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Simple Circuits: Engineering Irrigations Systems for Hydroponic Enthusiasts



**Description and Context**

This design-based unit integrates science and engineering design practices. The goal of this unit is to understand what a water pump is, investigate how a water pump can be integrated in a circuit, and to investigate how to a circuit can be modified to influence the output of the circuit. Specifically, students will explore how to create simple circuits and the physics relating to their construction. Students will apply their science understanding and engineering design practices to construct a circuit that operates a water pump with adjustable output options to control water flow rate.

The unit is comprised of five lessons based on a four-phase generative learning model (Cosgrove & Osborne, 1985).

* Lesson 1 comprises the *Preliminary Phase*,
* Lesson 2 includes the *Focus Phase*,
* Lessons 3-4 include an extended *Challenge Phase*, and
* Lesson 5 encompasses the *Application Phase*.

Elements of the engineering design process are integrated in Lessons 1-4. Lesson 5 serves as a capstone of applying the design process. Individual lessons may be reduced or elaborated on as needed.

Prerequisites: Before starting this unit, students should:

* Understand what a complete circuit,
* Know how to light a light bulb with one battery and wire,
* Be able to identify various circuit elements (i.e. switch, battery, wire, and resistor), and
* Be familiar with Ohm’s law.

To set the stage of the unit, the teacher may show a video clip highlighting what hydroponic systems are, why are they useful and important.

Possible video clips are:

* <https://www.youtube.com/watch?v=6kUm_I7bLYw>
* <https://www.youtube.com/watch?v=Rj4MzjxjGck>
* <https://www.youtube.com/watch?v=EJjAWF2DfWY>
* <https://www.youtube.com/watch?v=aJorITEWCWk>

Also the teacher may remind students of the larger goal of the overarching hydroponic systems unit that they are working on in other sciences and that they will be working on a small portion of building the overall hydroponic system. Specifically, they will need to design a way in which water can be supplied to the plants in whatever tray arrangement is be utilized to hold the plants.

The teacher will read the following opening inquiry, design challenge story to set the goal of the unit.

*You are working as an engineer for a company that manufactures irrigation systems for hydroponic farmers. Recently, your company has begun to meet the specific needs of home hydroponic enthusiasts that are remotely located i.e. they are not accessible to any electrical power grid.*

*You and your team is tasked with the challenge to produce an electrical pumping system i.e. the pump along with the electrical circuit and power source that drives the pump to serve the needs of such hydroponic enthusiasts. Further, you are also asked to produce a user’s manual for hydroponic enthusiasts that would enable them to use the system for their specific criteria and constraints, such that the water flow rate and height of water delivery can be adjustable for multiple hydroponic plan configurations.*

The major science and engineering assessment in this unit is a written hydroponic farmer’s user manual for the hydroponic farmer to assist in building a hydroponic garden. The “DesignSTEM Design Guide” will inform elements of the user manual.

**Lesson 1 – What is a Water Pump (*Preliminary Phase*)**

Learning Goal:

The goal of this lesson is to set the tone of the challenge story and engage students in their engineering design task throughout the unit. It will allow students to identify the problem and gather ideas. Students will learn about what water pumps are by analyzing the various model pumps. They will then learn about how and why water pumps are used and what may be required to operate a water pump.

Central Question(s)

* What is a water pump?
* Where are water pumps used?
* What is required to operate a water pump?

Major Concepts

After completing this unit, students should understand the following:

* What is the basic principle of a water pump
* What are some of the different kinds of water pumps

Potential Misconceptions and Difficulties

There is no literature to date of specific misconceptions and difficulties that students may have about water pumps.

Safety/Ethical Issues: NA

Materials

* Various DC water pumps
* Science notebooks to distribute to each student

Activity To begin the unit, the teacher introduces the following inquiry/design challenge story (*described previously*).

The teacher will indicate to the students that they will be engineers to help the manufacturing company and potential hydroponic enthusiast who are making their own home systems and at the end of the unit they will design, make, test, and communicate results of there water pump integrated circuit. But first, they must make some scientific investigations to gain a better background understanding to help solve the problem. Also, the teacher can have the students identify the problem/concern of the user and lead them to think about aspects of the problem for which they will need to understand (i.e. understanding what a water pump is and what is needed to run a water pump). This will help guide the rationale/goals of the following lessons. The teacher will distribute the science notebooks to each student that will be used throughout the unit.

