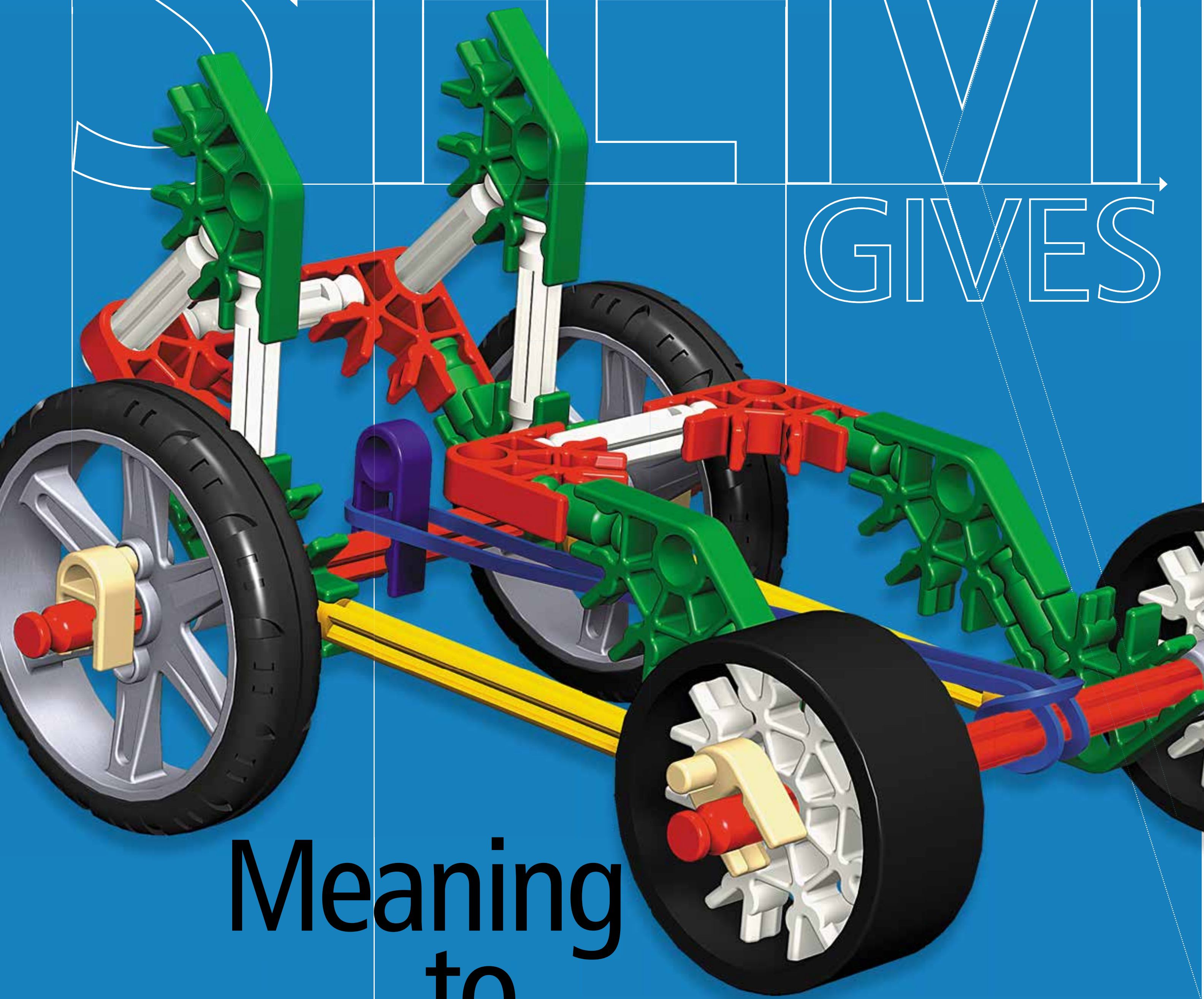
