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| **Lesson Title : From Motor to Generator** | **Unit #:**  **1** | **Lesson #:**  **2** | **Activity #:**  **3** |
| **Activity Title: Design and build a generator from a small motor (CHALLENGE)** |

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| **Estimated Lesson Duration:** | **3 weeks** |
| **Estimated Activity Duration:** | **2 weeks** |

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| **Setting:** | STEM workshop & computer lab |

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| **Activity Objectives:** |

Students will design and build a small generator using the Engineering Design Process. In their write-up, they must be able to use Ohm’s law to explain how their generator works and use the multimeter to reverse-calculate the resistance of the motor from which their generator was built.

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| **Activity Guiding Questions:** |

* **What is electricity and what rules govern its behavior?**
* **How do batteries work?**
* **How does a generator work?**
* **What forms of energy might we harness to generate electricity?**
* **What are the parts of a generator?**
* **How does Ohm’s Law inform the design of a generator?**
* **What solutions already exist for portable generators?**
* **What causes heat in electrical systems?**

| **Next Generation Science Standards (NGSS)** | |
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| **Science and Engineering Practices (Check all that apply)** | **Crosscutting Concepts (Check all that apply)** |
| ☒ Asking questions (for science) and defining problems (for engineering) | ☒ Patterns |
| ☒ Developing and using models | ☒ Cause and effect |
| ☐ Planning and carrying out investigations | ☐ Scale, proportion, and quantity |
| ☒ Analyzing and interpreting data | ☒ Systems and system models |
| ☒ Using mathematics and computational thinking | ☒ Energy and matter: Flows, cycles, and conservation |
| ☒ Constructing explanations (for science) and designing solutions (for engineering) | ☒ Structure and function. |
| ☐ Engaging in argument from evidence | ☐ Stability and change. |
| ☒ Obtaining, evaluating, and communicating information |  |

| **Ohio’s Learning Standards for Science (OLS)** |
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| **Expectations for Learning - Cognitive Demands (Check all that apply)** |
| ☒ Designing Technological/Engineering Solutions Using Science concepts **(T)** |
| ☒ Demonstrating Science Knowledge **(D)** |
| ☒ Interpreting and Communicating Science Concepts **(C)** |
| ☒ Recalling Accurate Science **(R)** |

| **Ohio’s Learning Standards for Math (OLS) and/or**  **Common Core State Standards -- Mathematics (CCSS)** | |
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| **Standards for Mathematical Practice (Check all that apply)** | |
| ☒ Make sense of problems and persevere in solving them | ☒ Useappropriate tools strategically |
| ☒ Reason abstractly and quantitatively | ☒ Attendto precision |
| ☒ Construct viable arguments and critique the reasoning of others | ☒ Look for and make use of structure |
| ☒ Model with mathematics | ☐ Look for and express regularity in repeated reasoning |

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| **Unit Academic Standards (NGSS, OLS and/or CCSS):** |

* HS-PS2-5: Plan and conduct an investigation to provide evidence that an electric current can produce a magnetic field and that a changing magnetic field can produce an electric current.
* HS-PS3-2: Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motion of particles (objects) and energy associated with the relative positions of particles (objects).
* HS-PS3-3. Design, evaluate, and/or refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations, to convert one form of energy into another form of energy.
* HS-PS3-5. Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.
* 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.

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| **Materials**: |

* Small white boards (8 ea.)
* Dry erase markers (8 ea.)
* Small [electric motors](https://www.amazon.com/Nextrox-Mini-Torque-Electric-Motor/dp/B00BX54O8A/ref=sr_1_4?ie=UTF8&qid=1499389297&sr=8-4&keywords=small+electric+motor)
* Scrap building materials that could be used to construct crank handles or spinning wheels or cord-pullers
* Spool of [insulated wiring](https://www.amazon.com/RoadPro-RPCBH-25-Hardwire-Replacement-25-Feet/dp/B001JT1CEE/ref=sr_1_5?ie=UTF8&qid=1499389976&sr=8-5&keywords=insulated+wire), (75+ feet length total)
* Multimeters (8 ea.)
* [Crimp tool kit](https://www.amazon.com/LepoHome-Insulated-Terminals-Connectors-Assortment/dp/B071HJNXZ5/ref=sr_1_15?ie=UTF8&qid=1499389817&sr=8-15&keywords=insulated+wiring)
* Tools for shaping and assembly (e.g., pliers, saws, hammers, glue guns, soldering irons, etc.)
* [Electrical tape](https://www.amazon.com/Industrial-Grade-Electrical-Tape-10-Pack/dp/B01L37RSTY/ref=sr_1_18?s=industrial&ie=UTF8&qid=1499390128&sr=1-18&keywords=electrical+tape)
* Spool of [solder wire](https://www.amazon.com/Austor-0-8mm-Lead-Solder-Rosin/dp/B01M071WEE/ref=sr_1_20?s=industrial&ie=UTF8&qid=1499390203&sr=1-20&keywords=solder)

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| **Teacher Advance Preparation:** |

Confirm all motors work; organize materials so that they are easy to get and easy to put away.

