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ROCKET-POWERED SCIENCE

Invent to Learn!

Create, Build & Test Rocket Designs

Ed Sobey

GOOD YEAR BOOKS

Dedicated to

Woody and Andrew

Who launched water rockets with me

On hot summer days

GOOD YEAR BOOKS

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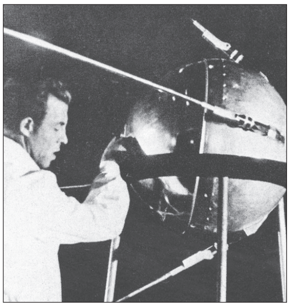
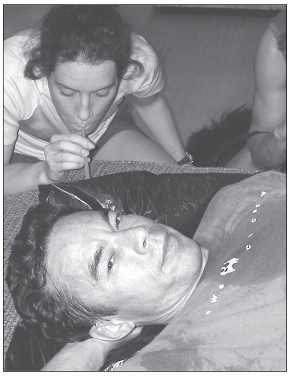
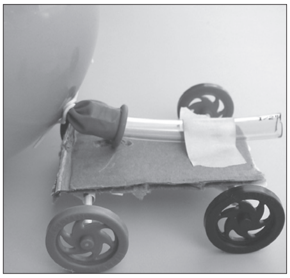
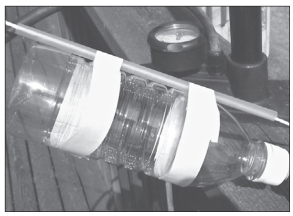
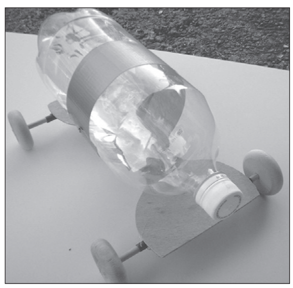











Baking Soda

Getting Started

On the Launch Pad

When you tell students that they are going to make and launch rockets, you fire their interest and focus their attention. Doing "rocket science" is as cool as science gets. Even cooler is that they get to design and build the rockets themselves. They don't follow a cookbook or pattern; they're free to express their ideas. They become rocket scientists.

You can build on the excitement and foster the interest by following our methods of "inventing to learn." Even without the methodology, these rocket activities will provide fun learning experiences. With the methodology, you will establish new levels of learning interest.

The allure of rocket science (and inventing and other sciences) is coming up with new ideas, testing them, and seeing the product of your creativity fly high. It's what fuels the excitement at NASA, and it can fuel the excitement at your school or home school. Remove the elements of self-discovery and innovation and you lessen the interest and lose much of the learning value. So, instead of teaching a unit on rocket science, create a NASA-like design laboratory. Instead of talking about rocket science, establish a team of rocket scientists and engineers who pursue their own research interests.

Your Role as Head Rocket Scientist

In *Rocket-powered Science*, the doing of science is divided into activities that lend themselves to demonstrations of phenomena ("Try This") and those that encourage experimentation ("Models to Make"). It also provides historical context for the technology being discussed ("Rocket-powered History") and examples of how the technology demonstrated is applied ("Rocket-powered Applications").

This book assumes that you, the teacher or presenter, will be conducting the demonstrations. However, students can also present them. Anyone doing a demonstration should wear safety goggles to model safety procedures.

Like the demonstrations, the models in this book are directed at an adult demonstrating to students. The models include building and testing activities, some of which encourage measurement, collection, and analysis of data. Some also encourage additional experimentation.

Your role in the lab is to provide the challenges (the tasks to be accomplished and the goals against which each will be measured) and materials, and to launch teams into higher orbits of understanding. The instructions for each demonstration and model in this book outline the challenges and list the materials you will need. Many are recycled materials that you can gather for free. The rest are inexpensive. That leaves the question of how to launch teams into higher orbits.

To get outer-space results in the classroom, treat your students as NASA engineers. Challenge them to work in teams to solve design problems that you issue. Tell them the criteria they will use to measure success and show them the materials they can use. Then, get out of their way.

Once you've issued a challenge, let teams work with a minimum of guidance. Let them make mistakes or head directly toward success without criticism. As long as they are working diligently, they are learning. Encourage them and push them to make prototypes quickly, but otherwise let them work on their own.

