By Jonathan W. Gerlach

How many of our students come to the classroom with little background knowledge about the world around them and how things work? If students' hands-on experiences only scratch the surface of true understanding, they'll be left with more questions than answers. To help students develop conceptual understanding and explore the design process, I brought the NASA "Engineering Design Challenges" program to my district, redeveloped for elementary students (see Internet Resources). Our program trains teachers how to use real-world scenarios to teach scientific concepts through engineering design challenges.

Elementary Design Challenges

Fifth-grade students emulate NASA aerospace engineers as they design and build Styrofoam and paper clip planes.

At "Educators at Space Academy," I trained and completed the challenge and process myself, and a lightbulb clicked. Students need more than one chance to be successful at a task. So many times they are left thinking, "next time I would have…." The design process allows students to have that next time.

I put this program into practice in some of our renaissance Title I schools in which students seem to lack the most background knowledge when it comes to science. In a fifth-grade classroom, I taught a lesson on forces and motion while discussing how more than one force affects an object at the same time. I set the stage by telling students that they were aerospace engineers working for NASA. It was then that students began to see how science is used outside the four walls of the classroom.

PHOTOGRAPH COURTESY OF THE AUTHORS

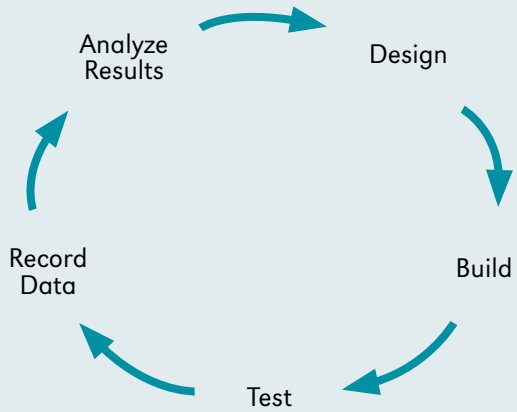
Students build their plane.

Engagement Activity

The class was engaged by a video compilation I put together of various types of planes and flying machines (see Internet Resources). (A simulation, PowerPoint presentation, or game could also be used.) This video gave them a background on what NASA has already developed, so they knew where we (NASA) had already been. I also showed them a flash animation from NASA all about X-planes through history (see Internet Resources). In general, the engagement activity should be based on a real-world scenario to build understanding of how science is used in the real world (e.g., plane design, levee design, lunar lander, or shipping container design).

Figure 1.

Design process.