The teacher may pose the following guiding questions to the class and allow students to discuss and identify the problem in the story. After students have had time to formulate/debate ideas they can be prompted to write their ideas in their science notebooks.

Possible Questions for Guiding Engineering Design:

* What is the problem?
* Who is your end-user in this story?
* What are the needs of your end-user?
* What information do you need to solve this problem? (Students may provide a variety of answers. Guide the students to think about the end user’s concern and how it relates to the hydroponics garden. This will help set the stage for the next portion of the activity.)
* What are possible design considerations?

Possible Questions for Guiding Inquiry:

* Have you ever wondered how to move water up to a certain height? Have you ever wondered how water can be removed from flooded basements?
* Do you know what a water pump is?
* How do you think a water pump works?
* What might you need to get a water pump to work?
* Can you find a way to run a water pump using a battery and be able to adjust its flow rate?

To generate interest in the problem, the teacher may also wish to show relevant video clip(s) from YouTube or other media about water pumps. Specifically showing a variety of water pumps being used in various ways. The teacher may also choose to have students spend a short amount of time researching online what water pumps are, how are they used, considerations that need to be made, and how do they work.

Possible YouTube video clips include:

* <https://www.youtube.com/watch?v=2hP5ZKZfO1Q>
* <https://www.youtube.com/watch?v=OBp8-WWhxJU>
* <https://www.youtube.com/watch?v=mP8_RAt75bQ>
* <https://www.youtube.com/watch?v=BaEHVpKc-1Q>

Then, for several minutes, students will read a brief write-up about how water pumps work located in their science notebook. The teacher will then encourage the students to gather around a display of various internal and external water pumps and guide the students to relate the information they have read to parts of the parts of the pumps and compare and contrast the various pumps. The teacher may also provide the pump specifications that may be provided on or with the pumps when purchased.

It is important to emphasize that there are two varieties of pumps (external or internal to the water source) but they operate in similar ways to provide the intended function – to move water. Additionally, there are pumps that use alternating current (AC) or direct current (DC).

Students should be guided to recognize the constraint in the inquiry/design challenge story is such that they will need to use DC water pumps. This is because pumps that use an AC power source, are those that receive power from the socket i.e. they should be accessible by the power grid. Since, they are designing a pumping system for remotely located hydroponic farms, that do not have energy supplied by the power grid, they must think about a DC water pump. This may be a good point for the teacher to emphasize differences in AC and DC if they wish to discuss the two kinds of electrical power.

It is also important to stress that each pump may have different specifications for necessary current and voltage requirements and may provide varying outputs.

Possible Guiding Questions:

* What might you need to run a water pump?
* Do you think it is important to consider what current/voltage source you may need?
* How might an individual operate a water pump?
* Is there a difference in how you might operate water pumps if it were an AC pump or DC pump?

Finally, the teacher will encourage student to individually make design predictions in their notebooks as to how they might connect a water pump to a battery for it to operate. Also the students will make predictions of ways in which they may adjust the output rate of the water pump.

NOTE: In later lessons, students should be prompted to refer back to this design and modify based on what they have learned. Then they can share in groups and agree upon a design.

**Lesson 2 – Simple Circuits: Parallel and Series Circuits (*Focus Phase*)**

Learning Goal:

In this lesson students will engage in a challenge to generate ideas and create and test simple circuits that causes light bulbs to light and explore various ways to construct circuits in which the bulbs appear bright or dim when lit. Specifically, students will explore with and use materials to design parallel and series circuits. Additionally students will have an opportunity to compare their circuit designs and generate ideas as to why the bulbs appear dim or bright based on the circuit configuration. The light bulbs are intended to serve as resistors and provided a simple observable effect before the use of multi-meters as in Lesson 3 and the discussion of what variable resistor are in Lesson 4.

Central Question(s)

* What criteria make a complete circuit (i.e. makes the bulbs light)?
* How can you create a circuit such that the light bulbs appear bright or dim when lit?
* What are the differences between series and parallel circuits?