In designing their rockets some kids will want to sketch designs, others will talk to each other, and others will want to build immediately. All are methods of thinking. Kids express their preferred learning styles by how they undertake the design process. In learning to invent methodology, kids are free to work and think in their own ways.

Although some students will avoid making sketch designs before they build (preferring to design in three dimensions either in their minds or with their hands), they do need the experience of expressing ideas on paper. You can have them document their designs with drawings and text as part of a culminating project.

As teams work on their challenges, your job as the Design Chief is to circulate among them and check progress. You should not tell teams how they are doing or how they should be tackling the problem, but you should ask how they are doing and how

Design Philosophy

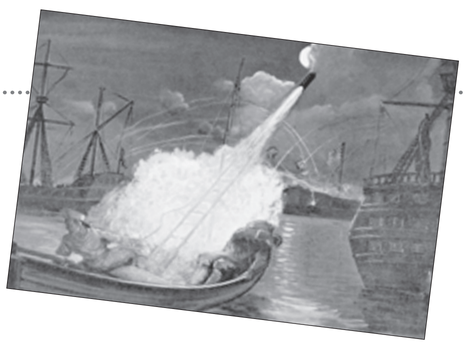
When doing something new, it's almost always better to speed through design and start making and testing prototypes quickly rather than overanalyzing what you don't know. Schools have taught students to spend time designing and thinking instead of prototyping, and you'll have to overcome this tendency. Not that we're against thinking. Quite the contrary, we're advocating thinking with brains and hands. Unless you have experience in designing rockets, you won't be able to foresee the design difficulties until you assemble the components and test them. So get on with it and understand that you're going to make mistakes.

We tell rocket scientists to work quickly and make mistakes as quickly as possible. Because they won't know if they're making mistakes until they test prototypes, they have to make their prototypes quickly.

Rocket-powered History:

The Rockets' Red Glare

During the War of 1812, British troops fired Congreve rockets at Fort McHenry in Maryland. These rockets were made before the invention of fins and used a 16-foot-long staff to guide them. Sir William Congreve developed the rockets and the British used them during the Napoleonic Wars, as well as the War of 1812. The rockets could travel as far as 1.5 miles (2.4 kilometers). Francis Scott Key, who witnessed the attack, wrote the "Star-Spangled Banner" based on the battle.



they are tackling the problem. When kids answer your questions, they have to think about what they are doing and have to express their ideas in words. The expression of ideas in words is a vital thinking process that they may avoid unless you ask them questions. Asking questions also allows them to express their existing knowledge base, showing you their level of understanding or misunderstanding.

When you see an obvious mistake—kids showing a naive misunderstanding of science—encourage them to test their ideas, and make sure you are present when they do. Faced with research results that contradict preconceived understandings, most people attribute the failings to conditions and not to their understanding. Your job at this stage is to ensure that they confront their misunderstandings and not intellectually duck out of learning. Ask them questions about what happened and why it happened. Force them to test each hypothesis they toss out as to the origin of the outcomes until they see that they need a new understanding. You can assist them by asking questions and ensuring intellectual honesty.

A case in point is making a car or boat powered by a balloon. It is common among kids (and adults) to mount a sail on the vehicle for the balloon (also mounted on the vehicle) to blow on. The thinking is that the balloon needs a surface to blow against to propel the boat or car. Of course, jets and rockets don't carry sails behind their engines, and they wouldn't work if they did. But, explaining that to kids without giving them the opportunity to test their ideas gives rise to two sets of understanding: one to use in the classroom and one to apply in the real world. Forcing the confrontation of ideas is the only way for them to consolidate their understandings. Allowing, even encouraging, balloon sail models consolidates understanding through failure and analysis of the failure.

We point out where students often make mistakes and give suggestions for where to tie in standards-based content in the boxes called "Learning Moments." These are valuable opportunities for you to help students make connections between their experiences and a firmer understanding of the science involved.

A Discussion of Failure

Failure, as Thomas Edison proclaimed, is a stepping stone to understanding. Unlike most learning activities, inventing to learn encourages thoughtful mistakes as a method of learning. In fact, it encourages making mistakes as quickly as possible as the fastest way of learning.

