. Such a device can be effectively used to grow crops with minimal water wastage. In order to begin working on building the soil moisture sensor, students will first learn about the steps involved in the Engineering Design Process.

Engineering is a process that involves several steps. The first step is how to define the problem or need. The next step is to establish design criteria which will define the products physical and functional characteristics. In addition, one must develop constraints which are factors that limit the design. Once the criteria and constraints are decided, the research process begins. Engineers research the problem and make use of current technologies to help them arrive at creative ideas. After the research phase, Engineers will brainstorm possible solutions that meet their design criteria and constraints. Engineers will then create a prototype of the selected plan and will test the prototype based on the criteria of the design. After evaluating the results, Engineers improve their design and redesign. This process is repeated several times until the desired results are achieved. [11] Once done with building the prototype, students will present their work to the class, where they will get to share their experiences, the challenges they faced, and how they solved their challenges, in the process of creating the soil moisture sensor.

Soil Moisture Sensor Circuit Materials

In order to build the circuit, the following materials have been used: one breadboard, one 9 Volt battery, jumper wires to connect to the battery, one CD4011 NAND gate integrated circuit (IC), two 100 KW resistors (the resistors will have brown, black, yellow, gold stripes), one 470 W resistor (the resistor will have yellow, purple, brown, gold stripes), one red LED, one 10 MW resistor, jumper wires (in different colors). In order to test the device, one will have to use samples of wet soil and dry soil. [12] In addition, you will need a small plastic container with a lid in which you can save your device when you are not using it.

Soil Moisture Sensor Circuit

Once you have identified and secured the required materials it is time to look into the assembly of the moisture sensor. I have included the information from the slides on the sciencebuddies.org website on the procedure to build the circuit for the moisture sensor. Table 1, in the procedure section of the sciencebuddies.org website, shows pictures of the electronic components used if one does not know how each of these parts looks like. I would highly recommend using a round nose plier (commonly used for jewelry making, and available at many craft store) to work with the wires while inserting them in the breadboard and securing the wires in the breadboard.

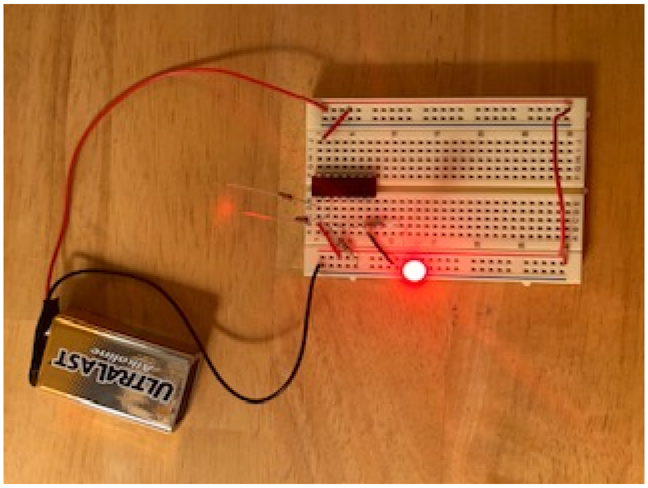

Figure 3: Soil Moisture Sensor Circuit.

The circuit in Figure 3, is built using the following procedure, which includes 12 steps that need to be followed. Step 1: Get a blank breadboard. Step 2: Insert a 4011 NAND gate into the rows 1- 7 straddling the middle of the breadboard. Over here, it is important that the semicircular notch of the NAND gate points up towards row 1. Step 3: Connect a jumper wire from the (+) bus to B1. Step 4: Connect a jumper wire from J1 to the (+) bus. Step 5: Connect a jumper wire from A7 to the (-) bus. Step 6: Connect a 10 MW resistor (has brown, black, blue, gold stripes) from B2 to the (-) bus. Step 7: Connect a 470W resistor (has yellow, purple, brown, and gold stripes) from B3 to B11. Step 8: Connect an LED from A11 (long lead) to the (-) bus (short lead). Step 9: Use a jumper wire to connect the left (+) and the right (+) buses. Step 10: Connect a 100 kW resistor (has brown, black, yellow, and gold stripes) to C2 (leave one lead free). Step 11: Connect a 100 kW resistor (has brown, black, yellow, and gold stripes) to D1 (leave one lead free). Step 12: At this point it is important to double-check all the connections before connecting to the battery. Connect snap connector to battery. Red lead to the (+) bus, black lead to (-) bus. The LED should turn on. The circuit works by “detecting” the resistance between the two free 100 kW resistor leads. Make sure the free 100 kW resistor leads are not touching each other. The LED should turn on, because the resistance between the leads is very high.