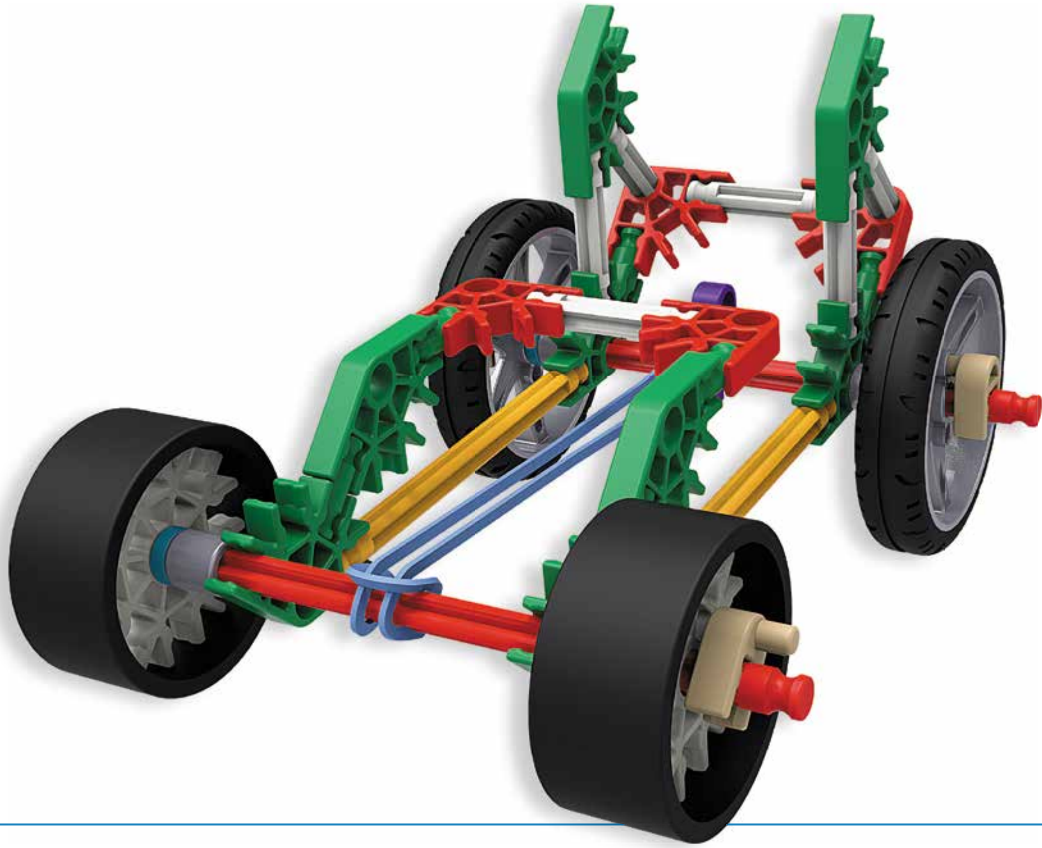
STEM GIVES Meaning to Mathematics





