Taking Engineering Design Out for a Spin

How a simple whirligig design challenge can highlight both inquiry and design

By David Crismond, Mark Soobyiah, and Ryan Cain

A Framework for K–12 Science Education maps out a new vision where engineering design takes a "prominent place" (NRC 2012) alongside of inquiry in science instruction. This topic, which used to be taught only at colleges and universities, first appeared in the *National Science Education Standards* as "technological design" (NRC 1996). Adoption of that standard was spotty. The *Framework's* release marks a renewed and more muscular approach to including engineering design in K–12 science classrooms.

Are you familiar with Nickelodeon's cartoon figure "Dora the Explorer?" Dora prepares for her travels by first filling her backpack with a map, tools, and other materials. So what can you put in your backpack to prepare for taking engineering design out for a spin with your students? What affordable, hands-on design tasks can you stuff into your sack that will engage them while they learn relevant STEM ideas? What route can you all follow that will include both inquiry and design as final destinations, and how will you measure your students' accomplishments in each?

This article highlights what inquiry and design have in common, and points to two signature practices that make engineering design uniquely different from inquiry. Two New York City elementary science cluster teachers describe how they use a design activity from *Problem-Based Inquiry Science* (GTRC 2008) to give their students practice in conducting fair-test experiments, in troubleshooting to learn how to make designs better, and in building science-based explanations for how things work.

Comparing Engineering Design and Scientific Inquiry

One tool worth putting in your knapsack for your trip is knowledge of distinctions between science and engineering. Briefly, science creates and tests explanations and predictions about nature and how it works, while engineering makes products that solve problems or fulfill the needs of users. Another is a memorable analogy from the *National Science Education Standards* that helps separate the two: "Inquiry is to science as design is to engineering" (NRC 1996, p. 23).

Having standards that ask you to put design on an equal footing with inquiry in your teaching may seem daunting. To make this challenge more familiar and more doable, the *Framework* provides a signpost (see Figure 1) that shows *practices* shared by both inquiry and design. Previously, "practices" were called "process skills" or "strategies;" the new term includes both the processes and contexts in which students learn them.

You may notice that the *Framework* describes both how engineering design is similar to inquiry, and how they are different. First, the similarities:

- Both inquiry and design use simplified models of complex phenomena to create explanations of nature (science) or build better products (design).
- Both involve doing research to understand problems better, and both involve arguing from evidence when choosing what plan to build or hypothesis to support.

Figure 1.

Shared practices between inquiry and design (NRC 2012, p. 42).

Both inquiry and design use simplified *models* of complex phenomena to create *explanations of nature* (science) or *build products* (design). Both involve doing *research* to understand problems better, and both involve *arguing from evidence* and *analyzing data* that gets gathered during testing or aggregated using *mathematics*. Both ask students to *communicate* results to others.

PRACTICES FOR K–12 SCIENCE CLASSROOMS

1. Asking questions (for science) and defining problems (for engineering)
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations (for science) and designing solutions (for engineering)
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

Table 1.
Side-by-side comparison of science inquiry and engineering design.

Scientific Inquiry	Engineering Design
Observe/Question	Identify/Frame Problem
Research	Research
Generate Hypotheses	Generate Ideas
Use Models/Predict	Use Models/Build Prototypes
Conduct Experiments	Conduct Experiments
Interpret Data/Iterate	Troubleshoot/Iterate
Communicate	Communicate

- Both involve conducting experiments and analyzing data that gets gathered during testing or aggregated using mathematics.
- Both ask students to communicate results to others.

Table 1 shows these two STEM endeavors when they are aligned side by side. In Table 1's left-hand column are seven inquiry practices based on Wynne Harlen's model (2001). Some of the engineering design practices shown in the right-hand column may be unfamiliar to you. Two contribute to design's unique character and help make it distinctly different from inquiry:

