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IMPLEMENTING HANDS-ON ACTIVITIES AND ONLINE SIMULATIONS TO MIDDLE SCHOOL CURRICULA: ELECTRIC CIRCUITS

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Implementing Hands-on Activities and Online Simulations to Middle School Curricula: Electric Circuits

Synopsis:

The combination of in class experiments with computer simulations is an excellent cost and time effective way of teaching middle school electric circuits, as well as many other required topics in physics.

Implementing Hands on Activities and Online Simulations to

Middle School Curricula: Electric Circuits

This work reflects on the results obtained from a collaborative project between the local city public school system and the local university as part of the grant Making Connections: Preparing Teachers to Integrate STEM. The program developed in 2016 was designed to support mathematics and science teachers to improve their institutional skills and to help them integrate STEM in their classrooms. Institutional knowledge was provided by faculty from the College of Engineering in collaboration with the public school math and science specialists as part of their effort to advance STEM integration into city public schools. Part of this program was a 10 days summer institute specially designed for the 7^{th} and 8^{th} grade teachers covering the state required technical content for these grade levels, including Properties of Matter, Energy (including Thermal Energy and Phase Transformations), Electrical Circuits and Electromagnetism, Forces, and Motion. A combination of hands-on activities developed by the authors coupled with online available simulations applicable to 7^{th} and 8^{th} grade level was presented and tested during the summer institute. This professional development experience culminated with STEM instructional units developed by the participant teachers in collaboration with the school district mathematics and science representatives.

According to the Next Generation Science Standards[1], MS-PS2-3 , the students should be able to determine the factors that affect the strength of electric forces. Similar, according to the Ohio New Learning Standards[2], part of the model curriculum for grade 7^{th} is the concept that the electrical energy transfers when an electric source is connected in a complete electrical circuit to an electrical device.

According to Ohio Learning Standards[2], “An electric circuit exists when an energy source (e.g., battery, generator, solar cell) is connected to an electrical device (e.g., light bulb, motor) in a closed circuit. The energy source transfers energy to charges in the circuit. Charges flow through the circuit. Electric potential is a measure of the potential electrical energy of each charge. Differences in voltages can be measured with a voltmeter. … Current is the rate of charge flow through conductors and can be measured with an ammeter. The degree to which current is opposed in a circuit is called resistance. Generally, for a particular energy source, the greater the resistance, the lower the current. The resistance through a wire depends upon the type of metal, the length of the wire and the diameter of the wire. …Testing and experimenting (3-D or virtually) with electrical circuits to evaluate the energy transfers, resistance, current and changes in voltage are required”.

At this grade level (7th), the students are already familiarized with the following concepts [2]:

1) Grade 3: “Heat, electrical energy, light, sound and magnetic energy are all forms of energy”
2) Grade 4:
   - “Electrical conductors are materials through which electricity can flow easily. Electricity introduced to one part of the object spreads to other parts of the object (e.g., copper wire is an electrical conductor because electricity flows through the wires in a lamp from the outlet to the light bulb and back to the outlet)”
   - “Electrical conductivity must be explored through testing common materials to determine their conductive properties”
   - “In order for electricity to flow through a circuit, there must be a complete loop through which the electricity can pass. When an electrical device (e.g., lamp, buzzer, motor) is not part of a complete loop, the device will not work. Electric circuits must be introduced in the laboratory by testing different combinations of electrical components. When an electrical device is a part of a complete loop, the electrical energy can be changed into light, sound, heat or magnetic energy. Electrical devices in a working circuit often get warmer”
3) Grade 6: “Electrical energy is associated with the movement of electricity through the wires of an electrical device”

The current work focuses on the authors’ experience to improve 7th grade student’s knowledge regarding Electrical Circuits through a combination of both hands-on activities and online available simulations. Our results show that a combination of in-class hands-on experiments coupled with computer simulations is an excellent cost and time effective way of teaching electric circuits, as well as many other required topics in physics. The instructional activities proposed herein and detailed in Table 1, focus on identifying the factors that affect the resistance in a wire. The authors reflections performing such activities at a local school, as well as some of the students’ results are also included.

<u>Investigation 1: Wire Type and Electric Resistance</u>

The students were provided with 1-meter long sections of 18-gauge wire of different materials. The wire types tested were aluminum, brass, copper, nichrome, and steel. The students performed the experiment using a LabQuest2[3] with a Vernier energy sensor [4] to measure the current and potential of each type of wire. A power supply (set at 2A, 0.03V) was used as the source of electric energy. The students recorded data for 30 seconds and used the statistical functions of the LabQuest2 to find the mean current and mean voltage for the last five seconds of data collection. An example of the experimental set-up and students taking measurements are presented in Figure 1.

