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NGSS says Yes! to teaching circuits

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For the past 10 years, the Next Generation Science Standards (NGSS) have been available standards for K–12 science education and have been adopted in many states.[1] For example, California adopted a version of the NGSS known as the California NGSS Framework.[2] Other supporting materials have been published for implementation and curricular guidance in the form of Appendices, Evidence Statements, District Guides, and Department Curriculum Guides. Despite all the guides and guidance, there still remain large curricular discrepancies among schools, districts, and states.[3] Here we will highlight one such discrepancy that has been observed in our work with physics teachers around the state of California, specifically whether we should be teaching circuits. In this article, the authors demonstrate that the NGSS contain both explicit and implicit performance expectations which support circuit experiments as a standard part of the high school physics curriculum.

Structure of the new standards

The authors of this paper live in California, which, like 19 other states and the District of Columbia, has adopted the NGSS as written. Thus, we both remember the previous California State Standards.[4] Here is an excerpt:

- *5a. Students know how to predict the voltage or current in simple direct current (DC) electric circuits constructed from batteries, wires, resistors, and capacitors.*
- *5b. Students know how to solve problems involving Ohm's law.*

These old standards were highly ranked for their content and rigor, their clarity and specificity, and their "solid sense of interconnection."[5]

However, research on pedagogy has progressed in the time between standards, so new standards were developed to incorporate that progress.[6] The NGSS are structured to focus on the process of learning by including Science and Engineering Practices to help teachers look for observable behaviors in their students that make learning visible. Additionally, Crosscutting Concepts were developed to help teachers and students take a coherent view of the science content. These pedagogical "dimensions" along with the content itself (Disciplinary Core Ideas) form the three-dimensional structure of the NGSS (see Fig. 1).[1] Thus, the NGSS "are student performance expectations—NOT curriculum."[7] Therefore, teachers should not expect to go directly from the NGSS to lesson plans, but rather use them as inspiration or general guidance.

Explicit and implicit guidance

So what does the NGSS say about circuits? We first find the concept in the 4th grade Performance Expectations:

> *4-PS3-2: Make observations to provide evidence that energy can be transferred from place to place by sound, light, heat, and electric currents.*[1]

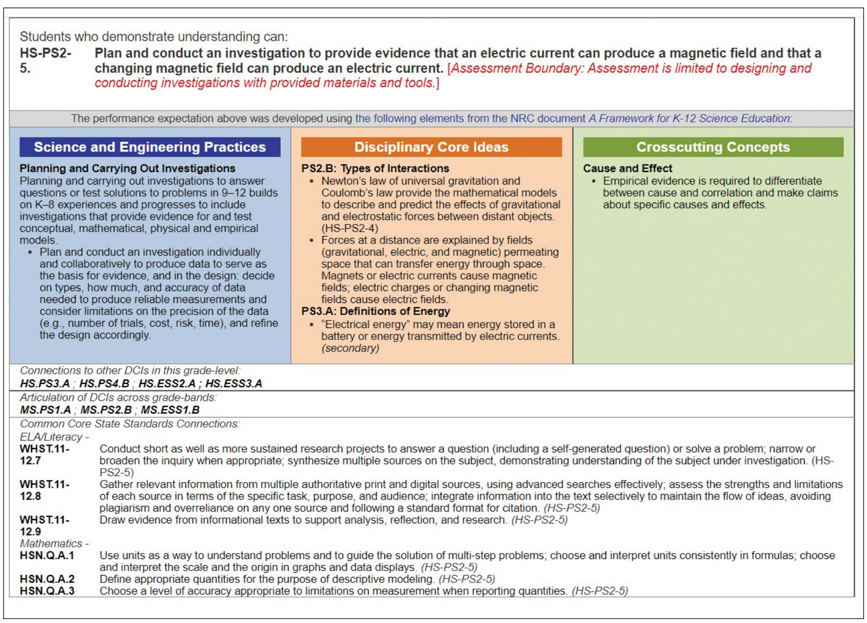
The National Science Teaching Association has interpreted this standard with an activity described below:

> *This lesson introduces the concept of electric circuits. The lesson explicitly mentions the battery as the source of the electric current needed to light the bulb. Students learn that they must create a complete circuit in order for electricity to move from place to place.*[8]

It is the intention and verbiage of the NGSS that the standards progress and that students will build a coherent view of science, with every grade level at the appropriate depth. Later, in the high school standards, HS-PS2-5 tasks us to

> *Plan and conduct an investigation to provide evidence that an electric current can produce a magnetic field … [and understand that] "Electrical energy" may mean energy stored in a battery or energy transmitted by electric currents.*

Such possible investigations of currents are displayed in Fig. 2.