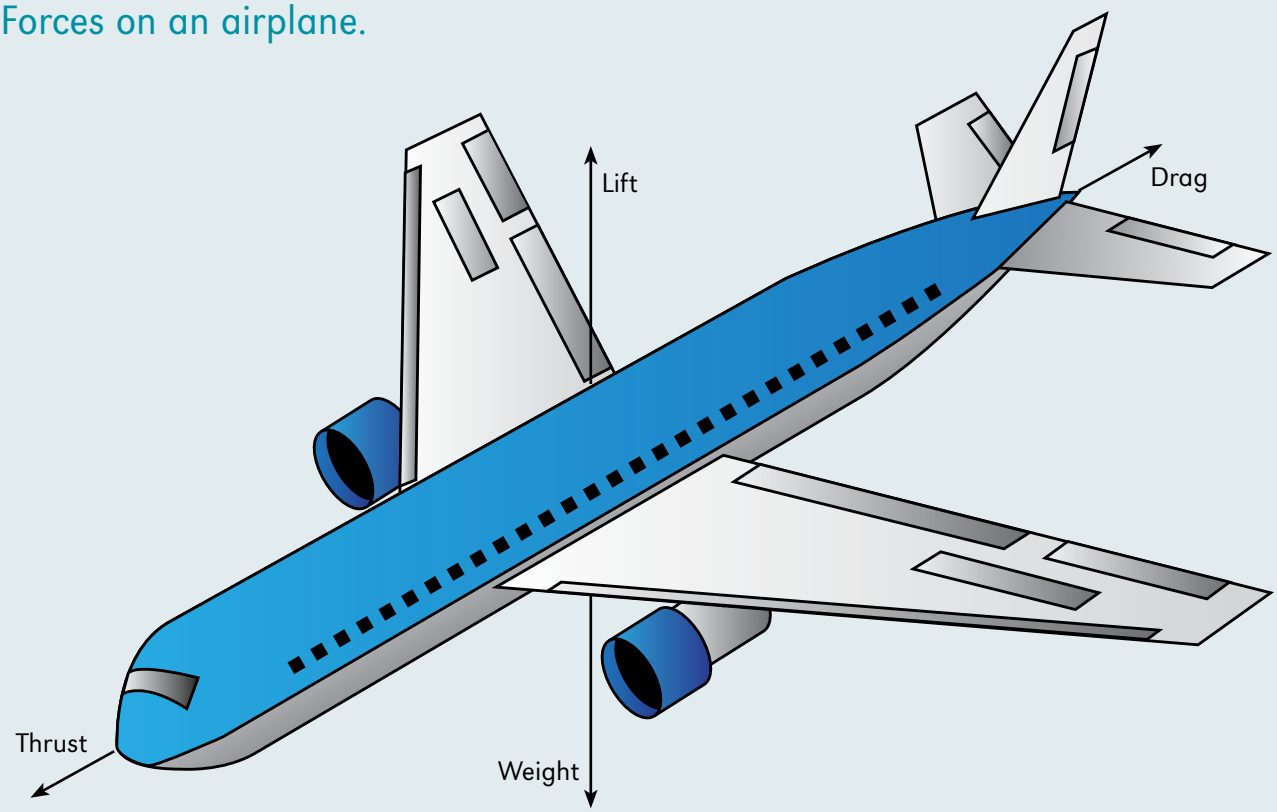


Introduce the Design Process

The design process is a learning cycle that allows students to solve problems the way scientists and engineers do in the real world. Engineers use a continual process of design–build–test–record data–analyze data and redesign until they have created a product that meets their specifications. Some engineers continue this cycle for years to solve a problem. To help students visualize the cyclic nature of the design process, I have provided a chart that you can use to lead class discussion and stimulate accountable talk (Figure 1). By having students communicate thoughts, ideas, and theories to each other and myself, students are learning the importance of communication to a scientist and they are held accountable for their own learning. Posting the design process in the classroom is a great reinforcement tool to remind students that the process is just as important as the result. The design process can also be used to teach the importance of models and how two- and three-dimensional models can be used to evaluate and discuss creations before the final outcome. During this activity, I asked students to think about how engineers might work on a product. We talked about drawing blueprints, conducting trials, and going back to the drawing board. I then showed the students the design process chart (Figure 1) and had them copy it into their notebooks.

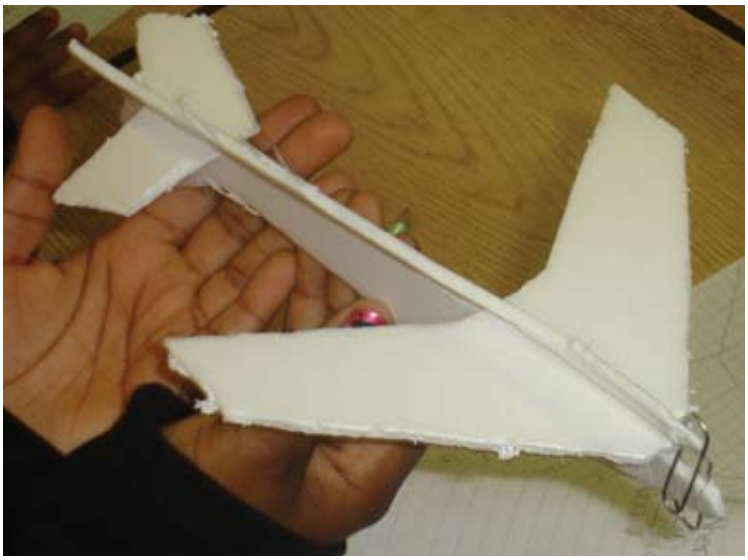
Figure 2.

Forces on an airplane.