Accepting and even encouraging failures gives students freedom to try even their "dumb" ideas. Everyone will encourage students to test their great ideas—there is no freedom there. Allowing them to test what may appear to be dumb or what they're not confident of is granting freedom to experiment. A very few of these ideas will lead directly to success, but most will not. However, nearly all will lead to better understanding and to satiating one bit of curiosity.

Teams will work long and hard as long as you give them the freedom to make mistakes and have successes of their own design. The first design undoubtedly won't work well. New designs rarely do. It takes engineering and experimentation to find the optimal designs. This is an iterative process, like practicing hitting a ball. Each swing provides information on how to refine the swing for better results. By working fast, teams will have opportunities for many tests of their designs and will have a much better chance of meeting the design goals.

Blasting Off With Rockets, Jets, and Ballistics

Rockets move forward by burning fuels and venting them in the direction opposite to the desired travel. As the fuel burns in the combustion chamber, it generates hot gases that expand and push out the exhaust nozzle. The gases escaping to the rear force the rocket forward. This simple system provides more power than any other engine of comparable size.

Rockets are one type of jet propulsion. Jet engines in airplanes are another. In general, rockets carry their own supply of oxygen to mix with fuel so they can operate outside the earth's atmosphere. Jets and missiles operate in the earth's atmosphere and draw air into combustion chambers, where the air is mixed with fuel and burns. Aside from this difference, jet engines and rocket engines operate similarly.

A liquid-fuel rocket engine heats gases to about 5,000 degrees Fahrenheit (°F), or 2,760 degrees Centigrade (°C). This causes the gas molecules to move about three times faster than they do at room temperatures. The engine converts chemical energy stored in the fuel to kinetic energy of the moving molecules. The faster-moving molecules raise the pressure inside the combustion chamber and move toward the area of lower pressure outside the nozzle.

Note that the high temperatures of rocket exhaust gases are hot enough to melt many of the materials we commonly use. Even much cooler jet airplane exhaust reaches 3,600°F, which is hot enough to melt the aluminum that the engine is made of. Obviously, operating at these high temperatures requires development of new materials and creative engineering.

The nozzle directs the exhaust to extract the most energy possible from the gases. It only allows gas to escape in the direction that is opposite to the direction of the rocket's motion. The shape of the nozzle speeds up the exhaust and causes the pressure to drop, which transfers more thrust to the rocket. (Louis Bloomfield's book, *How Things Work: The Physics of Everyday Life*, has a nice section explaining how nozzles work.)

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A common misconnection is that these exhaust gases have to push against something to give thrust to the rocket. A physics student observed that aircraft carriers raise panels on the deck behind planes taking off to give the exhaust better leverage. (The raised panels are there to protect the people and equipment on the deck.) If this were true, rockets couldn't operate in the void of space where there is nothing to push against. It is the downward acceleration of the gases that has an equal and opposite reaction that pushes the rocket upward. The gases don't have to push on the ground to lift the rocket.

Similarly, in airplanes and helicopters the wings (or rotors) deflect air downward. Thus the wings exert a force on the air, so the air exerts an equal and opposite force on the wings. This force is the lift that keeps aircraft in the air. The downward-moving air doesn't have to press against the ground to provide lift; it provides lift because the wing deflects it downward. (If it were true that the downward-moving air has to push against the ground to provide lift, helicopters would have difficulty as they climb farther away from the ground. The upper limitation on flight is not the distance from the ground, but the density of air that the rotors deflect downward and that the engines need to mix with fuel.)

Try This:

Soda Can Engine

Here is an easy way to visualize how rockets and jets propel themselves in one direction by forcing out fluid in the opposite direction. The force powering this engine is gravity.

Materials

- Empty aluminum soda can
- String
- Nails

Procedure

1. Tie one end of the string to the tab opener on the top of the can. You can use this to suspend the can. You'll get even better results from this experiment if you tie the upper end of the string to a fishing swivel (available at sporting goods stores) to allow the string to turn without twisting.

2. Poke two holes on opposite sides of the can as close to the bottom as possible. Cover the holes with your fingers and fill the can with water. When the can is full, let the water flow out of the holes as you support the can only by the string. In a few seconds the water will have drained out of the can without imparting any significant motion to the can.