Table 1: Instructional Activities – Electrical Resistance Unit

Day	Topic
1: Introduction to Unit	pre-assessment
	learning targets
	real world connections
	connections to previous learning (charges, complete circuits)
	new electricity vocabulary (voltage, current, resistance)
	demonstration of experimental procedures.
2: Wire type and electric resistance investigation	data collection – hands on experiment
3: Wire type and electric resistance investigation	data analysis
	comparison of results
	lab reports
4: Area of a wire and electric resistance investigation	data collection – online simulation
	data analysis
	lab reports
	comparison of results
5: Length of a wire investigation	data collection – student choice of hands on or online simulation
	data analysis
	lab reports
6: Length of a wire investigation - analysis	comparison of results
	post assessment

The Students completed a lab report, in the form of a *Four-Square Lab Report* document, as presented in Appendix 1.

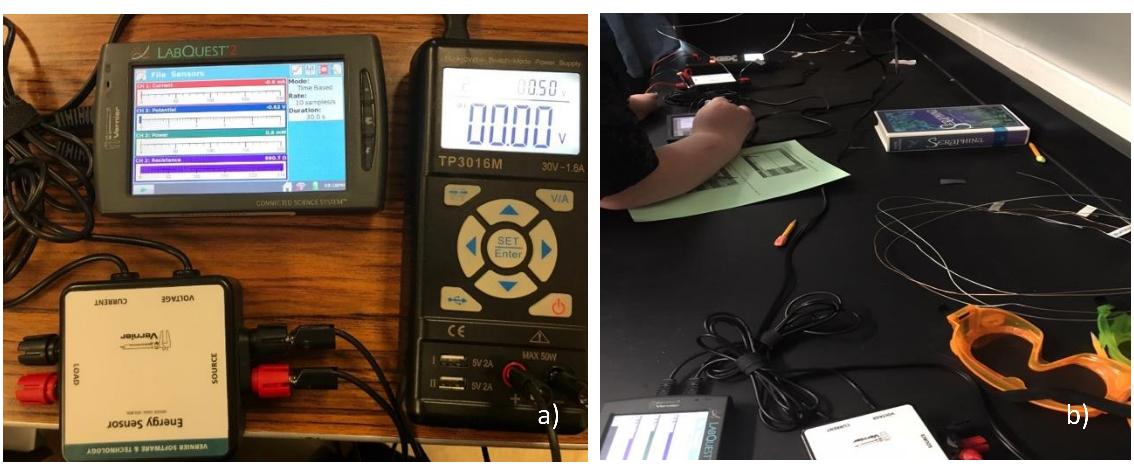


Figure 1: Experimental Set-up (a) and Students Taking Measurements (b)

An example of the data collected by the students is presented in Table 2. All student groups found that nichrome had the highest resistance compared to the other types of wire. Two groups found that copper had the lowest resistance and two groups found aluminum to have the lowest resistance. Considering the similarity in expected resistance values for these two types of wire (aluminum 0.03Ω and copper 0.02Ω), as well as the limited number of trials, the results were not unexpected. What was unexpected is the fact that group 1 and group 3 had surprisingly high resistance values for aluminum. This experimental error may be due to the fact that students tested aluminum wire first and their unfamiliarity with the experimental procedure may have led to human error in the initial experimental set-up. Group 2 found brass to have the lowest resistance. It is worth noting that this group had higher values for most types of wire compared to the rest of the class. This may indicate a source of error in their experimental procedure such as not successfully zeroing the probe at the start of the experiment or human error in the way they connected the wire to the energy sensor. The students also discussed that scientists arrived at the expected values because of many trials not just few as done in the classroom. The students also noted how similar some of their test results were to the expected results.

Table 2: Students Collected Data

	Group 1	Group 2	Group 3	Group 4	Group 5	Expected results
Aluminum	.85	.16	.85	.08	.01	.03
Brass	.81	.10	.11	.11	.11	.11
Copper	.02	.16	.02	.11	.06	.02
Nichrome	1.52	4.53	1.36	1.36	1.01	1.4
Steel	.58	.80	.58	.14	.07	.76

Upon conclusion of the lab and the comparison of classroom results, the students finalize the experimental activity by adding a claim to their lab reports, claim detailing what they learned about electric resistance of different types of wire. Samples of the students' claims are presented below:

- "Nichrome has the highest resistance"
- "Nichrome has a higher resistance compared to the other wires"
- "I learned the highest wire is the nichrome and copper is the lowest"
- "All the wires have different resistance"

Reflections:

1. The voltage setting on the power supply had to be kept low because the power supply has a shut off mechanism that is triggered when a short circuit is detected. The experimental procedures were tested on three different occasions prior to the lesson and it was determined that the ideal power supply settings were 2A for the current and 0.6V for the potential. At these settings the power supply did not shut down during the test of the copper wire. When

in classroom, the 0.6V setting caused the power supply to shut down; consequently, a potential of 0.3V was selected for all measurements.