Major Concepts

* A complete path, or circuit, should be made for a continuous flow of electrons
* How to connect series and parallel circuits.
* Qualitative differences between series and parallel circuits

Potential Misconceptions and Difficulties

Students often have difficulties understanding what a complete circuit is. These have been documented in the literature (e.g. Engelhardt & Beichner, 2004). Further, students may not necessarily understand how a light bulb is internally wired and its implications for making a light bulb light, such that to make a light bulb light, the bottom of the light bulb should be connected to one end of the battery and the side of the light bulb should be connected to the other end of the battery.

Safety/Ethical Issues

To make handling of materials easier, the teacher should fill quart-sized bags with necessary materials for each group. This will help to facilitate students to make predictions prior to handling the materials. Students should not cut the insulation around the wires or the coating around the batteries. Students should be warned that if the bulbs, wires, or batteries feel hot, they should disconnect the materials. Materials such as wires or bulbs should not be placed in electrical sockets.

Materials

* 1 Battery (6V Lantern Battery)
* 6 Wires (with alligator clips on either end)
* 2 identical bulbs (incandescent flashlight bulb 6.3V/250 mA or 7.5V/220mA)
* 2 light bulb sockets (E-10)
* 2 Multimeters (can be used as Ammeter, Voltmeter, or Ohmmeter)

Activity

The teacher should introduce the idea that the light bulb is actually a resistor. This will be revisited later in Lesson 4, where a distinction will be drawn between a light bulb and a variable resistor.

In this lesson, the teacher may choose to utilize hands-on materials and/or computer simulations. For the hands-on materials, the teacher should distribute a baggie of materials (see above) to each group of 3-4 students. The students should not open the baggies just yet, but instead examine the contents they see and make predictions. For the first several minutes, student are encouraged to individually predict how they can connect one light bulb with a battery and wire such that it will light. Next, they will predict how they can add additional light bulbs to the battery with additional wires. Students should be prompted to look for more than one way to connect the bulbs, wires, and battery. After students had time noting predictions in their notebook, the teacher may encourage students to share their designs in groups or as a class. Students can also explore if their predictions worked (i.e. bulbs light in more than one way). Students should be guided such that there is more than one way to connect light bulbs.

Next, the teacher will pose an additional challenge to students. They will need to put together circuits such that: the light bulbs will appear dim, and the light bulbs will appear bright. They are then encouraged to record their ideas in their science notebooks. For each design, students should explain how they think their design should work. Next, students are encouraged to share their ideas in their group and arrive at an agreement on which design they will create to meet the criteria of having light bulbs that appear dim and light bulbs that appear bright. The group’s designs and explanations for the designs should be recorded in their notebooks. Once each group has arrived at an agreement on their designs, the students should then begin creating and testing their circuit designs. Results of their design testing should be recorded in their notebooks. As the groups are working on their circuit designs, the teacher may circulate among the groups asking questions to facilitate students’ thinking of their designs, what is occurring in the circuit, and how are the materials being put together for the light bulbs to light. Once a group has discovered a way to make the bulbs appear bright or dim, the teacher may ask the group to share their ideas and/or draw their configuration on the board for the class to discuss. This would be a great opportunity for students to generate qualitative explanations about what is occurring the circuits and the teacher to provide feedback to other groups on their designs.

As students work in groups during this activity, the teacher may circulate among the groups asking questions to help facilitate their thinking.

Possible questions include:

* What are your ideas?
* What were some similarities and differences that members of your group had?
* How are you creating your circuit?
* What ideas are you using to inform your design?

As students set-up their circuit and test it by making complete connections (i.e. closed circuit), the teacher may ask:

* What was your result?
* How might you improve your design?
* What were strength and weakness of your design?
* How might you explain why your design worked or did not work?

The goal is for students to recognize that light bulbs can be connected in either series or parallel, which influences their brightness. This goal will then lead to the next lesson to explore why brightness is influenced based on the design.

Possible Guiding Questions:

* Can you find a way to connect the battery, light bulbs, and wires to make the bulbs appear dim when lit?
* Can you find a way to connect the battery, light bulbs, and wires, to make the bulbs appear bright when lit?
* Why do you think this configuration worked and caused the light bulb to appear bright/dim?
* Are there any similarities or differences in how you connected the light bulbs for dim and bright lighting?
* How might you think the circuit arrangements influence why the bulb appears bright or dim?
* How are these configurations similar to or different from those in which you predicted?

If the computer simulations are utilized, the teacher may provide constraints in how many wires, light bulbs, and devices students may use. The following are possible computer simulations. Please note that these simulations may only utilize DC or DC+AC components. For this unit, DC is only necessary however if the teacher wishes to discusses differences in current these simulations may provide additional support to facilitate those discussions.

