STEAM Lesson: Doughy Circuits

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This lesson seeks to engage a wide range of students with an inquiry into conductivity and conduction within circuits by utilizing conductive and non-conductive dough, light-emitting diodes (LED), resistors, and a power source so students can create dynamic sculptures using light, color, and electricity melding physics concepts with the six elements of art, and design engineering: line, shape, forms, space, color, texture and engineering efficiency (J Paul Getty Trust, 2011) (see Fig. 1-8). As mentioned in the Lesson Extension portion of this paper, more time, and increased student and instructor capabilities can incorporate chemistry, digital technology, and various levels of sophisticated mathematical circuit analyses.

The key to science, technology, engineering, arts, mathematics lesson (STEAM) is that the activity "is about integration and bringing all the pillars together to work as a whole, rather than as independent subjects" thus facilitating transdisciplinary, and transferable skillsets while still meeting the goals of one's particular subject if the class is not STEAM specific (Shelley, 2020, para. 5). Shelly (2020) suggests instructors should first brainstorm with students, or independently, on how one's specific curricular objectives can incorporate other multidisciplinary learning goals, then investigate and apply the overlapping ideas to create a lesson, which when complete, requires assessment for future improvements.

The lesson has been improved upon by the author over four years of trials with physics cohorts. Doughy circuit activities potentially incorporate physics electromagnetism concepts with art, design, mathematics, chemistry, electrical engineering, and ICT, depending on the instructor's scope and sequence. This lesson is the hour-long condensed version with a focus on the fundamental physics of circuits and creative artistic design to be completed in one class period. Having the students spend more time investigating the chemistry of conducting vs.

nonconducting dough, utilizing software to plan and engineer circuit diagrams and artistic models, creating a robust report for presentation with data-collection and calculations, and experimenting more with the recipes for conductivity are fantastic extensions if one has the bandwidth.

Context and Target Group

The doughy circuit lesson is an appropriate plan for Grade 9 to Grade 11 students of any STEAM subject area, with art, design, chemistry, engineering, and physics students as the more apparent natural target groups. The author has utilized various manifestations of this activity for his Grade 10 IGCSE physics students, and Grade 11-12 A level learners exploring electromagnetism and circuits, increasing the complexity based on the requirements in the physics syllabus and the capabilities of the students. The plan detailed here has a focus on Grade 10 IGCSE physics students.

The core assignment requires a rudimentary understanding of electricity and basic concepts around series and parallel circuits as per introductory electromagnetism Unit Chapters 9-12 in Sang (2014) or comparable preparatory materials to fully experience the course objectives. A less analytical, more qualitative than quantitative inquiry is possible for younger students, or even non-physics students in art or design courses wishing to incorporate STEAM into their practice.

Low to High-Level Transdisciplinary Objectives – IGCSE and Bloom's Taxonomy

Optional core Objectives from the IGCSE Physics syllabus Cambridge International Examinations (2020) of Safety in the Laboratory – Dangers of Electricity and Electromagnetism and Electrical Quantities and Circuits are detailed in Table 1 in the Tables section at the end of the paper.

STEAM lessons expand significantly on the curricular requirements of IGCSE physics, and similar curriculum, while meeting those requirements. The following transdisciplinary objectives are vital for crafting rubrics useful for formative and summative assessments by the instructor or students, utilized for learner self-assessment and peer assessments. Bloom's taxonomy informs and provides the structure for these objectives spanning the cognitive, affective and psychomotor domains with increasing levels of complexity; levels from low to high include *Remember*, *Understand, Apply, Analyze, Synthesis*, and *Evaluation* along with action phrases also in italics (Kasilingam, Ramalingam & Chinnavan, 2014).

- Students will *Remember* and *Understand* key physical concepts related to the IGCSE physics syllabus in Table 1, on Safety in the Laboratory and Electromagnetism.
- Learners *Apply* and *Synthesize* these physical concepts in a *creative, artistic, collaborative,* and *transdisciplinary* manner by *sculpting beautiful* luminescent objects that also demonstrate the physical laws governing circuits in their syllabus according to a *plan*.
- Students must *Analyze* and *problem-solve* issues around *creating* a complete circuit by *inquiring* into when to *utilize* conductive vs. non-conductive elements controlling the electrical current flow. Students must also *Analyze* changes in voltage, luminescence, and electrical current flow on series and parallel circuit designs by reading and interpreting *numerical values* on an ammeter and a voltmeter, and or, merely *reflecting* on varied degrees of LED luminescence.
- Opportunities for formative peer and *self-evaluation* feedback occur during the hands-on, *collaborative* activity providing an environment for collaborative

assessment for learning, *assessment as learning* experiences, including *social* and *affective* development (WNCPCE, 2006).