2. Students performed the laboratory procedures proficiency, especially considering that this was their first time using the LabQuests. Two of the six groups had some initial trouble collecting data because of their caution with the equipment. Some students were concerned about damaging the wires or the energy sensor so they did not tighten the cap on the binding post enough to establish a good connection between the energy sensor and the wire and consequently the LabQuest did not generate usable data. The students were able to recognize that their data was not usable and requested assistance.
3. The students struggled to correctly calculate resistance. The LabQuest reported the potential in volts and the current in milliamps. To determine the resistance in each type of wire, the students were required to first convert the current from milliamps to amps and second to divide the voltage by the current to calculate the resistance. The steps were shown in class and there was an example on the laboratory worksheet, but even with these supports, the students made multiple mistakes mostly related to decimal placement when converting from milliamps to amps and calculating the resistance. Ohio's Learning Standards expects students to develop a conceptual understand of the relationship between current, electric potential and resistance and are not required to use Ohm's Law or other mathematical calculation of electricity until high school. Given the students struggles and the expectations of the standards, it is recommended for the future to allow students to use online Ohm's Law calculators [5], to determine the resistance from their experimental data. Mathematical calculations can be used as an extension for higher performing students.
4. Some students struggled to complete the bar graphs that were on the lab report. Given the size of the graph, the scale of the graph, the small numbers (less than 0.10 Ω), and the students' understanding of decimals, the students struggled to accurately represent their data on the small bar graph. To improve the graph representation, a new graph, paper size, was created and presented to the students the following day. The students had the option to create their bar graphs on the larger graph paper or use the smaller graph paper that was on their lab report. 100% of the students choose the larger graph paper and were much more successful in accurately representing their experimental results.

<u>Investigation 2: Area of a Wire and Electrical Resistance</u>

This investigation can be done either as a hands-on activity, using the same experimental setup as that described in Investigation 1 and wires of different areas, or as online simulation, as described below.

The authors used the *Resistance in a Wire – Phet Interactive Simulation* [6] for this activity. In this online simulation, the students have the opportunity to adjust any of the resistivity, length, and area of a wire and to observe how these parameters affect the resistance, see Figure 2. The students were asked to keep the resistivity and length settings at the default values of 0.50Ωcm and 10cm, to change the area of the wire, and to record the associated resistance as reported by the simulation. They have the option of working with a partner or by themselves, and the majority chooses to work alone. The students were asked to complete a lab report to communicate the results of the investigation. A *four-square lab report* for this activity is presented in Appendix 2. This lab report works well for the hands-on experiment as well.

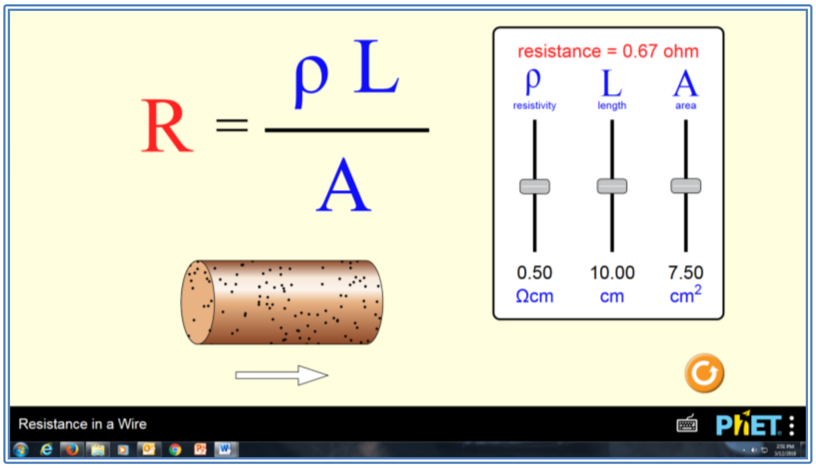


Figure 2: Resistance in a Wire[6] (Screenshot)

Table 3 shows the resistance data gathered by one of the students, while Figure 3 graphs the collected data. All students found that as the area of the wire increases, the resistance of the wire decreases.