Applying mathematics during engineering design challenges can help children develop critical thinking, problem solving, and communication skills.

By Lukas J. Hefty

"Understanding involves making connections" (National Council of Teachers of Mathematics [NCTM] 2000, p. 64). Challenging students with important mathematics prepares them to solve problems in class and at home. NCTM's *Principles and Standards for School Mathematics* (2000) outlines five Process Standards that are essential for developing deep understanding of mathematics:

1. Problem Solving
2. Reasoning and Proof
3. Communication
4. Connections
5. Representation

The Common Core State Standards for Mathematics (CCSSM) include eight related Standards for Mathematical Practice (SMPs) (CCSSI 2010). Both standards documents articulate the notion that mathematics is more than just learning content knowledge—habits of mind are just as important as knowledge that is absorbed.

How then can teachers help students see the importance of mathematics at the time that they are learning a new topic? Douglas L. Jamerson Jr. Elementary School has found one solution in the form of STEM (Science, Technology, Engineering, Mathematics) education. Developed by the classroom teachers with the assistance of local university professors, integrated engineering units of study allow for the application of mathematics skills in real-world contexts, removing engagement barriers and enhancing the development of NCTM's five Process Standards and the Common Core's eight Standards for Mathematical Practice. The purpose for learning is evident with a coherent, integrated curriculum, freeing students to reason about complex problems, analyze multiple solutions, and communicate ideas and results. They develop habits of mind along with the necessary mathematics skills.

Perfect math-application opportunities

Jamerson teachers share the belief that engineering—putting scientific knowledge to practical uses—presents an ideal avenue for the application of mathematics skills. Engineering design challenges in kindergarten through fifth grade offer a platform for students to collaborate in the development of solutions to real-world problems (see **table 1**). The engineering units overlap math and science concepts and give impetus to the mathematics curriculum. The school uses a design process modeled after those

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TABLE 1

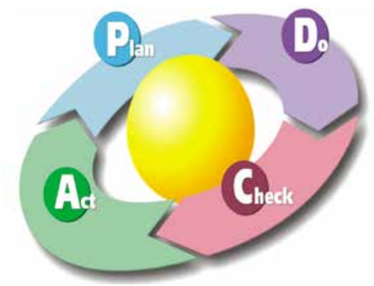
Jamerson teachers believe that putting scientific knowledge to practical use presents perfect opportunities for students to apply mathematics skills. Here are the major elements of one unit for each grade level.

Grade level	Force and Motion unit: Engineering design challenge	Design constraints	Math concepts
K	Humpty Dumpty falls safely off the wall	An egg falls from 1 m height without cracking.	Measurement of height
1	LEGO® tower	Height of 50–60 cm A color pattern withstands a gust of wind.	Patterns, measurement of height
2	Marble drop machine	A marble travels safely throughout at least three direction changes. Minimum height of 1 m	Measurement of height, angles, and time
3	Laser light maze	Light travels from laser to end target. Light reflects at least three times.	Measurement of height and angles
4	K'Nex® vehicle	The vehicle travels using rubber band energy.	Measurement of distance, time, and speed
5	Bridge	The bridge withstands 5 Newtons of force. Cost effective	Measurement of force Cost analysis/budget

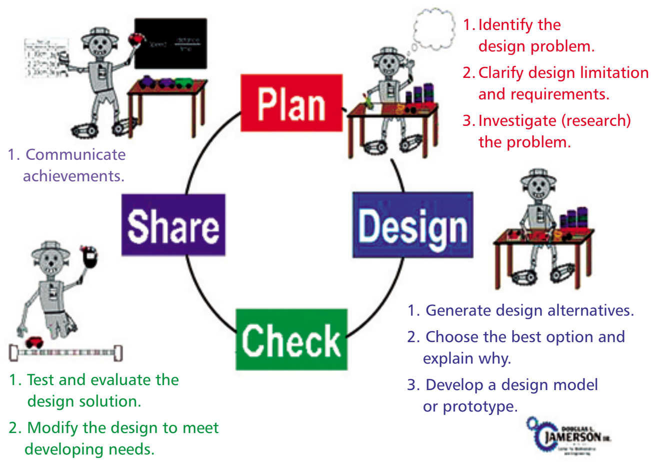
FIGURE 1

The engineering design process challenges Jamerson students in K–grade 5 to work collaboratively, communicate effectively, and design multiple solutions to complex problems. The model below outlines the fourth-grade Force and Motion unit of study.