3. Insert the nail back in each of the holes and bend it parallel to the base of the can toward the left. Repeat the experiment to see water flowing out of the can toward the left side of both holes and to see the can spinning toward the right.

Explanation

By bending the nozzles (openings in the can), you created an engine. The can now exerts a force on the water to get it to flow toward the left. The water exerts an equal and opposite force on the can, pushing it toward the right.

You can repeat the experiment by making more holes or making holes with different-sized nails. Dry off the can and cover the first set of holes with masking tape. Then make a new set. See what arrangement and size of holes causes the most revolutions of the can.

Model rockets are propelled the same way large rockets are. An engine containing fuel is inserted into a hollow cylinder, often a cardboard tube. The rocketeer closes a switch that passes electrical current to a small igniter at the base of the engine.

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Soda Can Engine (continued)

The current heats the igniter and that causes the engine to burn. The engine generates hot gases from combustion, and these escaping gases lift the rocket. A launch rod guides the rocket upward, and once in the air and moving fast, fins located on the base of the cylinder guide the rocket.

Fourth of July fireworks rockets work the same way. A fuse ignites coarsely ground gunpowder, and as it burns, it generates hot gases that exhaust through an opening in the bottom. These fast-moving exhaust gases push the rocket in the opposite direction.

Rocket-powered History:

The First Engine

Hero of Alexandria invented a steam engine around AD 60. His engine used steam to spin a sphere. A fire heated water that turned into steam and flowed into the sphere, which was free to turn. He vented the steam from the sphere through two pipes, and the escaping steam turned the sphere. The soda can engine models Hero's engine; however, it uses water and gravity instead of expanding gases to propel it.

Rockets that explode or send off second stages have additional charges of gunpowder. To get gunpowder to explode, rather than ignite and burn, it is ground to a finer power, which increases the surface area available for igniting.

Rockets or missiles originally had wooden tails to provide stability. The Chinese are credited with inventing rockets around AD 1200. Their fuel was a combination of sulfur, charcoal, and saltpeter (potassium nitrate). This fuel, packed into a hollowed-out piece of bamboo, would launch skyward when ignited.

These first rockets used a guide stick to keep them traveling in the desired direction. English inventor William Hale exchanged three fins for the guide stick in the mid-1800s. This innovation greatly improved the accuracy of the rockets.

Rockets without guide sticks or fins tend to tumble in flight. As they fly, any disturbance in the flow of air past the rocket exerts a force on the rocket. The force can cause the rocket to turn away from its line of flight, and without stabilizing fins, it will continue to turn and tumble. Once it tumbles, it presents a much larger surface area for air molecules to have an impact and it quickly loses speed and falls to the ground.

To get a rocket to fly well, it needs to have some drag behind the center of mass. Fins near the base of a rocket provide drag that returns the rocket to its path.

Students (and adults, too) confuse fins with wings. Fins provide drag. Yes, drag slows the rocket down, but the drag provides control to keep the back of the rocket from racing in front of the front of the rocket (tumbling). Airplanes have wings to provide lift; of course, they also provide drag, but drag is the price you pay for getting lift. Rockets don't need lift; they use their energy to overcome the pull of gravity. Like bullets and artillery shells, rockets don't fly per se (don't require lift), but they punch through the air as ballistic projectiles.

When students build rocket models with wings (instead of fins), the results are usually disappointing. Their rockets have high drag, travel slowly, and may glide, but they don't (typically) travel far. To work effectively, fins need to be placed at the rear of the rocket and need to be as small as possible (minimizing the drag) while being large enough to stabilize the flight.

With this introduction, let us make a distinction between the different models that follow in this book. Most models are not true rockets: You'll be delighted to know that you won't have 5,000-degree blasts of exhaust gases blowing through your classroom. Two of the models use chemical reactions to generate higher-pressure gases that propel the rockets. Several of the models look like rockets and fly like rockets but are propelled with an initial launch force. Straw rockets and pneumatic blast rockets are examples. Some use jet engines (venting high pressure fluids in the direction opposite to the flight); the water rocket is one. Regardless of whether each model meets the specific criteria of a rocket, students will learn science in these demonstrations and activities.

Rocket-powered History:

Faster Than Sound

Chuck Yeager was the first person to fly a plane faster than the speed of sound, in 1947. He flew a rocket-powered plane, the X-1.