Testing the Circuit

When you touch the two free leads directly with each other, the LED should go out, because the resistance between the leads is zero. Electricity can flow easily from one lead to another. Next, put a small pile of dry soil on a plate (about 50 grams). Touch both resistors leads with the soil at the same time. The LED should turn on because the resistance of the dry soil is very high.

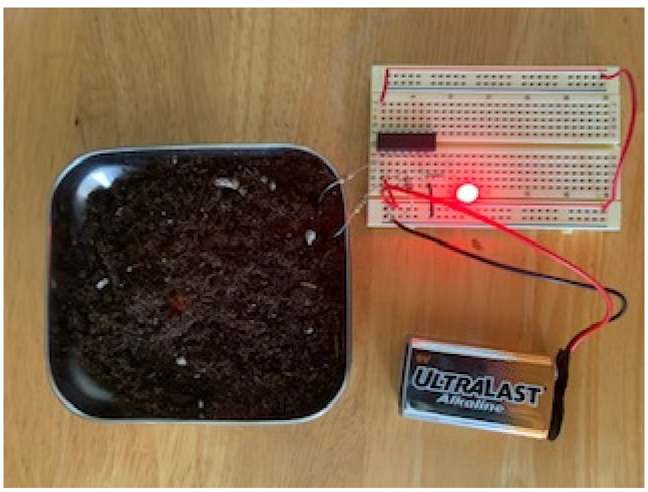

Figure 4. The LED turns on because the resistance of dry soil is high.

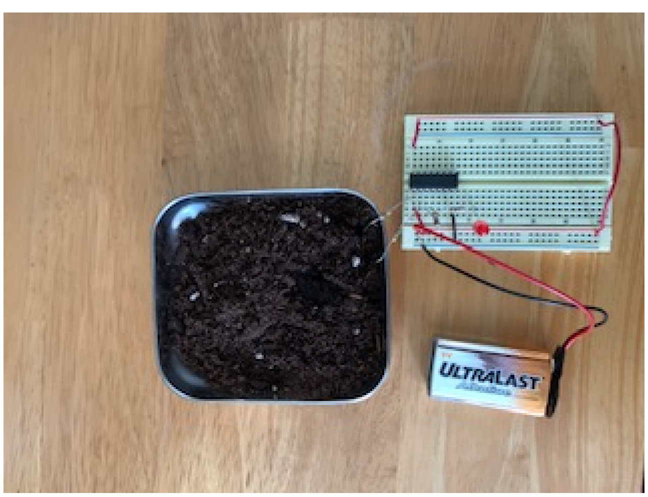

Figure 5: Here the soil is wet. The LED turns off because the resistance of wet soil is low.

Soil Moisture Sensor Electronic Components Details

In order to begin working with the soil moisture sensor, it is important to know each of the electronic components and their function, that are used in building this device. Electronic components used to build a soil moisture sensor, are also used to build thousands and thousands of other electronic devices. Electronic components that will be used in the classroom include resistors, capacitors, diodes, transistors, breadboard, LED light bulbs, integrated circuit chips, 9 V battery with a snap connector, and jumper wires. The YouTube video titled," A Simple Guide to Electronic Components" is a great resource to gather information on electronic components. [13] In this video, electronic parts are described along with their functions. The video is above seventh grade level and is a resource that is to be used by teachers while building students' knowledge of the electronic components.