(a) Corporate engineering design process



(b) Jamerson engineering design process

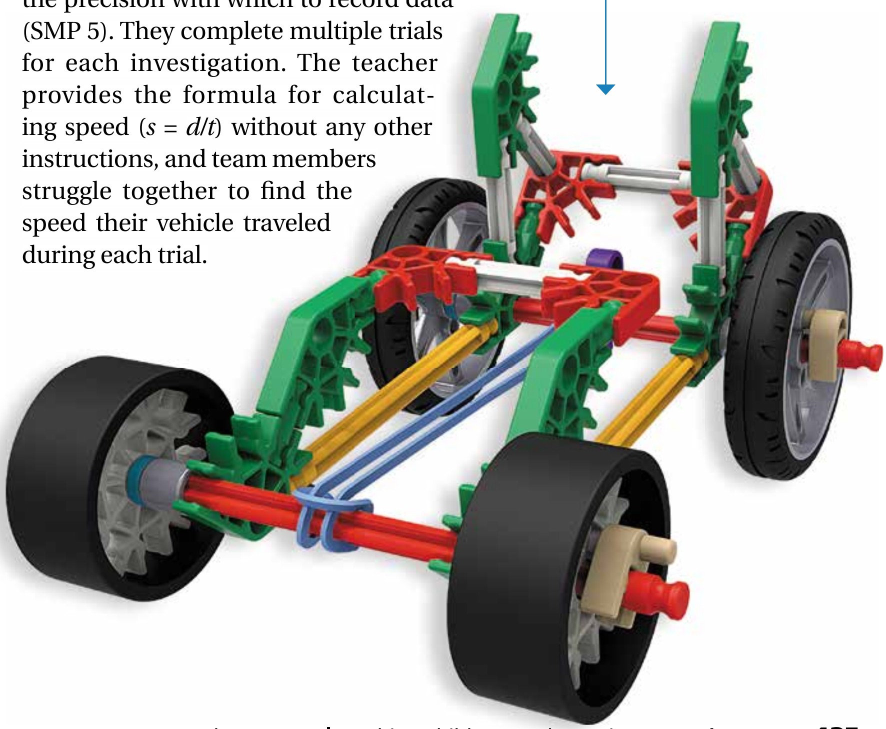


used in the engineering field: plan, design, check, and share (see **fig. 1**). NCTM's Process Standards are naturally embedded in such challenges, with the subtle, underlying benefit not being the products developed by students but the habits of mind developed as they unearth the meaning behind the mathematics. The following example outlines a fourth-grade unit of study.

An example: Rubber-band–powered vehicles

The K–grade 5 Force and Motion units were created around physical science standards related to forces that act on objects and their related motion. Fourth graders construct vehicles with rubber-band energy using K'Nex® pieces to learn those standards, along with standards related to scientific investigation. Teacher facilitators make purposeful connections that naturally integrate mathematics throughout the activities. As part of a deliberate sequence of lessons, students examine articles and other informational text about vehicle design, take notes, and engage in discussions ranging from cost to design and efficiency. They learn about the forces that act on vehicles and practice using measuring tapes, balance scales, and stopwatches with precision (SMP 6).

After developing significant background knowledge, teams of students construct the vehicles using a blueprint. They then perform several investigations regarding the distance the vehicles will travel, isolating such variables as the number of wraps of the rubber band, surface friction (carpet, tile, concrete), and vehicle mass. Students select appropriate tools to measure mass, distance, and time. Group members debate whether to measure distance using a meterstick or measuring tape, whether to measure in standard or metric units, and the precision with which to record data (SMP 5). They complete multiple trials for each investigation. The teacher provides the formula for calculating speed ($s = d/t$) without any other instructions, and team members struggle together to find the speed their vehicle traveled during each trial.



PERSEVERANCE DEVELOPED FROM THE DESIGN PROCESS … ENABLES STUDENTS TO PERSIST WHEN SOLVING CHALLENGING MATH PROBLEMS.

Although the math skills associated with the unit are challenging for fourth graders, the real-world connections are obvious, leading to intensely engaged students. Following each investigation, the class analyzes the data tables in search of patterns (SMP 8). Through whole-class discussion and debate, students determine results and draw conclusions. For example, if results indicate that the cars travel faster on tile than on concrete, the class may conclude that friction has less impact on the cars when traveling on tile. The teacher facilitates discussion while students communicate quantitatively and with specific math and science vocabulary. These students are obviously comfortable using appropriate tools strategically, analyzing data to find patterns, and communicating results; they have internalized the important mathematics process skills of consistent subject area integration during the previous five years (kindergarten through fourth grade).