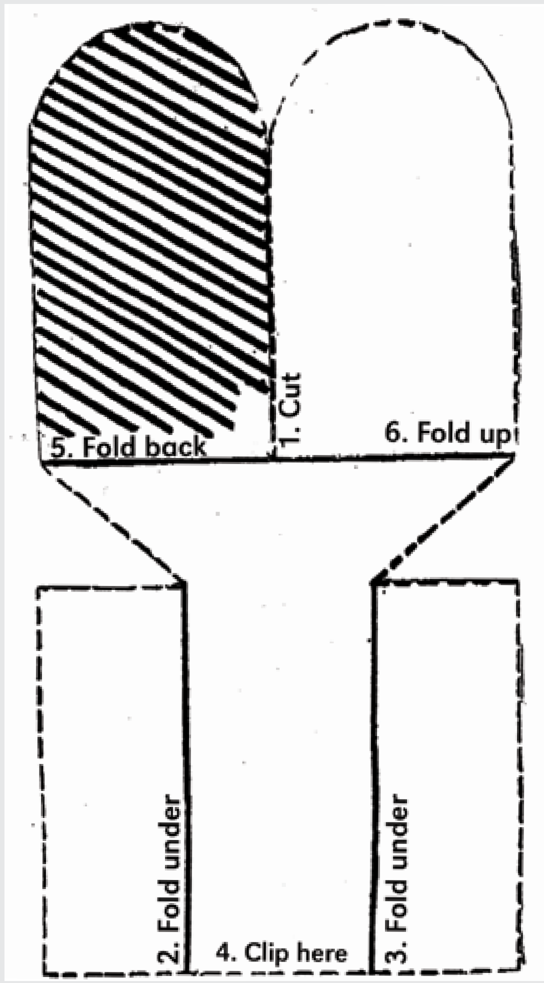
- *Generate Ideas (Brainstorm)* While designers are not asked to invent completely new solutions to challenges they face, they are expected to generate, combine, and rearrange ideas in creative and new ways. Among the many techniques for doing this, "brainstorming" may be the best known. The two basic guidelines for doing brainstorming are (1) to list as many ideas as possible—no matter how outlandish or improbable—and (2) not to criticize ideas presented during this time. This second condition is especially important when having children do brainstorming. Quantity of ideas, not quality, is the goal of a good brainstorming session.
- *Troubleshoot and Iterate* Designers learn best by building prototypes and then troubleshooting their performance—basically looking for problems during tests and then fixing them. This cycle of testing prototypes, troubleshooting, and improving the prototype is called a *design iteration* and is a signature practice of engineering design.

Case Study: Whirligig Design Challenge

The following composite vignette describes how two science cluster teachers, Ryan Cain (preK–grade 2) and Mark Soobyiah (grades 3–5), used a whirligig design challenge adapted from the *Problem-Based Inquiry Science's* "Diving into Science" unit (GTRC 2008). The whirligig, a very simple model made from a pattern cut and folded from a sheet of paper and paper clips (see Figure 2 and NSTA Connection), spins and falls slowly when released. Students were asked to design a spinning toy for kids that would be included for free in a box of cereal.

Mr. Cain wanted to use the whirligig activity as a way to introduce his second graders to design and also to give them practice doing fair-test experiments. Mr. Soobyiah wanted his students' introduction to design to focus on troubleshooting and on the process of combining ideas to create a "master design" or optimal solution after they experimented with single design variables. They had their students do the following practices—note that the order in

Figure 2.
Whirligig template.



which these practices get performed varies with different design tasks.

Identify the Problem

Both teachers started off by reading the design brief aloud to their students. This single-page set of instructions describes the context of the challenge, the *criteria* for how the desired product should perform—that the toy should take a long time to fall a given distance and be fun to use for kids—and the *constraints* that solutions must adhere to—the toy must be made of low-cost materials and fit inside a cereal box.

Research

After reviewing the brief, students were given scissors, paper clips, and a template and told to build their first no-frills whirligig. This initial or baseline template was created to perform adequately, but its design had lots of room for improvement. Sadler, Coyle, and Schwartz (2000) use this approach to give students an initial sense of success in their work and a solid starting point for improving and redesigning their devices.

Use Models/Build Prototype

Students then built and explored how their whirligigs worked by releasing and observing them as they fell. Since students initially tend not to focus their attention on how the whirligig performs, teachers made videos of drops and reviewed them with the entire class to help students take note of specific behaviors as the toys descended:

- Speed of Descent: How slowly does it fall?
- Spinning: When does the toy start spinning and how fast? Does the whirligig always spin in the same direction?
- Pathway: Is path of descent straight or wavy?
- Stability: Does the whirligig stay vertical when falling or not?