University of Colorado – Boulder PhET Interactive Simulations:

* <https://phet.colorado.edu/en/simulation/legacy/circuit-construction-kit-dc>
* <https://phet.colorado.edu/en/simulation/legacy/circuit-construction-kit-ac>
* <https://phet.colorado.edu/en/simulation/legacy/circuit-construction-kit-dc-virtual-lab>
* <https://phet.colorado.edu/en/simulation/legacy/circuit-construction-kit-ac-virtual-lab>

**Lesson 3 – Voltage, Current, and Resistance in Series and Parallel Circuits (*Challenge Phase*)**

This lesson is designed to delve deeper into series and parallel circuits and how they compare with each other. This lesson builds on Lesson 2 in the following way: Lesson 2 was a qualitative comparison of series and parallel circuits, this Lesson facilitates students to understand quantitative relationships between current and voltages of different light bulbs in series and parallel circuits.

This unit is comprised of two activities to address the following central questions. The teacher my lead these activities as a whole class or small group investigation. Students will enter data, generate graphs, and make inferences in their science notebook.

Central Question(s)

* How do the current, voltage, and power delivered compare across different resistors that are in series?
* How do the current, voltage and power delivered compare across different resistors that are in parallel?

Major Concepts

* The same current flows through resistors in series.
* The voltage across individual series resistances adds up to give the total voltage across the battery.
* The larger the resistor the greater the power delivered to it.
* Changing any one of the resistances affects the current through all resistances and the voltage across each individual resistance.
* The same voltage appears across resistors in parallel.
* The current through individual parallel resistances adds up to give the total current through the battery.
* The smaller the resistor the greater the power delivered to it.
* Changing any one of the resistances affects the current through only that resistance, and not the others.

Potential Misconceptions and Difficulties

Students often find it difficult to identify whether resistors are in series or in parallel. They often use the geometric arrangement of the resistors rather than how they are connected to identify whether they are series or in parallel. It is also counterintuitive and therefore difficult for students to understand that adding resistors in parallel actually decreases the overall resistance and increases the current. In a series circuit many students may have the ‘current consumed’ model i.e. they think that each bulb consumes part of the current and the remainder moves on to the next bulb in the circuit. In a parallel circuit, students may often believe that at each junction in the circuit, the current splits equally between the two branches of the circuit at each point.

Materials

* 1 Battery (6V Lantern Battery)
* 6 Wires (with alligator clips on either end)
* 2 identical bulbs (incandescent flashlight bulb 6.3V/250 mA or 7.5V/220mA)
* 2 light bulb sockets (E-10)
* 2 Multimeters (can be used as Ammeter, Voltmeter, or Ohmmeter)

Safety/Ethical Issues

Same as in Lesson 2

Activity 1

The teacher will begin the activity by asking: If you have single light bulb connected to a battery in a circuit, what will happen to the brightness of the bulb if you add a second bulb in the circuit as shown (i.e. in **series**)? What will happen to the current in the circuit? What will happen to the voltage across each bulb?

Next the teacher will ask them to conduct an investigation in which they start with one bulb, measure the current and voltage, and then add a second bulb in series and measure the current through and voltage across both bulbs individually. The students will need to connect multimeters, set to work as voltmeters or ammeters, to their circuits they made in Lesson 2. This may be a good opportunity for the teacher to discuss how to connect multimeters and how they can be set up to work as voltmeters, ammeters, or ohmmeters, especially if the students have not had prior experience using multimeters.

They will be asked to compare their measurements before and after adding the second bulb. Finally, they will be asked to predict what would happen if they unscrewed the first bulb? Second bulb? Then they will test their predictions. In the science notebooks they will first commit to a prediction and then take measurements, later they will compare their predictions with their measurements.

After completing and recording their measurements, the teacher should lead a discussion to facilitate students to realize the general patterns in their data:

* The same current flows through resistors in series.
* The voltage across individual series resistances adds up to give the total voltage across the battery.
* Changing any one of the resistances affects the current through all resistances and the voltage across each individual resistance.