Introduce the Design Challenge

Students should be first placed in groups of two. With this activity, too many students working on the same X-plane can make it hard to see who understands what. The teacher can set this design challenge as a contest in which students think they are competing against each other, but ultimately they are competing against themselves. Growth and seeing the learning process is what is being looked for as the ultimate goal. I challenged students to create a plane from Styrofoam and paper clips that would fly the farthest. They have limited materials, just like real scientists on a budget, and are only limited by guidelines set by their superiors at NASA.

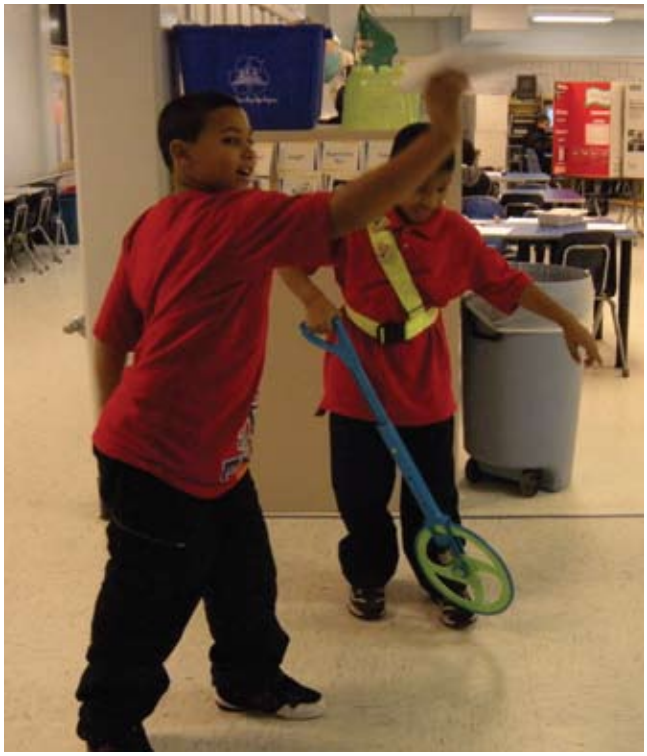


PHOTOGRAPH COURTESY OF THE AUTHORS

A student's plane is ready to fly.

In this challenge, the students will build an X-plane from provided materials that will glide through the air for the farthest distance in a straight line from the initial start point. Students first measure the distance they can get a paper airplane to fly. Then they design, build, test, and revise their own X-planes. Materials will include the following: plastic foam food tray (approximately 28 cm × 23 cm; size 12, supermarkets usually pack meat on these), paper clips (two jumbo paper clips, two regular-sized paper clips), sharp pencil, plastic knife, scissors, toothpicks (with rounded edge), and goggles (for eye protection). When students are working with sharp objects (e.g., scissors, plastic knives) precautions and

CAUTION



PHOTOGRAPH COURTESY OF THE AUTHORS

Students test their plane.

laboratory safety rules should be reviewed and followed carefully.

This challenge is open-ended and inquiry-based. I introduced the challenge and let the students begin working. Through watching the students work, I was able to see what kind of background knowledge they have in this subject. For example, a lot of students immediately built planes with small wings and no tail section, like a paper airplane. When they tested the plane, I asked them to think back on what a real airplane looks like and how their plane is different than a real plane. I was also able to assess and spot misconceptions and plan instruction accordingly. Formal instruction is provided after the students test their X-planes the first time, before I have them go back and redesign, starting the design process over. This way they are able to learn through experiences and the formal instruction clears up misconceptions and introduces vocabulary.

Many of the students in this class had never been on an airplane, had little background knowledge about planes, and had many misconceptions about how things fly. For example, many students thought planes had to go fast to fly, and they must look like jets.

Build and Test Design

Each group is given graphing paper and asked to draw a "blueprint" for its plane's design, based on how students want to build it. No real parameters are given to the students other than each group's design must be explained before building commences.

Students used an accountable talk strategy I call PB&J (Pivot, Blab, and Jot) in which they talked to a neighbor about similarities and differences in the planes they've designed, and then wrote in their journals about their discussions. Students have had experience writing in journals prior to the design challenge.