Conduct the Experiment

Both teachers then had their students pick a single feature in the whirligig's design (e.g., wing length, paper type, number of clips and size) and conduct experiments by changing one feature or design variable that might affect the toy's performance. The wings can be cut shorter or made longer during fabrication; fewer or more paper clips could be used. These and other variables are shown in Table 2.

Teachers asked students to do side-by-side tests with the new prototype in one hand and the no-frills (baseline) whirligig in the other. This use of "contrasting sets" (Bransford et al. 1989, pp. 487-491) helped them notice differences in performances they might have otherwise missed. Students then presented their results, and the teachers gave a minilesson on how the whirligigs work, including how the force of gravity makes the device fall, and how the air hitting the wings during descent makes the toy spin (see the How Does a Whirligig Work? p. 56).

Troubleshoot/Iterate

Students then learned to do troubleshooting, which involves the following steps (Crismond and Adams 2012): (1–2) Observe and identify issues or problems with the current design; (3) Explain why the problems are occurring; and (4) Suggest remedies or ways to improve it. Both teachers used video playback in slow motion to help students detect flaws during side-by-side testing. Slowing down the fall through replay was critical in helping students detect flaws in performance and fixing them. Having students keep a troubleshooting notebook based on these steps provided formative assessment data on student thinking—especially their explanations for why things went awry—and helped address Common Core literacy goals as well.

Mr. Cain noted that his students were quick to point out the order in which the whirligigs hit the ground: "Both are kind of fast, but the one with the wider top fell down last." Initially, however they were keen observers of whether the drops were conducted fairly: "They worried mostly about how the students dropped the prototypes." One student said, "I think Alan dropped the left parachute too early, and that's why the one in his right hand landed after the left one did." The next reported, "I think that he dropped them at different levels… I think one was lower than the other." As their experimental technique improved, Mr.

Table 2.
Whirligig variables.

Variables	Settings		
Wing length	Short	Basic	Long
# of paper clips	0	1	2
Scale (size)	Half	Basic	Double
Paper type	Transparency	Basic	Thick

Cain reported that his students started to pay more attention to which toys would spin faster and when they started to spin—key behaviors that determine the quality of the design. After finishing the unit, Mr. Cain's goals for teaching science with design had been met. "The big take-away for my young scientists was that they be able to run fair-test experiments successfully," he said.

Mr. Soobyiah's third graders "could tell which whirligig fell slower and what worked well and not so well" but "had trouble pinpointing when and where problems started." His fifth graders, however, "were able to analyze the videos with more precision and use them to modify their designs." Mr. Soobyiah had his fifth-grade students then build a "best whirligig" by combining findings about different variables and then iteratively revise these prototypes to make an optimal design.