Activity 2

The teacher will begin the activity by asking: If you have single light bulb connected to a battery in a circuit, what will happen to the brightness of the bulb if you add a second bulb in the circuit as shown (i.e. in **parallel**)? What will happen to the current in the circuit? What will happen to the voltage across each bulb? Next the teacher will ask them to conduct an investigation in which they start with one bulb, measure the current and voltage, and then add a second bulb in series and measure the current through and voltage across both bulbs individually. They will be asked to compare their measurements before and after adding the second bulb. Finally, they will be asked to predict what would happen if they unscrewed the first bulb? second bulb? and test their predictions. In the science notebooks they will first commit to a prediction and then take measurements, later they will compare their predictions with their measurements.

After completing and recording their measurements, the teacher should lead a discussion to facilitate students to realize the following general patterns in their data:

* The same voltage appears across resistors in parallel.
* The current through individual parallel resistances adds up to give the total current through the battery.
* Changing any one of the resistances affects the current through only that resistance, and not the others.

**Lesson 4 – What are Variable Resistors? (*Challenge Phase*)**

Learning Goal:

The main goal of this lesson is to facilitate students to develop an understanding of a variable resistor and its role in an electric circuit. Until this point, students have used light bulbs as resistors. The resistance of the light bulbs is almost constant (although it can increase a bit when the filament heats up), it cannot be controlled by the user. However a variable resistor can be controlled by the user with the turn of a knob and it makes it a useful and interesting device to use in any circuit where one has to control the voltage or current being supplied to a particular element of the circuit.

Central Question(s)

* What is a variable resistor and how can you change its resistance?
* What happens when a variable resistor is used in a series circuit? In a parallel circuit?
* How can a variable resistor be used to control the brightness of a bulb in a circuit?

Major Concepts

* A variable resistor is actually two resistors in series, such that the total resistance of the two resistors together is constant, but each individual resistance can be changed by turning a screw.
* The variable resistor has three terminals with one resistance between the 1st and 2nd terminal and another resistance between the 2nd and 3rd terminal. The total resistance between the 1st and 3rd terminals remains fixed.
* If a variable resistor is used in a series circuit with a light bulb, such that the 1st and 2nd terminals alone are used, it can be used to change the brightness of the light bulb by turning the knob and changing the resistance between the 1st and 2nd terminals.
* If a variable resistor is used in a parallel circuit with a light bulb, such that the light bulb is connected between the 2nd and 3rd terminals and the battery is connected between the 1st and 3rd terminals, then it can be used to change the brightness of the light bulb by turning the knob.

Potential Misconceptions and Difficulties

There are no documented student difficulties or misconceptions with variable resistors. However, given that a variable resistor is a ‘black box’ where one cannot see what is going on inside when the knob is turned, it is difficult for students to understand how a variable resistor works.

Safety/Ethical Issues

Same as in Lesson 2 and 3

Materials

* 1 Battery (6V Lantern Battery)
* 6 Wires (with alligator clips on either end)
* 1 Light bulb (incandescent flashlight bulb 6.3V/250 mA, 7.5V/220mA)
* 1 light socket (E-10)
* 1 Variable Resistor (25 Ohms, 3W)
* 1 Multimeter

Activity 1

Because the variable resistor is a black box, the teacher should pose a challenge to the students to figure out what it is. To do so, students can hook up a multimeter (set as an ohmmeter) between each pair of terminals and find out what happens to the resistance between that pair of terminals when the knob of the variable resistor is turned in a particular direction, say clockwise. For each setting of the knob, students should record in their science notebook the resistances between terminals 1-2, 2-3 and 1-3. They should find that turning the knob will either increase/decrease the resistance between terminals 1-2/2-3, but the resistance between terminals 1-3 will be constant. This will allow students to construct a model for what is inside the ‘black box’ of a variable resistor.

The teacher can ask the following guiding questions to facilitate students to construct a model of a variable resistor.

* How did the resistance between terminals 1 and 2 change when you rotated the knob clockwise?
* How did the resistance between terminals 2 and 3 change when you rotated the knob clockwise?
* How did the resistance between terminals 1 and 3 change when you rotated the knob clockwise?
* How does the resistance between 1-2 and 2-3 relate to the resistance between 1-3?
* Based on what you know about combination of resistances in series and parallel, are the resistances between 1-2 and 2-3 in series or in parallel? Why?