Still within the fourth-grade unit, all of this preparation builds up to the culminating engineering design challenge: Design the most *efficient* car, the car that travels a distance closest to 400 cm without surpassing it. Car design, mass, and number of wraps of the rubber band are left to the teams to decide. Team members get right to work, talking and drawing diagrams of their planned vehicle. They understand that their final vehicle will likely look very different from their initial sketches. They assemble their first-draft vehicles and begin testing, then make adjustments—first to their drawings and then to their vehicle—and the process continues.

No frustration

A surprising aspect of the students' interactions is their lack of frustration when transitioning back and forth between the design and check phases of the design process. They view the design process as an ongoing cycle rather than as a means to an end. This development of perseverance has taken time and repeated exposure to challenging problems in both math and engineering. Jamerson teachers find a delicate balance between coaching students through frustration and allowing them to work through it on their own. Allowing students to "fail" can increase tension among teams but has long-term payoffs: the development of perseverance as a part of the students' natural repertoire, which carries over into all aspects of their lives, including reasoning through complex mathematics.

Eventually every team develops a vehicle that meets the design constraints. Vehicles are tested, and results are recorded on a class data table. Students point out certain patterns they notice among the vehicles' mass, number of wraps, and distance traveled. Each student writes a final report, including his or her description of the design process, the mathematics and science involved, and overall reflections. One student noted,

> We had to redesign our car at least ten times. Every time we changed the mass or style of the car, the distance changed. We noticed that less mass led to more distance. It took a long time, but in the end we got really close to 400 cm.

The final reports help the teacher assess each student's understanding of the science, mathematics, and design concepts. The excerpt above, for instance, shows understanding of the inverse relationship of mass and distance and also exhibits perseverance and teamwork. Teacher collaboration in assessing students throughout the units helps them identify trends in student understanding. For example, if the teachers notice that many students have difficulty measuring length to the nearest whole centimeter, a skill mastered by the end of second grade, they can re-teach the skill and collaborate with the primary grade teachers to prevent future gaps in understanding.

Healthy habits of mind

At Jamerson, the Common Core Standards for Mathematics are taught during a daily mathematics block and applied throughout the engineering units. When planning engineering design challenges, teachers consider the mathematics standards that students have learned in previous grades while also recognizing that elementary school students are capable of learning about important math concepts earlier than anticipated when such concepts are presented through engineering design projects (National Society of Professional Engineers [NSPE 2007]). Understanding this progression enables them to create an engineering design challenge (see **table 2**) that requires the application of mathematics skills learned in previous grades.

How do the benefits of engineering design challenges carry over into math instruction? The answer lies in "habits of mind" development. "Engineering teaches kids a logical way to think and solve problems" (NSPE 2007, p. 18). If development of certain Process Standards is necessary for mathematics skills to be truly learned, activities that support such development would be invaluable (NCTM 2000). In our example, engineering design challenges develop in elementary-school–age students the ability to think critically, communicate effectively, and collaborate. Perseverance developed from the design process—in which repeated *failure* is common and viewed as part of an ongoing improvement cycle—enables students to persist when solving challenging math problems.

Teachers at Jamerson notice carryover from engineering to mathematics lessons—students learning a new skill are more likely to persist when struggling; they are used to class discussions and more likely to share their thinking or ask questions. Especially with problem-based activities, students are more likely to try out ideas without the looming fear of being wrong. In addition, students enter fourth grade with vast experience in the CCSSM Measurement and Data domain—using measurement tools, measuring with precision, and collecting and analyzing data—allowing teachers to go into greater depth with other domains: Number and Operations, Algebraic Thinking, and Geometry (CCSSI 2010). The effects of integrated units of study over time have led to steady increases in student achievement in both math and science at Jamerson. Mathematics achievement, as measured by state standardized testing, has increased each of the past five years and far exceeds district and state averages (see **table 3**). Students making one year or more learning gain in mathematics in 2013 rose to 81 percent overall and 90 percent of the lowest 25 percent. Likewise, science achievement levels have increased each year and currently exceed the state and district averages by 17 percent.

