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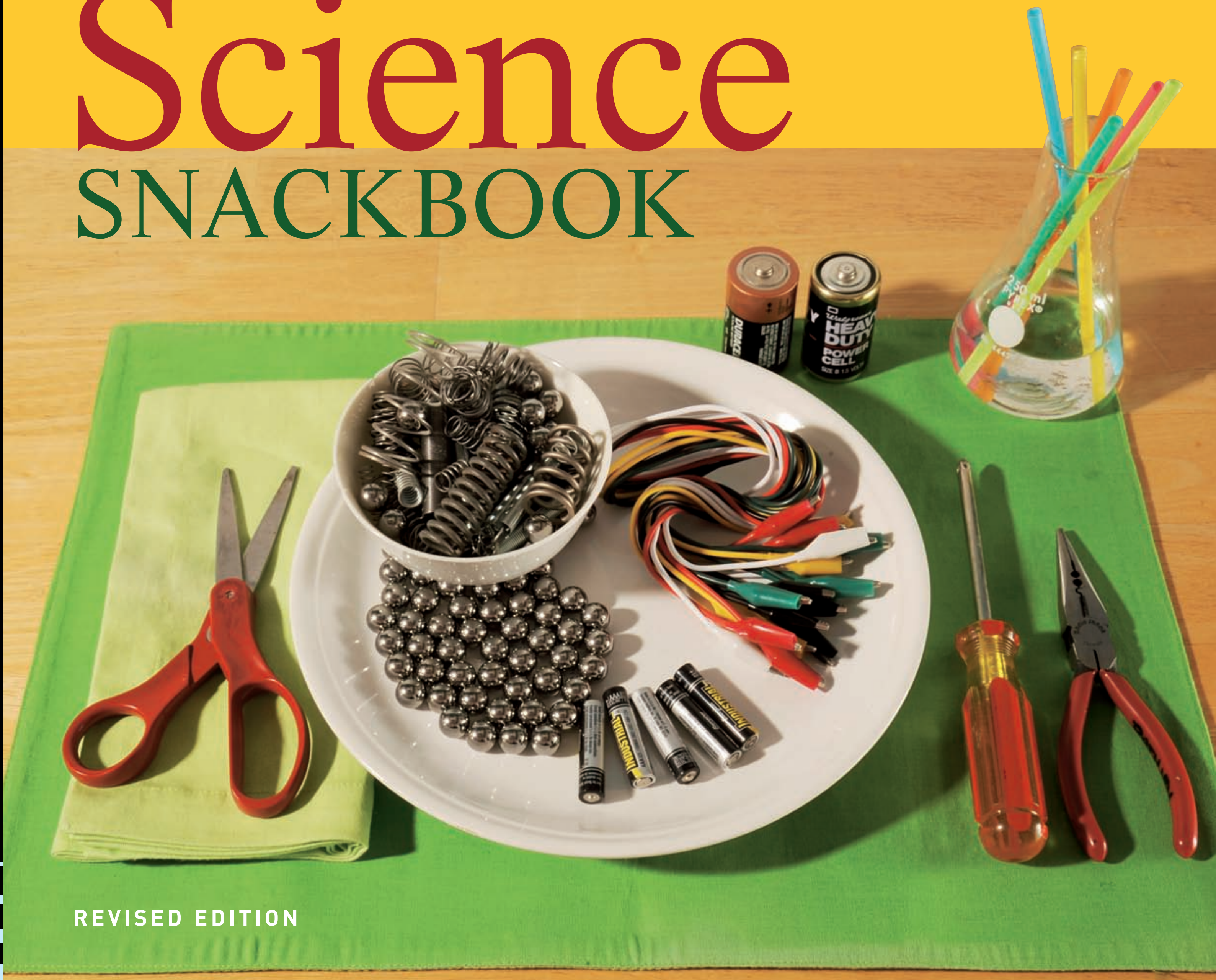
JOSSEY-BASS TEACHER 5–12

The Exploratorium Science Snackbook



REVISED EDITION

Cook Up Over 100 Hands-On Science Exhibits from Everyday Materials

The Exploratorium

SCIENCE SNACKBOOK

Cook Up Over 100 Hands-On Science Exhibits from Everyday Materials, Revised Edition

Exploratorium Teacher Institute

For the Exploratorium—www.exploratorium.edu

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Welcome to the 2009 Edition of the *Exploratorium Science Snackbook*

The Exploratorium turned forty in 2009, and this volume is just one of the many ways we're celebrating four decades of creativity, collaboration, and growth with the science-education community.