Table 3: Student Data - Area

Area (cm^2)	Resistance (Ω)
0.32	15.7
1.01	4.95
1.93	2.59
3.01	1.66
5.32	0.94
6.24	0.80
7.47	0.67
15.0	0.33

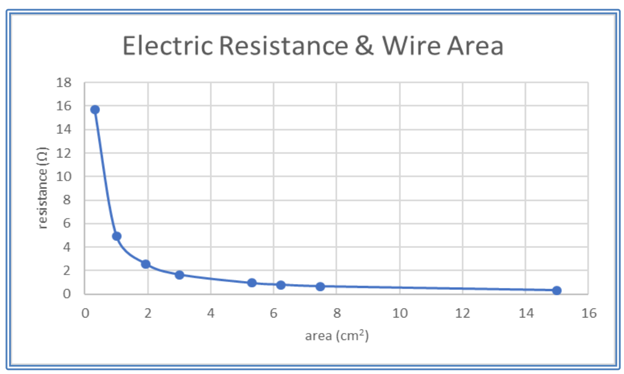


Figure 3: Graphical Representation of the Data - Area

Upon conclusion of the lab and the comparison of classroom results, the students added a claim to their lab report describing what they learned about the relationship between the area of the wire and electric resistance. Samples of the students' claims are presented below:

- "The bigger the (area of the) wire, the lower the resistance"
- "The thicker the easier (for electricity) to go through the thinner the harder (for electricity) to go through"

Reflections:

1. The students were finished with their data collection in about 10 minutes. This is compared to the approximately forty-five minutes it took students to collect data with the LabQuest2 and wires. The efficiency of the lab is an advantage when educators do not have much time for data collection.
2. The online simulation can easily be completed by an individual student in an efficient manner. The procedures of the hands-on lab are most efficiently done when a team of students works together. When the students work in teams they tend to talk about their observations and results. These conversations likely result in a deeper processing of the data.
3. The students do not need to worry about sources of error in the online simulation. This allows the student and teacher to have a high level of confidence in the accuracy of the results. The nature of the hands-on lab requires students to be thoughtful about the reliability and validity of the experimental results. This increased consideration means the students are engaging with the data at a deeper level than when they collect data using an online simulation.
4. The online simulation reported the resistance values directly to the students. There was no need to calculate resistance which was a source of frustration and errors for students in the previous lab.
5. Considering that the students struggle with graphing small numbers in the previous lab, the students were provided with the option to graph the data using the small grid on the lab report or a larger graph (paper size). All but three of the students choose to use the large graph paper to graph their data.

Investigation 3: Length of a Wire and Electrical Resistance

This investigation can be done either as a hands-on activity, using the same experimental setup as that described in Investigation 1 (using LabQuest2, Vernier energy sensor, Voltmeter) and wires of different lengths, or as online simulation, using the same online simulation as presented in Investigation 2 (see Figure 2).

The students using the PhET simulation were asked to use the default values of 0.50Ωcm for resistivity and area of 7.50cm^2, to change the length of the wire, and to record the associated resistance as reported by the simulation. The students using the LabQuests2 hands-on experiment tested various lengths of nichrome wire following the same procedure as described in Investigation 1. A *four-square lab report* as presented in Appendix 3 is used and recommended for the online simulation activity, while a *four-square lab report* as presented in Appendix 4 is used and recommended for the hands-on experimental activity.

Table 4 and Figure 4 show the resistance data gathered by one of the students from the PhET simulation. All student groups who used the PhET simulation found that as the length of the wire increases, the resistance of the wire increases.

Table 4: Student Data – Wire Length

Length (cm)	Resistance (Ω)
.10	.01
1.02	.06
4.65	.28
6.39	.39
7.92	.48
9.25	.56
10.78	.66
12.41	.76
18.34	1.12
20.00	1.22

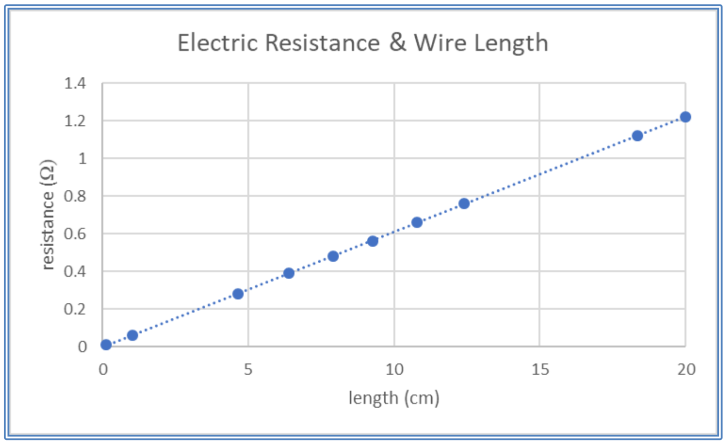


Figure 4: Graphical Representation of the Data – Simulation

Table 5 and Figure 5 show the resistance data gathered by one of the student groups from the hands-on lab. The trendline shows that resistance increases as the length of the wire increases.