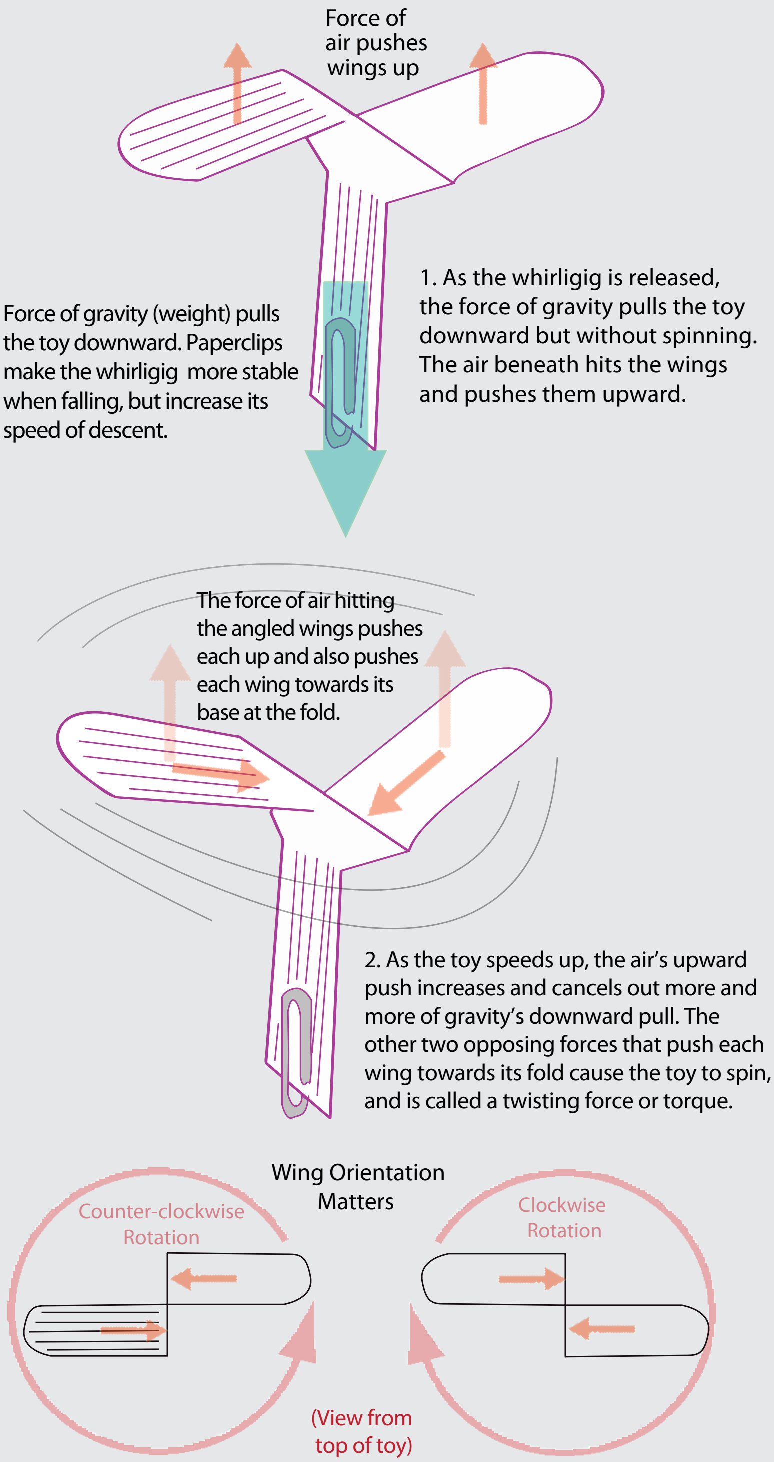
Mr. Soobyiah noted that his third graders' experiences in troubleshooting, even with the help of slow-motion video replays, were not at quite the same level as his older fifth graders who were able to notice and give written descriptions of how different designs performed differently—perhaps suggesting that developmental differences are at work here with the practice of troubleshooting. Still, he found that "both grades were successful in creating their final products" as evidenced by his students' final project presentations.

Conclusion

The *Framework* asks teachers to help students use both science and engineering ideas and practices when solving design challenges where single "right answers" rarely exist. Students need encouragement to be creative, to take risks with ideas when designing, and especially to learn when things fail, which they inevitably do.

When implemented well, design activities can lead to deeper understanding of science ideas (Kanter 2010). Taking the easy-to-make whirligig activity for a spin is just one of a number of engaging low-cost, hands-on activities (see Design

How Does a Whirligig Work?



3. Orientation of the wings (shaded wing up or down) sets the direction of the twisting force (torque), which will make the toy spin either clockwise or counterclockwise. Having children draw arrows on the wings of their paper models can help them predict the direction of spin as they design and test their whirligigs.

in the Classroom website in Internet Resources) that you can explore using to help your students reach *Framework's* new learning destinations. ■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Internet Resources

Design in the Classroom website
http://designintheclassroom.com/designProcess/whatIsDesign/designTutorial.html

Video case study of the IDEO product design firm from Nightline's *Deep Dive* episode:
www.youtube.com/watch?v=JkHOxyafGpE&feature=related

NSTA Connection

For the student data sheet and a sample rubric, visit *www.nsta.org/SC1301*.

Connecting to the Standards

This article relates to the following National Science Education Standards (NRC 1996):

Content Standards

Grades K–4

Standard A: Science as Inquiry

- Abilities necessary to do scientific inquiry

Standard E: Science and Technology

- Abilities of technological design

National Research Council (NRC). 1996. *National science education standards*. Washington, DC: National Academies Press.