A half size breadboard will be used for building the circuits for the soil moisture sensor. The website sciencebuddies.org has an excellent video on the introduction to breadboards. At the time of this writing it was accessible at sciencebuddies.org/science-fair-projects/references/how-to-use-a-breadboard. [14] Watching this video will allow you to know how to use the breadboard. It shows the inside clips of the breadboard (which have five notches) that hold wires or LED leads in place, when pushed into the breadboard. Breadboards represent a grid from which one can make electrical connections. The rows on the breadboard are labeled from 1 to 30. The columns on the breadboard are labeled from A through J. These labels make it easy to follow the directions when building a circuit. There are long strips on either side of the breadboard that are usually labeled with red and blue lines, and also a plus or minus sign. These lines are called buses or power buses or rails and are used to deliver power to the entire circuit. The red line, marked with a + sign will connect to the positive battery, and the blue line marked with a - sign will connect to the negative battery terminals. Each set of five holes forming half a row, that is, those on the left, in columns A through E, and those on the right in columns F through J, are electrically connected. The power buses run vertically on the sides of the breadboard, and are typically connected over more than five holes, although this can vary from breadboard to breadboard. The individual power buses are not connected to each other.

The primary purpose of a Resistor is to limit the flow of electricity/current. A resistor is generally made up of a carbon film or metal film wound, and they contain a ceramic tube which is coated with either the metallized coating or a carbon coating up to a specific thickness, and thicker the carbon coating on it, and the type of the composition of the coating, the more conductive the resistor will be. A resistor can be fine-tuned, when you cut a spiral around it, which creates a long thin path of the carbon and that increases the value of the resistance. A metal cap is then put at the ends. In a situation where you want an LED to light from a battery. If you connect a LED directly to a battery it can burn the LED. The color code is used to denote the tolerance rating of the resistor. Resistors do not have polarity, i.e. the direction in which the leads of the resistor are connected on the breadboard, is not important.

Diodes are available for different functions. Signal diode, rectifier diode and light emitting diodes (LED's) are the different types of diodes available. The function of a light emitting diode is to allow current to flow in only one direction, but not the other (defined as polarity). Current flows from the anode (+) to the cathode (-). If you reverse the polarity (when the light bulb leads are switched), very little current, if any, will flow through that diode in reverse. LED is a diode junction that is optimized. It behaves like a normal diode, but when it is forward biased and when current is flowing through it, it emits light. LED's do not have a very high reverse blocking voltage, as they are just about 5 volts. So, if you were to connect the polarity wrong, and exceed about 5 volts, then in that case the LED will end up just conducting but not lighting up. In addition, both leads of the LED must be in the same row for the LED bulb to glow i.e. it has to be in a complete path or closed circuit for electricity to flow, when used on a breadboard.

Jumper wires and jumper clips are used to make connections on the breadboard. It is inexpensive to buy pre-made jumper wires as they are already cut and the ends are bent at 90 degrees, which makes them convenient to use on the breadboard. Integrated circuit chips are used to saddle the gap between the rows of the breadboard, with the semicircular notch facing up.

Electronics Donation and Recycling

Electronics donation and recycling is a great way to help conserve resources and natural materials. It is important to make sure you are donating and/or recycling electronics safely and correctly.[15] Electronic products are made from valuable resources and materials, including metals, plastics, and glass, all of which require energy to mine and manufacture. Donating or recycling consumer electronics conserves our natural resources and avoids air and water pollution, as well as greenhouse gas emissions that are caused by manufacturing virgin materials. For example, recycling one million laptops saves the energy equivalent to the electricity used by more than 3,500 United States homes in a year. For every million cell phones we recycle, 35 thousand pounds of copper, 772 pounds of silver, 75 pounds of gold and 33 pounds of palladium can be recovered.