This book, originally published in 1991, began as a labor of love, as science teachers from the San Francisco Bay Area looked for innovative ways to bring the Exploratorium experience into their classrooms—all on a teacher's budget! Today, these explorations have been adapted for schoolrooms, universities, and educational enrichment programs all over the world.

We hope this new edition of the *Exploratorium Science Snackbook* continues to offer new insights and tools to inspire teaching and learning in the sciences and beyond.

Dennis Bartels
Executive Director, Exploratorium
San Francisco
July, 2009

Contents

Introduction

This book is full of Snacks … but they're not the kind you eat. Exploratorium Science Snacks are miniature versions of some of the most popular exhibits, demonstrations, and activities at the Exploratorium, San Francisco's famed museum of science, art, and human perception.

For lack of a better description, the Exploratorium calls itself a museum. But the half-million visitors who come through the doors each year don't find hushed corridors, watchful guards, or "do not touch" signs. Instead, they walk into a cavernous space filled with whirring, buzzing, spinning things, where people of all ages are smiling and laughing and calling out to one another.

At the Exploratorium, you can touch a tornado, look inside an eye, or pull a giant bubble over your head. You can make your way through a pitch-dark labyrinth using only your sense of touch, participate in a lecture and discussion with some of the leading scientists of the day, or watch the production of a live Webcast. When you're done, you might find that you understand a little more about the world around you than you ever have before.

What is a science Snack?

Since the Exploratorium opened in 1969, teachers from the San Francisco Bay Area have brought their classes on field trips. As the popularity and reputation of the museum spread, teachers began to ask if there might be some way to bring the popular hands-on exhibits to their students. Our response was the creation of the *Snackbook.*

For three years, nearly a hundred teachers from the museum's Teacher Institute worked with staff members to create scaled-down versions of Exploratorium exhibits. The results were dozens of exciting "Snacks"—miniature science exhibits and investigations that teachers could make using familiar, inexpensive, easily available materials.

Why are they called Snacks?

At the Exploratorium, nobody thinks twice when someone says they're "building a Snack." People know they're a lot more likely to get instructions for creating a mini-exhibit than they are to get something to eat. Over the years, a community of teachers has spread the term to some far-flung places, but few know how it began. In fact, three books containing detailed instructions, or "recipes," for building exact full-sized replicas of Exploratorium exhibits were published in the 1980s. These publications, designed for other science museums engaged in building their own exhibit collections, were called *Cookbooks.* Need we say more?

What can you do with a Snack?

When this book was originally published, we knew teachers would be able to use Snacks as demonstrations, lessons, and labs, and that students could use Snacks for group and individual projects. But it wasn't long before we began to realize that Snacks were really getting around.

Within a week of publication, for example, we received a message from a teacher in the Australian Outback who needed help finding materials. We heard from elementary school teachers and university professors. Art teachers were using Snacks, as were shop teachers and math teachers. Sixth-graders at one school were building their own miniature science museum. At another school, an English as a Second Language (ESL) teacher found that building Snacks helped her students interact more: Those who understood science best were helping those more adept at building things, and all were getting better at communicating with each other. Teachers from all grade levels and many subject areas were finding useful ideas in the *Snackbook.*

And it wasn't just teachers who found Snacks useful: Children were bringing Snacks home to their families. Scouts were using Snacks to help get science badges. Snacks were making appearances at science fairs, birthday parties, and impromptu "magic" shows. In some cases, Snacks even found their way back to the Exploratorium as activities and demonstrations in museum events and programming.

Why republish the *Snackbook?*

The first edition of the *Snackbook,* which gathered together 107 science explorations based on Exploratorium exhibits, was published by the Exploratorium in 1991. In 1995, a revised and updated series of four books published by John Wiley & Sons offered many of the Snacks from the original book. Over time, however, the books went out of print and became more and more difficult to find. Materials once easily available were becoming scarce as well (record turntables, for instance, have become very hard to find, as have a variety of other handy toys and gadgets).

To commemorate the Exploratorium's fortieth anniversary, we decided to bring the *Snackbook* out of retirement and make it available once again. As a testament to the staff members and Teacher Institute teachers who worked so hard to make the first *Snackbook* a reality, we decided to update the activities, but keep the funky, fun flavor of the originals. So in this new edition, we've left the 1991 version much as it was—from the simple line drawings in the Snacks to the telltale fashions of our models.

On the surface, then, this book may look a bit retro, but there's nothing old about it. In addition to redeveloping the Snacks, we've included helpful information, updated the references and resources, added a new section of sound and hearing Snacks, and included charts identifying associated National Science Education Standards. There are helpful indexes, new time estimations, and suggestions for activity extensions.