Activity 2

Next, the teacher will pose an additional challenge to students. They will need to put together a circuit consisting of a variable resistor and a light bulb, such that they can change the brightness of the light bulb by changing the variable resistor. The teacher should emphasize that there are more than one way to do accomplish this goal.

As students work in groups during this activity, the teacher may circulate among the groups asking questions to help facilitate their thinking.

Possible questions include:

* What are your ideas?
* What were some similarities and differences that members of your group had?
* How are you creating your circuit?
* What ideas are you using to inform your design?

As students set-up their circuit and test it, the teacher may ask:

* What was your result?
* How might you improve your design?
* What were strength and weakness of your design?
* How might you explain why your design worked or did not work?

The goal is for students to recognize that a variable resistor can be connected in either series or parallel with a light bulb to influences the brightness of the light bulb. This goal will then lead to the next lesson in which a variable resistor can be used to change the speed of a pump in either of the two configurations: series or parallel.

Possible Guiding Questions:

* Can you find a way in which the variable resistor (say between terminals 1-2) is connected in **series** with the light bulb to make it bright/dim?
* Why do you think this configuration worked and caused the light bulb to appear bright/dim?
* Can you find a way in which the variable resistor (say between terminals 2-3) is connected in **parallel** with the light bulb to make it bright/dim?
* Why do you think this configuration worked and caused the light bulb to appear bright/dim?
* What if any, are the similarities or differences between the two circuit arrangements that used the variable resistor to change the brightness of the light bulb?
* Does either one of the two arrangements provide better control than the other in terms of controlling brightness of the light bulb?

**Lesson 5 – Design Challenge – Creating a Water Pump Circuit (*Application Phase*)**

Learning Goal:

The main goal of this lesson is to facilitate students to apply their understanding of a variable resistor and electric circuits (both series and parallel) to design an electrical circuit that can control the height and rate at which a water pump supplies water. The teacher should describe the appropriate units and unit conversions for the teacher and how to correctly calculate the flow rate and or measure the height.

The teacher will emphasize to students that there is no unique answer to this design challenge. In other words, they are not asked to determine a particular circuit that drives the pump to provide water at a particular flow rate at a particular height. Rather, students must be challenged to explore multiple design possibilities and record their observations for each in their science notebook.

The capstone assessment of this Lesson and the Unit as a whole is for students to compose a written user manual for the end user who will be using the electrical system to run the water pump. The user manual should use graphs and tables to provide the end user with information that would allow her/him to run the pump to supply water at different flow rates and different heights above the water trough, such that they can customize the circuit for their particular use.

Central Question(s)

* For a given amount of electrical power supplied to the pump, what is the relationship between the flow rate and head (i.e. the max height above the water level) at which the pump delivers water?
* How can you control the relationship between the flow rate and head at which the pump delivers water? (Hint: Think about the variable resistor)

Major Concepts

* There are two variables that determine the output of the water pump: *flow rate* (volume of water delivered per unit time e.g. gallons/minute) and *head* (height to which the water is delivered e.g. in feet). These two variables are inversely related in that if the flow rate is increased, the *head* decreases and vice versa.
	+ Students should understand this relationship and represent it on a graph of flow rate vs. head.
* The inverse relationship between flow rate and head is mediated by the electrical power that is provided to the pump. By increasing/decreasing the electrical power that is delivered to the water pump, it is possible to increase/decrease the maximum flow rate and head output of the pump.
	+ Students should understand that the electrical power, which in turn can be controlled by tuning the variable resistor in the electrical circuit can control the pump

Potential Misconceptions and Difficulties

There are no documented student difficulties or misconceptions with electrical water pumps. However, many of the misconceptions or difficulties with understanding series and parallel circuits will be relevant here. Also, any misconceptions regarding the variable resistor ‘black box’ may cause difficulties in the challenge.

Safety/Ethical Issues

In addition to the safety issues in Lesson 2 and 3, students should make sure that they are careful with using the submersible water pumps. These water pumps must be fully submerged otherwise they tend to overheat and will burn up. Further, although the pump is submersible, the electrical circuit that drives the pump should be kept away from water and should not get wet.