Table 5: Student Data – Wire Length

Length (cm)	Resistance (Ω)
10	0.12
20	0.28
30	0.38
40	0.65
50	0.65
60	1.15
70	.009
80	1.17
90	1.27
100	1.43

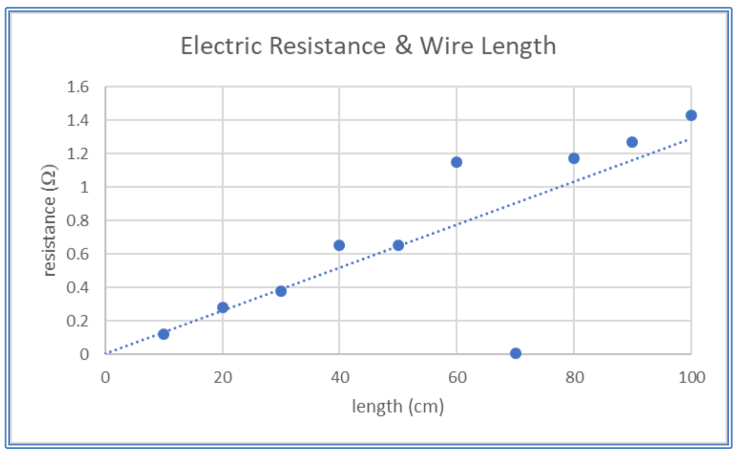


Figure 5: Graphical representation of the data – Hands-on

Upon conclusion of the lab and the comparison of classroom results, the students added a claim to their lab report, explaining what they learned about the relationship between the length of the wire and electric resistance. Below are samples of students' claims:

- "The longer the wire, the greater the resistance"
- "It is easier for electricity to go through a short wire"
- "longer length = more resistance"
- "More length means more resistance"

Reflections:

1. The students choosing the online simulation finished with their data collection in about 10 minutes, vs. 35 minutes to complete the data collection by using the hands-on investigation. The authors recommend that if a teacher plans to offer the students to choose between hands-on and online simulation, there should be an additional activity planned for the students who choose the online option, like an online program that improves their technology and typing skills.
2. All the students who chose to do the online simulation worked individually.
3. The students who used the online simulation did not need to worry about sources of error. All the students who did the hands-on investigation had at least one data point that did not seem to fit the trend which indicated experimental error. Even with the presence of this experimental error, the general trend in the data allowed students to observe that resistance increases as the length of the wire increases.
4. Giving the students the option of using an online resistance calculator allowed students to focus on the trends in the data and not be distracted or frustrated with the mathematics.
5. A large graph paper was available to students, but surprisingly, majority of them used the small grid that was included on the four-square lab report. This shows that these experiences improved the students comfort and proficiency with graphing small numbers.

Data Analysis

To determine the content knowledge of the students, a pre-and post-assessment were administered. Since the authors were interested in evaluating the students' knowledge gained from participation in these investigations and not from test preparation and memorization, the students were not given the chance to study or prepare for the post assessment test. A comparison of pre- and post- test results show that students made significant gains in content knowledge related to electrical resistance because of their participation in the investigations.

Table 6: Pre- and Post- Test Data

	Pre-test (%)	Post-test(%)	Comparison pre vs. post	
Mean	26	63	Increase:	+37%
Median	20	62.5	Percent Increase:	142%
Mode	20	50		
Minimum	10	30		
Maximum	50	90		

Comparison of content knowledge for hands-on vs. online learning for different concepts

The students investigated the resistance of different types of wire with a hands-on experiment, while the relationship between electrical resistance and area of a wire was investigated using an online simulation. The pre-test and post-test results were analyzed to compare the change in students' content knowledge if using hands-on vs. online science investigations.

The post test results show students performed equally well on electrical resistance content for the type of wire (hand-on investigation) and the area of a wire (online simulation investigation) with a post-test average of 62% for questions related to the type of wire and 62% for questions related to the area of a wire, see Table 7 and Figure 6. Students showed a greater overall increase (pre-test to post-test) in content knowledge gained from the hands-on investigation with a change of +47% for questions related to the type of wire and +31% for questions related to the area of a wire.

Table 7: Comparison of Change in Content Knowledge Based on the Type of Investigation

Hands-On Science Investigation (electrical resistance and type of wire)		
Pre-test data	Post-test data	Comparison pre- vs. post-test
Mean – 15%	Mean – 62%	
Median – 0%	Median – 50%	Increase +47%
Mode – 0%	Mode – 100%	Percent Increase 313%
Minimum – 0%	Minimum – 0%	
Maximum – 100%	Maximum – 100%	
Online Simulation Investigation (electrical resistance and area of a wire)		
Pre-test data	Post-test data	Comparison pre- vs. post-test
Mean – 31%	Mean – 62%	
Median – 33%	Median – 66%	Increase +31%
Mode – 33%	Mode – 100%	Percent Increase 100%
Minimum – 0%	Minimum – 0%	
Maximum – 100%	Maximum – 100%	