Students were allowed to change their design as they tested their plane as long as they changed their blue print as well. As students were building and testing their planes, they became lost and frustrated at times because of the lack of background knowledge they possessed. When asked questions about their planes, students explained that the designs were mostly based on cosmetic appearances (instead of an understanding of flight). They spent extra time adding racing stripes and color, instead of changing their plane design after test flights. When asked why their plane flew a certain way, they were unable to explain their thoughts. This was due to a lack of understanding of the concepts and a lack of command of terminology.

Students are often left with that feeling of wanting to try again, knowing they can do better. Before the students begin again, discuss as a class the different design successes and failures that occurred. Use scientific/engineering terminology with the students and discuss any misconceptions they have. Focus on the concept you are trying to teach. With the X-planes, we discussed balanced forces and unbalanced forces. I drew an example of a plane on the board and had students do the same in their journals. As a group we then discussed what forces might be acting on the plane and how we use the forces to make the plane do what we wanted (Figure 2). We brainstormed ideas on how to increase thrust and lift. Students always wonder why their plane seems to only do flips. This is a time to create talk about how the mass of the plane must be level to fly in a straight line. One student said, "Oh, that's what the paper clips are for…." At this point, take all the materials away, and have every team start from square one.

Modify Product

This time, as students start from square one, they will have an actual experience to base their designs on. They will have knowledge of terminology and have a beginning understanding of the concepts that may lead to success. The students were unable to do this the first time, which led to frustration, because they had no experience to look back on. The students were taking stabs in the dark or trying to design something based off misconceptions.

Each group's design is tested and recorded by the entire class. Each group discusses their ideas and design concepts

Figure 3.

Topics to consider for design challenges.

- Creating better levies: Coastal erosion
- Building a better lunar lander
- Creating the best reentry vehicle from space
- Designing the best shipping container
- Creating the best cooler to keep drinks cold in the summer
- Designing an animal to live in a specific environment
- Creating the perfect planter

before its product is tested. When students went back to the drawing board, they worked with a renewed vigor; it took them half the time to design and build their planes. Because they now had an experience to base their design on, they knew what worked, they knew what didn't work, and they had a basic understanding of the physics of flight. They started to use the terminology in their explanations and showed an understanding of balanced and unbalanced forces.

When students had to explain their final product to the class before the final test flight, there was a miraculous change in the conversation. Students were using physics to explain their designs instead of what "looked cool" and were informally assessed based on these descriptions. One group described their giant wings and weight distribution as "just like a Frisbee, the weight has to be equal everywhere…." Another group said, "…we used larger wings to allow more area for more lift…." Assessment for this lesson can be done through anecdotal notes, journal checks, and conferencing with students. The discussion that takes place between students and teacher during this lesson is critical and should show a deeper understanding.

Reflect in Journals

What worked? What didn't work? What would they change? I used a rubric to assess each student's learning through their journals and anecdotal notes (see NSTA Connection). Amazingly, the students totally forgot about the competition piece of the lesson—they were so excited about their successes and finally "getting it." One student, when writing about the changes to his group's design said, "I saw another group's plane fly real far and realized theirs looked way different than ours. When we did it again, we thought about what theirs looked like when we designed ours." Another said, "I can't always throw it super hard, you have to throw it soft sometimes to make it catch the air under its wings…."

This type of activity allows students to build their knowledge and gain that deeper understanding of concepts. There are many potential topics for design challenges; see Figure 3 for a list. We need to give students the opportunity to experience science before we start explaining science. Students are developing science skills, connecting to the real world, and developing conceptual knowledge all at the same time. Through engineering and challenging students, we are able to excite and build content knowledge in our students that will last not only until the next test, but for a lifetime ahead of them. ■

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Internet Resources

Design Challenges
www.teachertube.com/viewVideo.php?video_id=153857&title=Design_Challenges&ref=Gerlacj

Dryden Flight Research Center
www.nasa.gov/centers/dryden/history/HistoricAircraft/X-Planes/index.html

Engineering Design Challenges
http://edc.nasa.gov

NSTA Connection

Download the rubric at *www.nsta.org/SC1003.*

Connecting to the Standards

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

Content Standards

Standard A: Science as Inquiry

Grades K–8
- Understanding about science inquiry

Standard B: Physical Science

Grades K–4
- Position and motion of objects

Grades 5–8
- Motions and forces

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