- The students and instructor will provide summative *Evaluations* of final completed designs assigned as homework along with a self-made rubric and group reflective questions to guide instruction and assessment.

Interdisciplinary Teaching Strategy: The Lesson

There are many ways for the instructor and students to collaboratively perform this lesson ranging in levels of complexity and time, as well as the incorporation of transdisciplinary STEAM activities. In the most straightforward, safest, and timely scenario the students receive ‘conductive’ and ‘non-conductive’ dough, food coloring, wires with crocodile clips, LEDs of varying colors, and various types of batteries as a power source as well as a simple diagram of a series vs. a parallel circuit (See Fig. 6-7). Examples of past creations can also be useful for students who may be unfamiliar with synthesizing art and physics (see Fig. 1-8). Students should design beautiful, efficient circuits that demonstrate the fundamental series and parallel circuit laws.

The next level of complexity can involve students creating the conductive (salt, lemon juice, cream of tartar, tap water) and non-conductive dough (deionized water, sugar) using flour, sugar, salt, cream of tartar, lemon juice, vegetable oil, measuring cups, deionized water, pot, a large spoon, and a heat source such as a hotplate or laboratory Bunsen burner and trivet/tripod pot stand as well as safety gloves and goggles. Also, if a hand-crank AC-current generator is available, a safe AC-current can be generated, taking advantage of the diodes one-way nature to create beautiful flashing lights that vary depending on the circuit design. In the author’s classroom, advanced students have created quite impressive “light shows” using this technique as the AC-current in combination with the diodes adds timing to specific areas of luminescence depending on the current's direction, and the speed of the crank – just like a string of fairy lights.

After a review of laboratory safety procedures and electrical equipment, students should form small collaborative groups to facilitate peer-scaffolding and differentiated learning, promoting student engagement and social interaction (Ward, 1987). Students brainstorm artistic design plans and then try out their variations of the primary circuit configurations provided with instructor scaffolding (See Fig. 6-7). Students are required to take qualitative notes, at a minimum, detailing their observations. Observations would include varied brightness in the LEDs under different circuit configurations such as series and parallel, with changing numbers of LEDs, lengths of wire, and voltages (adding more batteries or using an adjustable low voltage power source, or turning the crank faster) (See Fig. 5). Conductive vs. non-conductive dough configurations should be addressed by the students as well. Guiding questions for learning and assessment might entail:

> Why is the non-conductive dough necessary for current to flow through the LEDs? What happens to the luminescence when increasing the number of LEDs in a series? What happens to the radiance when adding more LEDs and wires in a parallel configuration? How do increases in voltage affect the luminescence and current? What entails a beautiful design? How did your group utilize line, shape, color, form, space, light, and texture? What constitutes a well-engineered design? What challenges has your group experienced, and how did you overcome them? (Andreas, 2020).

Assessment of Learning Outcomes

The *assessment as learning* and *assessment for learning* paradigms inherent to this activity allow for the instructor to formatively assess group and individual progress during observation and scaffolding and pivoting the instruction to adjust for feedback. Jotting down notes during this process or recording observations into a voice recorder is recommended for later summative assessments. Students should be provided with the desired learning outcomes and assigned the creation of collaborative group rubrics in a preparatory period or the night before for an extension of the assignment. Group question forms also provide an opportunity for summative assessment and student peer and self-assessment (WNCPCE, 2006).

Lesson Extension

As previously mentioned, extending the lesson is only limited by one's creativity. Designing unique circuit diagrams using the online tool at https://www.circuit-diagram.org/ can be accomplished even by younger, less experienced students, and facilitates digital design skills. Expansion of question forms requiring the collection and mathematical analyses of voltage and electrical current data to test Kirchhoff's Laws and Ohm's law (V=IR) by including fixed resistors of known or unknown values in place of LEDs, and copper wires instead of dough, increase the challenge and guides advanced inquiry.

For more experienced students using digital technology for data collection, graphing the non-Ohmic (variable) resistance of a small light bulb, including uncertainty and error analyses, can quickly increase the complexity along with the required time and capabilities of the learners, culminating in a formal report or presentation. For those instructors with knowledge of chemistry, a more in-depth analysis of various conductive dough recipes linked to data collection and investigations regarding circuit current and voltage relationships allows measurements and the testing of the theoretical conductive capacity of one's unique dough concoctions.

Conclusion

This lesson hopefully demonstrates one example of the full range of options for implementing STEAM under a variety of subjects as well as student grade levels and capabilities, to provide a differentiated, creative group activity capable of engaging students of varied interests in developing transferable and transdisciplinary skillsets while still mastering materials in a physics or other syllabus. This activity also provides numerous options for assessment and expansion of the scope and sequence to incorporate more complex cross-disciplinary scenarios.