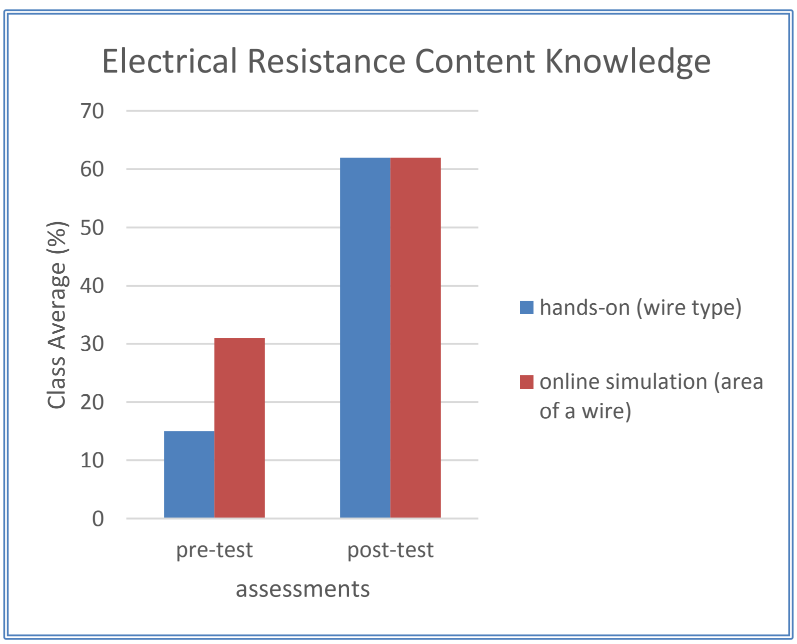


Figure 6: Content Knowledge Gained by Different Modes of Investigation

Comparison of content knowledge for hands-on vs. online learning for the same concept

As presented in Table 1, days 5 and 6 of this electrical resistance unit of study were dedicated to investigating the effect of length of a wire on electrical resistance. The students had the opportunity to investigate this topic using either the PhET online simulation or the hand-on experiment using various lengths of nichrome wire, a LabQuest2 and a Vernier energy sensor.

The pre-test and post-test results were analyzed to compare the change in content knowledge of students who chose the online investigation vs. students who chose the hands-on investigation. Out of a class of 18 students, seven students chose to do the hands-on investigation, while the remaining chose to use the online simulation.

The students who chose each type of investigation performed similarly on the pre-test with both groups of students averaging 50% (see Table 8). The students who did the hands-on investigation showed an increase in content knowledge related to the length of a wire and electrical resistance, while the students who used the online simulation showed a slight decrease (-7%). It is worth noting that students performed much better on pre-test questions related to the length of the wire (50%) compared to questions related to the area of a wire (31%) and type of wire (15%). This explains why the increase in content knowledge related to the length of a wire (+17%, -7%) is smaller than the increases in content knowledge resulting from the area investigation (+31%) and the type of wire investigation (+47%).

Table 8: Comparison of Change in Content Knowledge Based on the Type of Investigation

Hands-On Science Investigation (electrical resistance and wire length)		
Pre-test data	Post-test data	Comparison pre- vs. post-test
Mean – 50%	Mean – 67%	
Median –50%	Median – 50%	Increase +17%
Mode – NA%	Mode – 50%	Percent Increase 34%
Minimum – 0 %	Minimum – 50%	
Maximum – 100%	Maximum – 100%	
Online Simulation Investigation (electrical resistance and wire length)		
Pre-test data	Post-test data	Comparison pre- vs. post-test
Mean – 50%	Mean – 43%	
Median – 50%	Median – 50%	Increase -7%
Mode – 0%	Mode – 50%	Percent Increase -14%
Minimum – 0%	Minimum – 0%	
Maximum – 100%	Maximum – 50%	