The development of NCTM's Process Standards and the Common Core's SMPs is paramount to every child's success in mathematics. Without traits like perseverance,

TABLE 2

In planning the K'Nex® Vehicle Design challenge, grade 4 teachers studied the Common Core State Standards within the Measurement and Data domain and mapped out a K–grade 3 progression.

Grade	Common Core State Standards for Mathematics: Measurement and data standards progression
K	K.MD.1.1—Describe measurable attributes of objects
1	1.MD.1.2—Express the length of an object as a whole number
2	2.MD.1.1—Measure the length of an object by selecting and using appropriate tools 2.MD.4.9—Generate measurement data by measuring the length of several objects to the nearest whole unit
3	2.MD.1.1—Draw a scaled picture graph and a scaled bar graph to represent a data set with several categories

TABLE 3

The effects of integrated units of study over time have led to steady increases in student achievement in both math and science at Jamerson.

Grade/ Year	2011	2012	2013	2013 District	2013 State
3	53	60	67	48	58
4	47	57	64	54	61
5	48	65	69	50	55

> **WITHOUT TRAITS LIKE PERSEVERANCE, REASONING, CRITICAL THINKING, AND SENSE MAKING, THE KNOWLEDGE SKILLS LISTED FOR EACH GRADE LEVEL IN CCSSM WILL NOT BE TRULY MASTERED, AND UNDERSTANDING WILL BE SHORT-LIVED.**

reasoning, critical thinking, and sense making, the knowledge skills listed for each grade level in CCSSM will not be truly mastered, and understanding will be short-lived. The Process Standards can and should be developed in the mathematics classroom. The example presented above makes the case for an integrated curriculum to enhance the development of perseverance, critical thinking, and communication.

Integrating subject areas

Engineering design challenges provide one example of subject area integration. Each challenge was purposefully designed to align with science and mathematics standards, with teachers collaborating in their development. They were not presented as a set of unrelated activities but as coherent integrated units of study. Each sequence of lessons was designed to build the background knowledge necessary to successfully complete both the design challenge and postunit written assessments. Creating integrated units of study can be complex and time-consuming—it has been a ten-year process at Jamerson—but simple measures can be taken immediately.

School personnel suggest beginning with open discussion among math, science, and literacy teachers, or among grade-level teams. Develop a set time and place for team meetings. Jamerson staff members meet weekly in professional learning communities. Once a collaborative dialogue has begun, look for small ways to integrate mathematics into other subject areas. Create an engineering design challenge as a culminating performance assessment to align with current science units of study. Consider the mathematics skills necessary to successfully complete the challenge, and create a standards progression map (see **table 3**). Implement, debrief, and revise the challenges continuously, and add additional challenges over time. Remember that connections can be made both in and outside the mathematics classroom, and in doing so, teachers will motivate their students to achieve like never before.

In our less-than-perfect world

If you are not in a position to implement the type of total-school activities described above, what *can* you do? If you are a single-grade, K–grade 5 teacher, you can get sample engineering design challenges from the author and begin making changes in your own classroom and grade level. Start by presenting one engineering design challenge to your students, observing its effects, and modifying it to meet your specific needs.

If you are a school-based administrator, you can pose the notion to your staff and determine if any interest exists among teachers in implementing engineering design challenges. Over time, you can modify them to "make them your own."

If you are a district administrator or university faculty member, poll school faculty under your influence and determine who would want to proceed with such an adventure with your assistance. In short, you could take what Jamerson has designed, modify and build on it, and eventually develop ownership of the resulting units. Getting parents involved along the way is crucial to the success of the idea. (Obtain curriculum and design challenge samples by emailing the author.)

Common Core Connections
SMP 1
SMP 6
2.MD.A.1

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