References

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Tables

Table 1

IGCSE Syllabus Objectives (Andreas, 2020; Cambridge International Examinations, 2020)

General IGCSE Physics Objectives	**Detailed IGCSE Physics Objectives** (Cambridge International Examinations, 2020)
Safety in the Laboratory – Dangers of Electricity	State the hazards of: – damaged insulation – overheating of cables – damp conditions
“”	State that a fuse protects a circuit and explain the benefits of earthing metal cases
“”	
Electromagnetism – Electrical Quantities and Circuits	Recognize electrical symbols for resistors, wires, LED, Switch, Battery, AC/DC power source, Voltmeter, Ammeter and draw and interpret circuit diagrams containing sources, switches, resistors (fixed and variable), heaters, thermistors, light-dependent resistors, lamps, ammeters, voltmeters, galvanometers, magnetizing coils, transformers, bells, fuses and relays to the circuit components then into the surroundings
“”	Distinguish between electrical conductors and insulators and give typical examples
“”	State that current is related to the flow of charge
“”	Use and describe the use of an ammeter, both analog and digital
“”	State that the electromotive force (e.m.f.) of an electrical source of energy is measured in volts
“”	Understand that electric circuits transfer energy from the battery or power source
“”	Understand that the current at every point in a series circuit is the same
“”	Give the combined resistance of two or more resistors in series
“”	State that, for a parallel circuit, the current from the source is larger than the current in each branch
“”	State that the combined resistance of two resistors in parallel is less than that of either resistor by itself
“”	State the advantages of connecting lamps in parallel in a lighting circuit

Figures

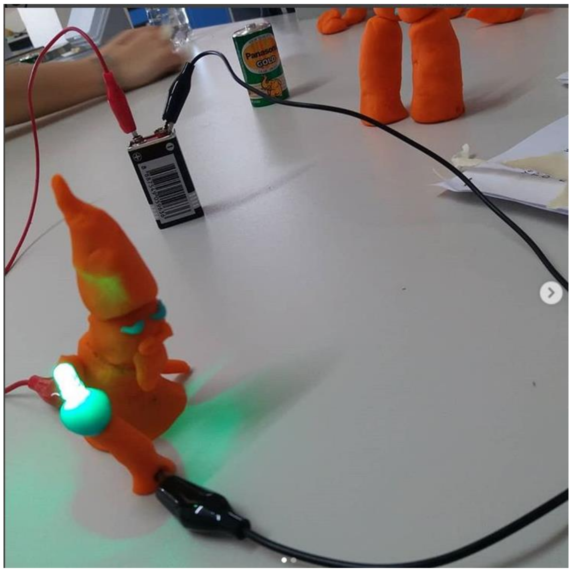

Figure 1. Wizard Series Circuit – orange conductive dough (Andreas, 2020).

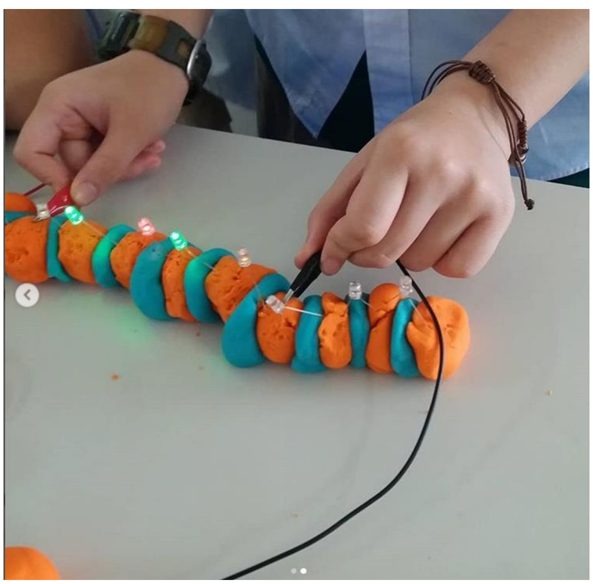

Figure 2. Caterpillar Series Circuit - orange conductive dough, blue insulating dough (Andreas, 2020).

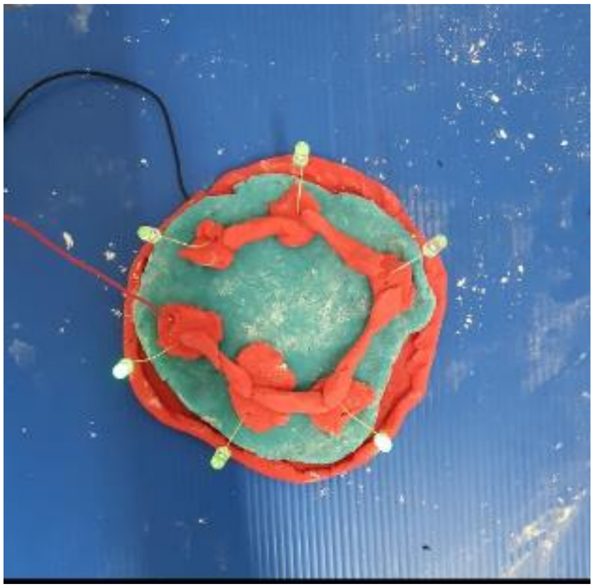

Figure 3. Strange Cake Series Circuit – orange conductive dough, green insulating dough (Andreas, 2020).

