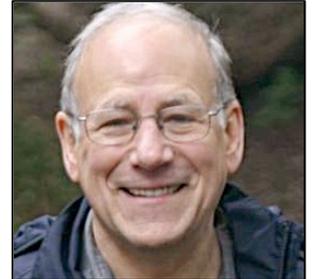


Untangling Science Inquiry and Engineering Design

Cary Sneider

Science teachers have long been urged to include inquiry in their lessons—both as a strategy for teaching and as a set of ideas to be learned. The specific knowledge and skills of inquiry were described in the *National Science Education Standards* (NRC, 1996), and in many state standards. Now the *Next Generation Science Standards* (NGSS Lead States, 2013) requires that students also learn about engineering design.

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Many experienced science teachers already present engineering design activities. Design activities common in science classes include the egg drop challenge, in which students design a holder to cushion a raw egg so it does not break when dropped, a tall tower built from a limited amount of newspaper, and a bridge made of index cards and tape that will hold up a maximum amount of weight. These are engineering challenges, but they do not necessarily meet the requirements of the NGSS.

The NGSS specifies that engineering design challenges need to engage students in practices of engineering, which involve more than building and testing various devices. Perhaps the clearest overview of science and engineering practices and how they differ is a table in *A Framework for K-12 Science and Engineering* (NRC, 2012), which established the overall vision of the new standards. A shortened version of the table appears at the end of this paper. While the practices of science and engineering are similar, they are not exactly the same. To illustrate this idea, consider how the egg drop challenge might be adapted for a middle school physical science class to meet the following performance expectation from the NGSS:

MS-PS3-1. Construct and interpret graphical displays of data to describe the relationships of kinetic energy to the mass of an object and to the speed of an object.

Define the problem: Rather than giving the students a detailed challenge, present the students with a vague problem with instructions to define it more precisely. For example: "A manufacturer of bicycle equipment wants to design a safer helmet. Here

are some materials that you can use to create a model of a helmet, and a raw egg that can represent a person's head. Before you begin, identify what criteria you will use to judge a successful design, and explain how you will compare designs to see which best meet the criteria. Your constraints are to use just these materials, and to finish your model by the end of today's class, so you can test it tomorrow."

Develop and use a model: Provide materials for students to build and test a physical model, with instruments they can use to test their ideas. Provide opportunities for the students to reflect on the strengths and limitations of the model.

Plan and carry out an investigation: After preliminary testing, provide time for the students to investigate design concepts by planning and conducting controlled experiments, in which only one variable (such as the shape of the model or materials used to cushion the egg) is changed.

Analyze and interpret data: Engage students in defining measurable criteria, such as the height that their model helmet can be dropped from before the egg breaks, so results can be graphed and compared.

Design a solution: After all of the student teams have completed their tests, provide additional time for the students to redesign their models, based on the various models from the entire class, making explicit tradeoffs to develop an optimal solution.

Use mathematical and computational thinking: Have students calculate and graph the effects of different speeds on the magnitude of impact, based on the information that energy increases with the square of the speed. Engage students in using simulation software like that used by professional designers to observe the operation of safety devices for vehicles traveling at different speeds, and colliding with other vehicles of different masses.

Engage in argument from evidence: Have students present their methods and conclusions, with explicit reference to the evidence they collected, providing opportunities for students to offer constructive criticism.

In the discussion above, notice that engineering practices are explicitly taught. Although many of the activities, such as designing controlled experiments, and analyzing data, are the same as in science, other practices are quite different. Defining problems in terms of criteria and constraints, making tradeoffs, and optimizing a design are specific to engineering, and in the past have not typically been part of science class.

Also notice that an important principle from science is included in the activity—that kinetic energy of an object increases with the square of its speed. This part of the activity not only illustrates why it is important for professional engineers to study

science, but also explains the danger of speeding—whether on a bicycle or in a car.

Since the NGSS calls for all students to learn engineering design practices, it will be important for teachers to design such experiences for their students. And although the distinction is clear in cases such as the above, the distinction between a science and engineering activity is not always obvious. Consider the following middle school performance expectation from the NGSS:

MS-PS2-3. Ask questions about data to determine the factors that affect the strength of electric and magnetic forces.

Now compare the following challenges given to students that will give them experiences that will help them achieve this performance expectation.

Use these materials (wire, iron nail, battery, and paper clips) to determine the factors that affect the strength of an electromagnet.

Use these materials (wire, iron nail, battery, and paper clips) to design an electromagnet that will pick up as many paper clips as possible.

The first challenge, which asks students to answer a question, involves them in planning and conducting a science experiment. In the classroom, students given this instruction tend to control variables carefully, for example determining the length of a paper-clip chain they can make with a given length of wire. The second challenge invites much more creativity, such as using both ends of their electromagnet, to pick up as many paper clips as possible. In both cases students design and conduct controlled experiments, but the process is quite different.

In conclusion, this paper emphasizes two points: First, design activities do not necessarily meet the requirements of the NGSS unless they engage students in practices of engineering design at the appropriate grade level. Doing so is important, not because we expect all students to become engineers (although we hope more will be interested), but because learning to solve problems is a valuable skill for everyone. Second, the distinction between science and engineering activities can be subtle, since they could involve the same materials and even similar challenges. A definitive way of untangling science from engineering is to ask the student what goal they are trying to accomplish. If they are trying to answer a question, they are doing science. If they are trying to solve a problem, they are doing engineering.

Distinguishing Practices in Science from Those in Engineering

Adapted from *A Framework for K-12 Science Education* (NRC, 2013, pp. 50–54)

Science	Engineering
1. Asking Questions and Defining Problems	
Science begins with a question about a phenomenon, such as “Why is the sky blue?” or “What causes cancer?”	Engineering begins with a problem, need, or desire that suggests an engineering problem that needs to be solved.
2. Developing and Using Models	
Science often involves the construction and use of a wide variety of models and simulations to help develop explanations about natural phenomena.	Engineering makes use of models and simulations to analyze existing systems so as to see where flaws might occur or to test possible solutions to a new problem.
3. Planning and Carrying Out Investigations	
A major practice of scientists is planning and carrying out a systematic investigation, which requires the identification of what is to be recorded and, if applicable, what are to be treated as the dependent and independent variables (control of variables).	Engineers use investigations both to gain data essential for specifying design criteria or parameters and to test their designs. Like scientists, engineers must identify relevant variables, decide how they will be measured, and collect data for analysis.
4. Analyzing and Interpreting Data	
Scientific investigations produce data that must be analyzed in order to derive meaning.	Engineers analyze data collected in the tests of their designs and investigations.
5. Using Mathematics and Computational Thinking	
In science, mathematics and computation are fundamental tools for representing physical variables and their relationships.	In engineering, mathematical and computational representations of established relationships and principles are an integral part of design.
6. Constructing Explanations and Designing Solutions	
The goal of science is the construction of theories that can provide explanatory accounts of features of the world.	The goal of engineering is to solve a problem or meet a need.
7. Engaging in Argument from Evidence	
In science, reasoning and argument are essential for identifying the strengths and weaknesses of a line of reasoning and for finding the best explanation for a phenomenon.	In engineering, reasoning and argument are essential for finding the best possible solution to a problem.
8. Obtaining, Evaluating, and Communicating Information	
Science cannot advance if scientists are unable to communicate their findings clearly and persuasively or to learn about the findings of others.	Engineers cannot produce new or improved technologies if the advantages of their designs are not communicated clearly and persuasively.

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