Materials

* 1 Battery (6V Lantern Battery)
* 6 Wires (with alligator clips on either end)
* 1 Submersible water pump (DC 1020, 5.5V – 12V, 1-3 W)
* 1 Tub in which the water pump is submerged
* 1 Meter long tubing that can be attached to the output nozzle of the pump
* 1 Variable Resistor (25 Ohms, 3W)
* 1 Multimeter
* 1 Measuring tape
* 1 Stop watch
* 1 Container to measure volume (e.g. beaker)

Activity 1

In the first activity students explore the relationship between the two output variables that characterize the performance of a water pump: *flow rate* and *head*. The teacher will not identify these variables for the students, rather the teacher will facilitate students to think about what might possibly be output variables that are relevant to the performance of the water pump in its currently envisaged application i.e. providing water to a hydroponic plant bed. Then the teacher will facilitate students to design and experiment to explore the relationship between *flow rate* and *head*.

The teacher can ask the following guiding questions to facilitate students to discover the two variables.

* When you design a pumping system to hydrate a hydroponic plant bed, what are some of the features of the system that you should attend to?

If the above guiding question does not help, the teacher may consider asking the questions below.

* Think about the type of plant that you are growing and its hydration needs. Does that have any bearing on how the water pumping system that you are designing?
* Think about the physical set up i.e. the height of the plant bed above the water trough. Does that feature have any bearing on the water pumping system that you are designing?

At this point students should have identified the flow rate and head as the two relevant parameters. The next task is for students to explore the relationship between them.

The teacher can ask the following guiding questions to facilitate students to explore the relationship between the two variables: *flow rate* and *head*.

* How can you measure the *flow rate* of the pump using the materials provided?
* How can you measure the *head* of the pump using the materials provided?
* How can you measure the relationship between the flow rate and the head?

Students will need to set up an electrical circuit with the battery and the pump. They will need to change the height of the output end of the tubing that is attached to the pump and at each head (height measure) the flow rate. They will record the flow rate for different heads (heights) in a table in their science notebook and make a graph of flow rate vs. head for this pump.

The graphs should be created by plotting the flow rate on the x-axis and the head on the y-axis. The graphs should be similar to the example plot seen in Lesson 1, and shown below:



Activity 2

The goal of this activity is to be able to control the speed and output of the pump using an electrical circuit. Students will have to think back about how they controlled the brightness of the light bulb using a variable resistor and use a similar circuit design to control the pump. There is no unique solution to controlling the speed of the pump, just as there was no unique way to use a variable resistor to control the brightness of the bulbs.

The teacher can facilitate students in their design process by asking the following guiding questions: You are asked to design an electrical circuit that controls the speed of the water pump.

* When else did you use an electrical circuit to control an output variable?
* What are your ideas?
* What were some similarities and differences that members of your group had?
* How are you creating your circuit?
* What ideas are you using to inform your design?

As students set-up their circuit and test it, the teacher may ask:

* What was your result?
* How might you improve your design?
* What were strength and weakness of your design?
* How might you explain why your design worked or did not work?

At this point students would have designed a circuit that controls the speed of the pump and its flow rate and head. To do so, they would have to adjust the variable resistor which in turn would affect the speed of the pump and its flow rate and head.

Next, they have to document the exact measurements of the flow rate and head for different settings of the variable resistor. So, they would set the variable resistor to a particular value and them move the output end of the tubing to different heights and measure the flow rate at each height. Then they would repeat this process by setting the variable resistor at a different value.

For each value of the variable resistor they would be able to construct a graph of flow rate vs. head, similar to that constructed in Activity 1 above. All of these graphs shown together would provide information to a potential end user of what the resistance value should be to achieve a particular head and flow rate.

Teachers can facilitate students’ writing of the user’s manual for the end user of the electrical pumping system. The user’s manual would contain:

* An introductory paragraph explaining the general set up of the system and what it does.
* A paragraph explaining the design process to the end user i.e. how to connecting the various components to create the system and the rationale for the design
* A diagram showing the submerged pump and how it supplies water to the plant bed above it. The head and flow rate should be labeled and defined for the end user as two important parameters.
* Circuit schematics showing how the variable resistor, battery and pump are connected together.
* A paragraph explaining the circuit schematics and how the circuit works to control the flow rate and head by changing the variable resistor.
* The flow rate vs. head graph displayed for different settings of the variable resistor on the same graph.
* A paragraph explaining the graph of flow rate vs. head for different settings of the variable resistor. The paragraph should also explain to the end user, with a concrete example of how they should fine tune the electrical circuit to achieve a particular desired flow rate and head based on the graph.