With the growing importance of science and technology, and the unprecedented challenges being faced by science teachers today, this book offers the practical tools and information teachers need to transcend the limits of their textbooks and make science come alive in the classroom and beyond.

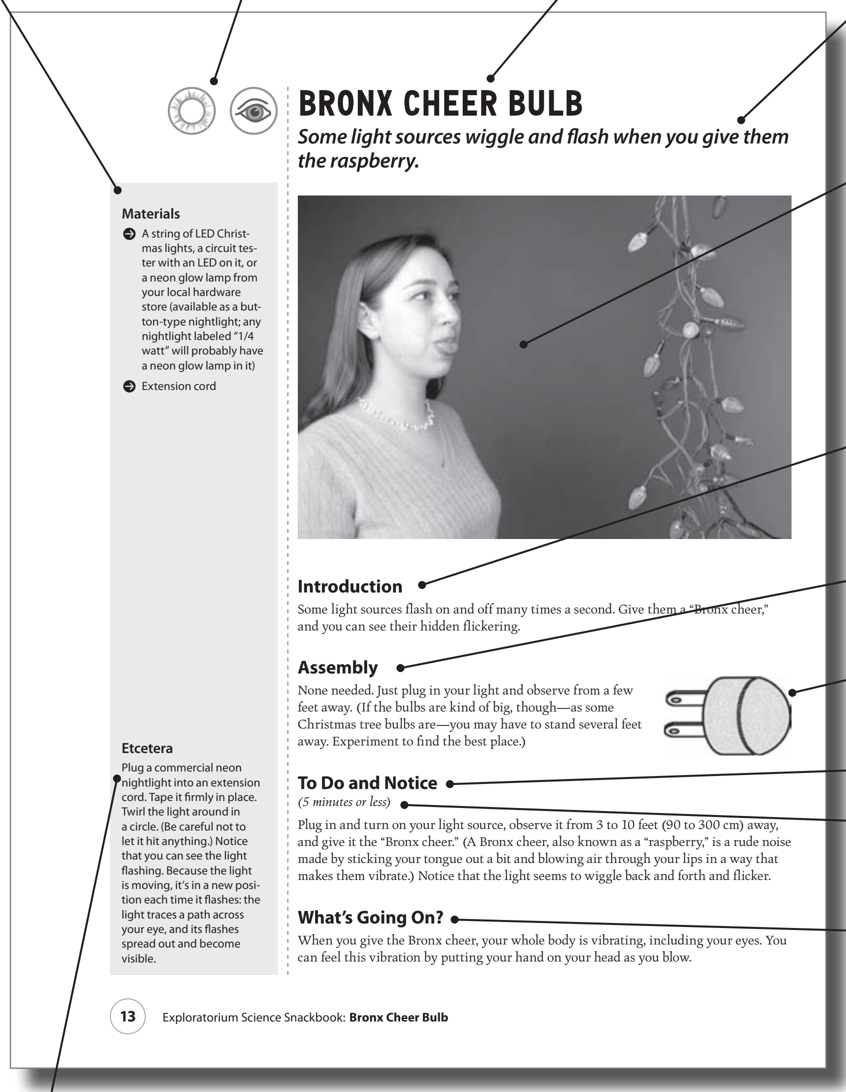
What's in a Snack?

Materials
A list of the materials you'll need to build the Snack; most include both English and metric units

Icons
Identify the major phenomena illustrated by this Snack

Snack Name
The name of an exhibit or activity created by Exploratorium staff

One-Liner
A one-line description of the Snack



BRONX CHEER BULB

Some light sources wiggle and flash when you give them the raspberry.

Materials

- A string of LED Christmas lights, a circuit tester with an LED on it, or a neon glow lamp from your local hardware store (available as a button-type nightlight; any nightlight labeled "1/4 watt" will probably have a neon glow lamp in it)
- Extension cord

Introduction

Some light sources flash on and off many times a second. Give them a "Bronx cheer," and you can see their hidden flickering.

Assembly

None needed. Just plug in your light and observe from a few feet away. (If the bulbs are kind of big, though—as some Christmas tree bulbs are—you may have to stand several feet away. Experiment to find the best place.)

To Do and Notice

(5 minutes or less)

Plug in and turn on your light source, observe it from 3 to 10 feet (90 to 300 cm) away, and give it the "Bronx cheer." (A Bronx cheer, also known as a "raspberry," is a rude noise made by sticking your tongue out a bit and blowing air through your lips in a way that makes them vibrate.) Notice that the light seems to wiggle back and forth and flicker.