Teaching Strategies and Activities

As students will be building a device, the pacing of the lessons will be based on the learning speed of the students. While sharing video clippings for a given lesson, I will be using blended learning in the classroom. While playing a video, I will pause and explain all of the concepts related to the topic. Later, I will be using direct instruction to teach students the basic electronic components used to build the soil moisture sensor. Notes about each of the electronic components used will be shared, so students can easily identify the various parts and know their functions. Students will participate with their teams and build a soil moisture sensor, test it, analyze their results, and communicate their results to the class.

The first section of this unit will introduce students to the process of the Engineering Design Process, I will go over each of the steps involved which include the identification of a problem or need, the design criteria which define the physical and functional characteristics, the constraints which will be factors that limit the flexibility of the product, alternate designs that come up while engineers brainstorm, building a prototype, testing and evaluating the prototype using the design criteria, analyzing the test results, make design changes and retest, and to communicate the results.

Section two will focus on introducing students to the basic electronic components. To get started, I will conduct a demonstration of how a breadboard is used to make a LED light bulb glow, when it is connected to a battery and a resistor. I will conduct it in five steps, so it is easy for students to follow. Step 1; The battery pack's red lead (+) is connected to the + side (red line) of the power bus on the right side of the breadboard. Step 2: Next a jumper wire is used to connect from the + side of the power bus (row 5) to row 5, column I. Step 3: Next, the longer lead (leg which is positive) of the LED bulb is inserted into row 5, column H, and the shorted lead (negative) is inserted into row 5, column E. Step 4: A resistor is connected from row 5 column B, to row 5 on the ground bus. Step 5: A black wire is connected from row 1 of the ground bus to the battery pack's black lead (i.e. the negative charge). The student will be able to see that the light bulb glows when the circuit is completed! Students will then make use of a breadboard and create a circuit to light up a LED bulb.

Under section three, I will engage students in a short discussion about being team players and will create heterogenous groups of students so they can work together. In order to help students get started with building the soil moisture sensor, I will go over the slides on assembling the circuit from the sciencebuddies.org website, along with identifying each of the markings on the electronic components and also the instructions that need to be followed at the bottom of the slides.[16] Students will then assemble the circuit for the soil moisture sensor.

Section four, will focus on testing the device and analyzing the results. Students will test their device with dry soil and then with wet soil. When I tested by using drops of water, the LED stayed on initially for the first three drops of water for 50 grams of soil that I used to conduct the test. As soon as I added the fourth drop of water the LED light went off. I shifted the resistors and conducted the test three times and I got the same results. Students will be required to share their work with the class and communicate their test results. If a group of students get done with their work early, they will be able to go individually, to help other groups to identify any problem that they may be having and help them solve the problem.

Section five, will allow students to participate in a discussion on how they will dispose of electronic waste in a responsible manner without impacting the environment.

Teaching Resources

One must ensure that they have the necessary materials before they begin working on building the soil moisture sensor. I got the materials needed from the website: sciencebuddies.org. I highly recommend getting additional resistors and LED bulbs as they tend to fuse out/burn out very easily. You will need the following items for each team: breadboard, a4011 NAND gate, jumper wires, 10 MW resistors, 470 MW resistors, LED bulbs, 100kW resistors, and a 5 Volt battery.

Appendix on Implementing District Standards

By working on the electronic soil moisture sensor, the following NGSS will be covered: Identify a problem/need (ETS1.A; already provided by me) which is to design a soil moisture sensor. Next, students will learn about the need to establish design criteria and constraints (MS-ETS1-1). The criteria will define the products physical, and functional characteristics. The constraints will be factors that limit the engineer's flexibility such as time, cost, safety, and legal issues. Students will build a prototype which will confirm that their design will work (ETS1.B). The next step will be to test, and evaluate their prototype using the design criteria under actual or simulated operating conditions, if it works to their satisfaction (MS-ETS1-4). Later, they will analyze the test results, make design changes if necessary (ETS1.C), retest and present their work to the class. They will conclude with a discussion on how to safely dispose of electronic waste materials.

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