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| **Activity Procedures:** |

1. This project is intense and will take the students a lot of time to complete; **a minimum of two weeks**, and likely longer. Safety must be reinforced daily with the tools (especially the soldering iron and the hot melt glue guns). Students will be tempted to waste insulated wire and connectors by crimping them absent-mindedly; do not set it out for them to freely access, but require them to submit an order for a specific length before you supply it. Only set up one soldering station to allow for meaningful supervision (a TA would be great here; if a TA is not available, have students submit work orders for soldering and schedule times when it can be supervised).
2. Students should already be familiar with Ohm’s law. They will use it to determine how to convert a motor into a generator. Each team will have to draw a diagram on their white board (formative assessment) showing what they believe to be the internal structure of the motor (including motors). They must label the anticipated flow of electrons through the system.
3. Upon achieving this milestone, they should open the EDP template in Google Assignment and work as a team to define the problem.
4. After achieving this milestone (stating **Who** needs **What** problem solved and **How badly** do they need a solution?) they must build a list of requirements and constraints, treating the teacher as the focus group representative for determining consumer needs.
5. They may bounce back and forth between research and defining requirements, or they may complete these steps in sequence, depending on their comfort with the material thus far
6. Groups that have completed the “Define the Problem” and the “Research” steps of the EDP (and have received milestone credit in the gradebook for doing so) may brainstorm options.
7. After brainstorming, students should score their options against the requirements and constraints and be able to show a rubric they developed to facilitate this ranking. Students will turn in their rubric and results for a grade. **NOTE: This is the stage where students will come up with multiple solutions to address the problem of how to manually drive a motor in reverse. The post has to spin, but there are many ways of making it do so: crank lever, pull-rope, spinning wheel, ratcheting, camming, etc. By 3D printing the connection piece, their design will commit to one of those options.**
8. Teams should design a locking lever to sleeve over the post of the motor so that it can be turned manually. This design must be based on the solution they chose (e.g., crank handle, wheel, spool, etc.) [Originally, this step was intended to be a subunit on 3D modeling using software; although as a class we spent a few days on this, in the end it was clear that the tolerances needed for the activity exceeded the tolerances of the software we were using to design the locking levers. Instead, we simply used the brass collars that came with the motor mounts and the students hand-crafted levers and spools and and crank handles and pull-cords and belt drives and twist knobs (depending on their specific designs) to operate each dynamo. No parts were 3D printed.]
9. Teams should then build their first prototype using the materials available. Students who wish to supply their own raw materials to supplement class supplies are welcome to do so, but no pre-made assemblies are permitted other than the motor itself.
10. As soon as students have a prototype ready to test, provide them with a multimeter and have them collect video of the results. They should use the video to determine peak current achieved by their design.
11. Students who have tested their prototype should be challenged to determine the resistance value of the original motor. They should be left to puzzle out on their own how to calculate this using Ohm’s law and the multimeters, but they must show their work on their whiteboard for a milestone credit in the gradebook. They must also record all calculations in their EDP, under “Test the Prototype,” along with their observations (how were the ergonomics of their build? How well did the device hold up under use? Were there any surprises during testing?)
12. As a team they should discuss their data and write up their conclusions, along with suggestions for refinement/improvement (which will be undertaken as Activity 4, along with making the marketing video). [Due to a problem with the high torque of the motors we used, students had to spend an exorbitant amount of time just getting devices to spin; in the interests of time we did not make the marketing videos. In the future, we plan to swap out these motors for lower-torque models so that we will still have time to make the marketing videos.]

**Formative Assessments:**

1. Motor-to-generator diagram with labels
2. A fully-defined problem, including requirements and constraints
3. Documented research, including videos, pictures, and text of hand-holdable generators/dynamos.
4. Screen capture of multimeter showing peak amperage

**Summative Assessments:**

1. A functioning locking lever (does it fit the motor spindle?)
2. Ohm’s law calculations showing the resistance of the original motor.
3. Conclusion paragraph of EDP, including multiple recommendations for refinement (at least one of which must be a credible way to improve current output of the device)

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| **Differentiation:** |

This activity allows students to **learn at their own pace** and to repeat steps as needed to achieve satisfactory performance. In addition, students are provided with **various ways to show what they know** regarding the targeted content, with formative assessments (and feedback) leading toward summative assessments in a logical progression that **allows for failure as part of the learning process**. Students can work **abstractly** to design their device purely through sketching or they may describe their ideas using objects in the room (**kinesthetically**) to illustrate each component they plan to construct. There are opportunities for **collaborative** and **solo** work, and there are multiple options for solving the same problem.

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| **Reflection:**  *After the activity is taught, reflect upon the successes of teaching this Activity in 5 or more sentences. Include a description of what Differentiation strategies worked and what should be changed – justify by presenting evidence and results.*  As noted above, this activity ran into multiple problems, the biggest of which was that the torque of the motors was too high. Due to that torque, only one of the 7 designs in the class was able to turn the spindle on the first iteration, and three of the teams were still unable to turn the spindle even on their second iteration. The most successful design (a hand-crank built from dowels and a compact disc) broke multiple times due to the torque of the spindle. Students became frustrated, and they were almost universally unhappy with their products. I am convinced that nearly all of the frustration stemmed from the torque of the motors. Another teacher in my school (Andrew Bridges, a CEEMS participant) is currently running this unit with his STEM 3 class; once he has finished running through it we will confer and refine the lesson for next year, comparing his class experience with my class experience. |