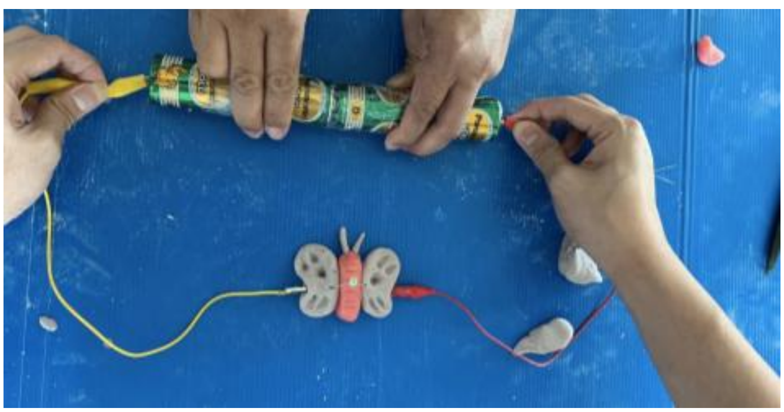

Figure 4. Butterfly Series Circuit – grey conductive dough, orange insulating dough (Andreas, 2020).

Figure 5. Parallel Circuit test using a low voltage adjustable power supply – (Andreas, 2020).

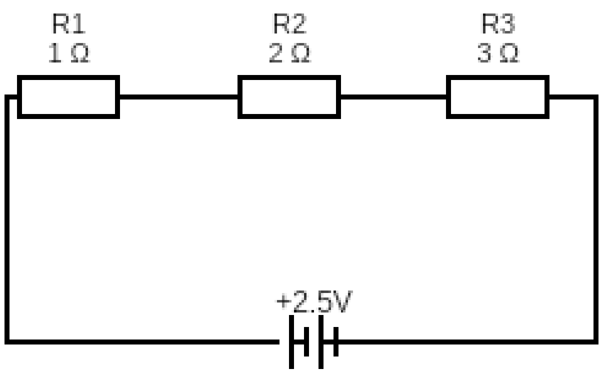

Figure 6. Series Circuit – created by Andreas (2020) using tools at http://circuit-digram.org

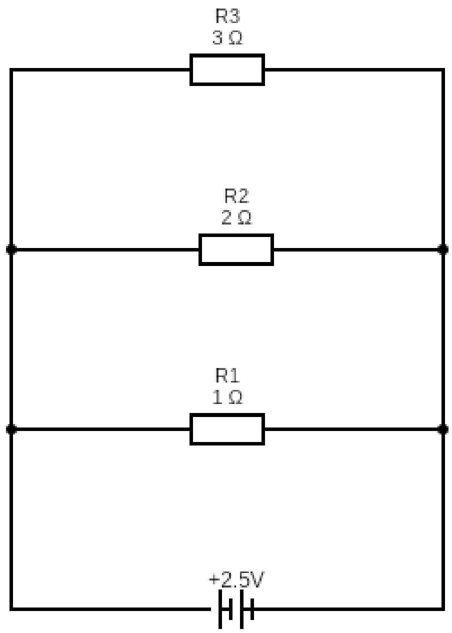

Figure 7. Parallel Circuit – created by Andreas (2020) using tools at http://circuit-digram.org

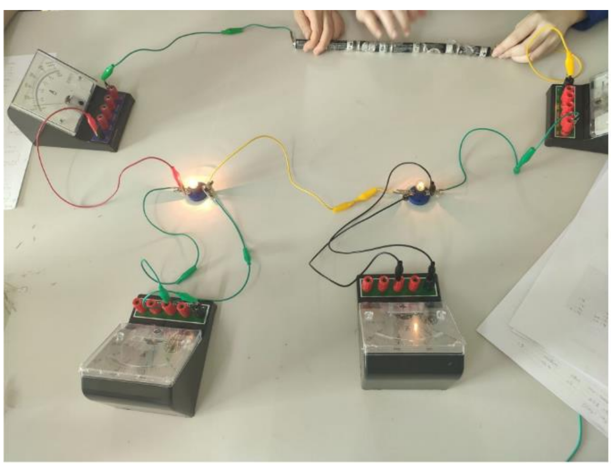

Figure 8. Analog ammeters and voltmeters measuring series voltage and 'non-ohmic' resistance of a bulb (Andreas, 2020).