Students who demonstrate understanding can:

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.** *[Assessment Boundary: Assessment is limited to designing and conducting investigations with provided materials and tools.]*

The performance expectation above was developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Planning and Carrying Out Investigations Planning and carrying out investigations to answer questions or test solutions to problems in 9–12 builds on K–8 experiences and progresses to include investigations that provide evidence for and test conceptual, mathematical, physical and empirical models. • Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly.	**PS2.B: Types of Interactions** • Newton's law of universal gravitation and Coulomb's law provide the mathematical models to describe and predict the effects of gravitational and electrostatic forces between distant objects. (HS-PS2-4) • Forces at a distance are explained by fields (gravitational, electric, and magnetic) permeating space that can transfer energy through space. Magnets or electric currents cause magnetic fields; electric charges or changing magnetic fields cause electric fields. **PS3.A: Definitions of Energy** • "Electrical energy" may mean energy stored in a battery or energy transmitted by electric currents. *(secondary)*	**Cause and Effect** • Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects.

Connections to other DCIs in this grade-level:
HS.PS3.A ; HS.PS4.B ; HS.ESS2.A ; HS.ESS3.A

Articulation of DCIs across grade-bands:
MS.PS1.A ; MS.PS2.B ; MS.ESS1.B

Common Core State Standards Connections:

ELA/Literacy -

WHST.11-12.7 Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation. (HS-PS2-5)

WHST.11-12.8 Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the strengths and limitations of each source in terms of the specific task, purpose, and audience; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and overreliance on any one source and following a standard format for citation. *(HS-PS2-5)*

WHST.11-12.9 Draw evidence from informational texts to support analysis, reflection, and research. *(HS-PS2-5)*

Mathematics -

HSN.Q.A.1 Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays. *(HS-PS2-5)*

HSN.Q.A.2 Define appropriate quantities for the purpose of descriptive modeling. *(HS-PS2-5)*

HSN.Q.A.3 Choose a level of accuracy appropriate to limitations on measurement when reporting quantities. *(HS-PS2-5)*

Fig. 1. HS-PS2-5 as it is usually presented in the "more is more" style of NGSS.[1]

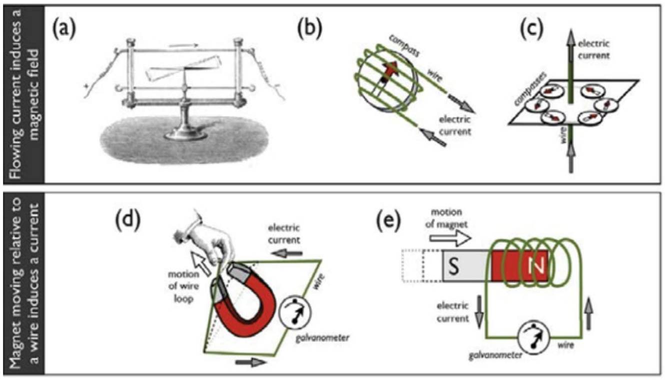


Fig. 2. The California Framework of the NGSS provides several examples of how we can use circuits to detect or control currents that are interacting with magnetic fields. Electrical energy can also be stored in batteries according to the same standard of the NGSS. Reproduced from Ref. 9, Fig. 7.52.

Helpfully, the California Department of Education defines an electric current for us when interpreting HS-PS4-5:

> *Free electrons are key ingredients of an electric current, but currents require those electrons to move systematically around a circuit.*[9]

Further, the CA framework states "Students might try to apply their understanding of microscopic collisions to … electrons, which move through a circuit." Also they suggest that "when students investigate … plastics and ceramics, they should note that … their electrons are locked in bonds and therefore resistant to the movement that is necessary for electric currents." This is the language of Ohm's law.

The state of New York has gone so far as to add their own PS-3-6: Ohm's law:

> *Analyze data to support the claim that Ohm's Law describes the mathematical relationship among the potential difference, current, and resistance of an electric circuit.*[10]

This removes the need for physics expertise when interpreting the standards. However, we have already seen that the above performance expectations imply that an effective way to address electrical energy is by building and analyzing circuits.

The American Association of Physics Teachers' panel on the NGSS has suggested that traditional circuit labs should "provide an excellent area of study where students can construct devices and build simple qualitative and quantitative models," which can "emphasize construction, measurement, and modification" as well as "provide very nice examples of conservation of energy and conservation of electrical charge."[11] This conclusion is supported implicitly by the language of the standards themselves and is a conclusion readily available to any educator with an expertise in physics.

Conclusions

We have repeatedly demonstrated that the concept of circuits is in the NGSS as interpreted by experts. However, circuits in this context serve as a means to an end and not the curricular outcome itself. For some teachers, it can be implicitly understood that explorations with circuit construction and Ohm's law are necessary steps for students to progress through to a complete mental model of electrical current and our society's use of electrical energy.

The goal of NGSS is "Science for All," meaning both teachers and students. The emphasis is on coherent science understanding rather than providing a list of curricular items or discrete lessons. Furthermore, the Next Generation Science Standards are not intended to limit what teachers choose to teach. On the contrary, NGSS encourages teachers to go beyond the stated curriculum. Although the word "circuits" does not appear in the NGSS document, it is a misreading of the document to interpret this as *we aren't supposed to teach them*. Some schools have erroneously attempted to remove circuits from their curriculum in their misunderstanding of the intention and design of the NGSS. This is a mistake. Indeed, the language of the standards encourages the inclusion of circuits. Similarly, we recommend that physics educators provide these experiences to their students.

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