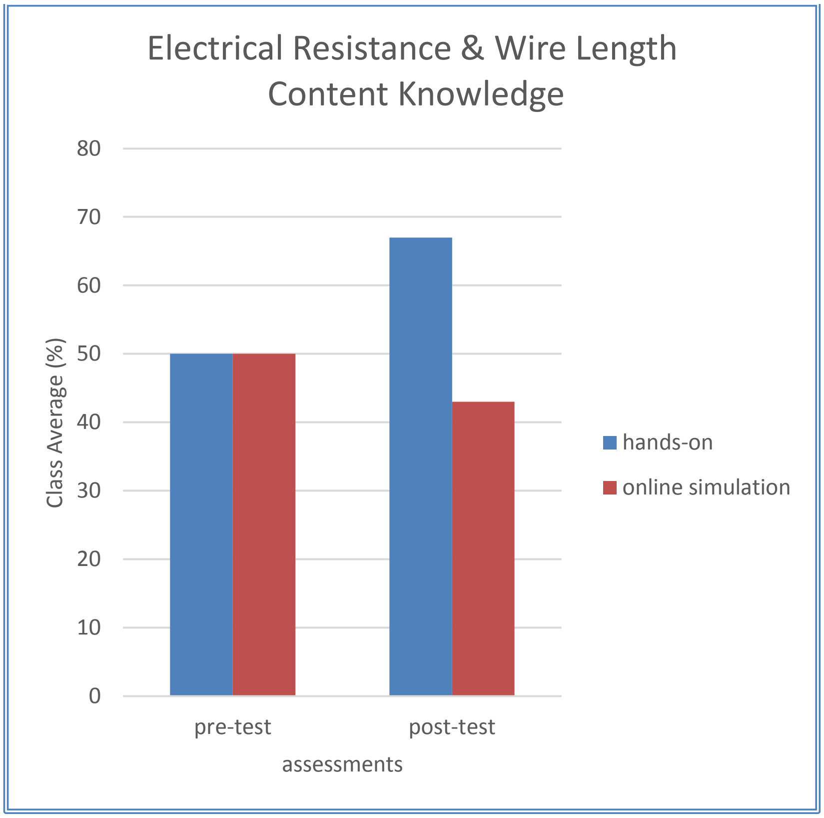


Figure 7: Content Knowledge Gained by Different Modes of Investigation

From Figure 7, it is visible that the students who chose to investigate the length of wire effect on the electric resistance using the hand-on investigation showed a greater increase in content knowledge compared to the students who choose to do the online investigation.

It is worth noting that the day the length of a wire investigation was performed there were few school events that could have affected the students focus: first day of spirit week, crazy hair day, ALICE drill (intruder emergency preparedness drill), and the upcoming Spring break.

Conclusion

The proposed instructional activities described herein proved the benefits of using hands-on experiments and online simulation to increase the students' knowledge content regarding electric circuits. These instructional activities were excellently received by the students. One student who enjoyed the hands-on investigation proclaiming that, "This is fun! If this is what engineers do, I am going to be an engineer when I grow up." Similar, the students' teacher liked the blend of online and hands-on activities, especially since it is good for students to be exposed to different methods of data collection. Furthermore, our results show that both the online simulations and the hands-on activities are effective ways for the students to build background knowledge.

References:

[1] https://www.nextgenscience.org

[2] http://education.ohio.gov/Topics/Learning-in-Ohio/Science

[3] https://www.vernier.com/products/interfaces/labq2/

[4] https://www.vernier.com/products/sensors/energy-sensors/ves-bta/

[5] https://www.rapidtables.com/calc/electric/ohms-law-calculator.html

[6] https://phet.colorado.edu/sims/html/resistance-in-a-wire/latest/resistance-in-a-wire_en.html

Appendix 1: Wire Type Investigation

Resistance in a Wire   Wire Type

Purpose & Variables

Purpose -

Independent Variable -

Dependent Variable -

Constant Variables –

Data Table

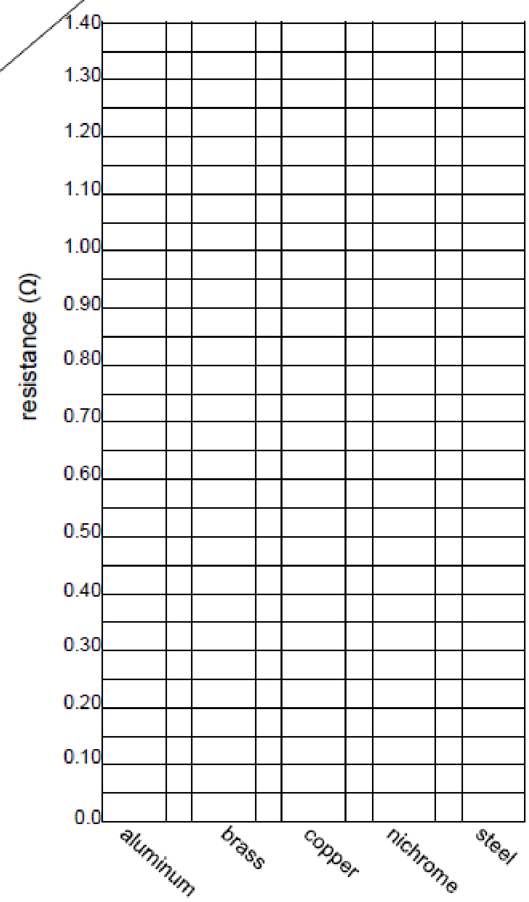
type of wire	Voltage (V)	Current (mA)	Current (A) Current in mA ÷1000	resistance (Ω)
	from LabQuest	from LabQuest	Current in mA ÷1000	Voltage ÷ Current A
example	*0.63*	*729*	*729 ÷1000 = 0.729*	*0.63 ÷ 0.729 = 0.864*
aluminum				
brass				
copper				
nichrome				
steel				

Claim

Diagram

List the wires we tested in order from least to most resistance.
Label your diagram.

Graph



Appendix 2: Resistance in a Wire: Area Investigation

PhET – Resistance in a Wire   Area Investigation

Purpose & Variables

Purpose -

Independent Variable -

Dependent Variable -

Constant Variables –

Data Table

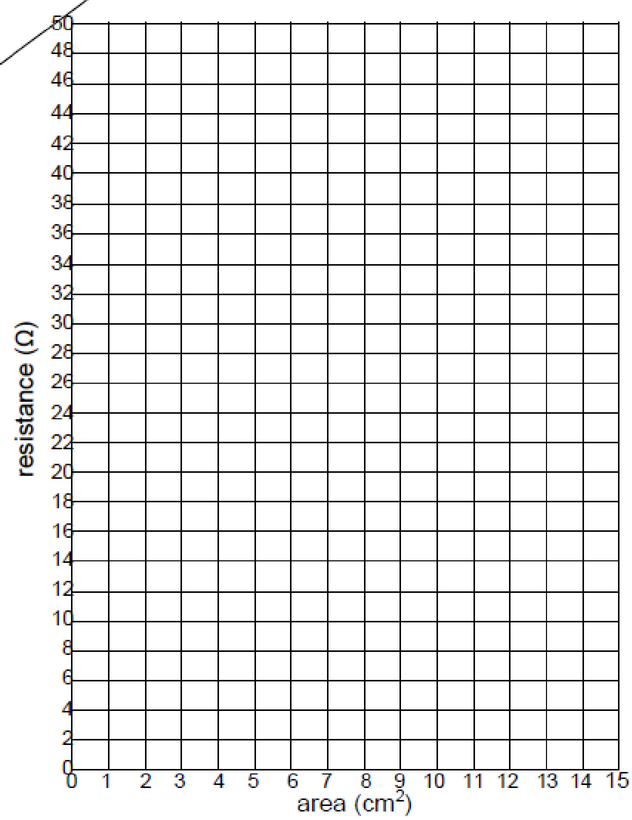
area (cm^2)	resistance (Ω)

Claim

Diagram

Draw a wire with an area that would result in high resistance and a wire with and area that would result in low resistance. Label your diagram.

Graph



Appendix 3: Resistance in a Wire: Length Investigation – Online Simulation

PhET – Resistance in a Wire   Wire Length Investigation

Purpose & Variables

Purpose -

Independent Variable -

Dependent Variable -

Constant Variables –

Data Table

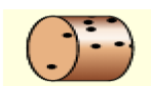
length (cm)	resistance (Ω)
0.10	
20.00	

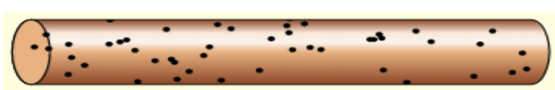
Claim

Diagram

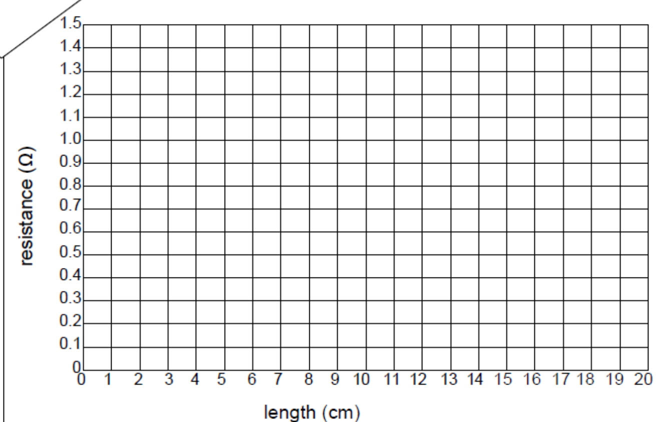
Place the correct label under each wire.

High Resistance   Low Resistance





Graph



Appendix 4: Resistance in a Wire: Length Investigation – Hands-on

Hands On – Resistance in a Wire   Wire Length Investigation

Purpose & Variables

Purpose -

Independent Variable -

Dependent Variable -

Constant Variables –

Data Table

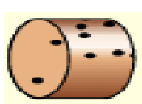
length (cm)	Voltage (V)	Current (mA)	resistance (Ω)
	from LabQuest	from LabQuest	from Website
10			
20			
30			
40			
50			
60			
70			
80			
90			
100			

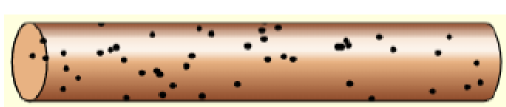
Claim

Diagram

Place the correct label under each wire.

High Resistance   Low Resistance





Graph