What's Going On?

When you give the Bronx cheer, your whole body is vibrating, including your eyes. You can feel this vibration by putting your hand on your head as you blow.

Etcetera

Plug a commercial neon nightlight into an extension cord. Tape it firmly in place. Twirl the light around in a circle. (Be careful not to let it hit anything.) Notice that you can see the light flashing. Because the light is moving, it's in a new position each time it flashes: the light traces a path across your eye, and its flashes spread out and become visible.

13 Exploratorium Science Snackbook: **Bronx Cheer Bulb**

Introductory Photo
Shows a completed Snack and how it's used

Introduction
A brief overview of the Snack

Assembly
Instructions, advice, and helpful hints for building the Snack

Illustrations
Show construction and use details

To Do and Notice
Instructions on how to use the Snack

Timing Estimates
Shows time needed

What's Going On?
An explanation of the physical principles involved in the Snack and the phenomena behind them

Etcetera
Related activities or information of interest

IMPORTANT SAFETY MESSAGE

(!) BE CAREFUL The experiments in this volume were designed with safety and success in mind. But even the simplest activity or the most common materials can be harmful when mishandled or misused. Use common sense whenever you're exploring or experimenting.

Icon Key


Chemistry

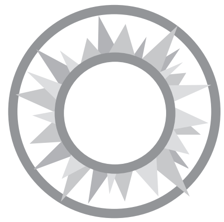

Color


Electricity

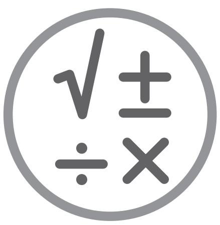

Fluids

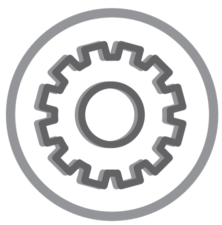

Heat


Life Sciences


Light


Magnetism


Math


Mechanics


Perception

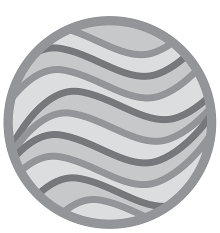

Polarization


Reflection


Refraction


Resonance


Sound


Waves

HOW TO USE CONTENT ICONS

Watch for the icons that accompany each Snack. Each icon represents a concept addressed, and/or the foundational ideas introduced or supported by the Snack. In addition to being a quick way to see how a Snack might be used for teaching and learning, icons can also offer ideas for extending and connecting concepts in the classroom.

Tips and Tales—By Teachers, for Teachers

The first *Snackbook* was published in 1991, and over the years, we've heard from hundreds of teachers and youth leaders who wanted to share their Snack-related ideas and experiences. Here are some helpful stories and suggestions—by teachers, for teachers.

Making Your Own Science Exhibits

In the years before the Snackbook *was published, teachers working with the Exploratorium Teacher Institute began experimenting with creating classroom-sized versions of museum exhibits. Erainya Neirro was so energized by the experience that she took it back to her classroom.*

Over the years, I've noticed that science becomes "real" for those students who can put something together and watch what it does. While looking for ways to expand my own repertoire of science activities for kids, I enrolled in a class offered by the Exploratorium Teacher Institute. I had such a great time! For six weeks, twelve teachers became inquisitive, involved students. We roamed the museum and played with exhibits. Our goal was to choose an exhibit and build a model that would somehow demonstrate the same scientific principle that the sophisticated Exploratorium exhibit illustrated.

During the class, I built four of my own original mini-exhibits and watched my colleagues construct and improve their own. I was more excited about hands-on science than ever. But most important, I really enjoyed and relied on the support of the other teachers as we all struggled together to perfect exhibits that sometimes worked—and sometimes didn't. I came away with innumerable projects for my classroom and the realization that this kind of approach didn't have to be just for teachers. My kids could do the same thing—learning about science, working with the support of their peers, doing things on their own, and having fun. I wanted my students to have this experience.

Since Presidio Hill School is close to the Exploratorium, most of my students were familiar with it. When I suggested the idea of an "Exploring Science" project based on my own experiences at the Exploratorium, the response was overwhelmingly enthusiastic. I brought in the four exhibit models I had built and let my students play with them. I told them that the Exploratorium exhibits I had replicated looked very different from my models, but both "said" the same thing about physics. Like me, the students wouldn't copy the construction of an exhibit; each student had to find some way to build a model that would show the same scientific principle that an Exploratorium exhibit demonstrated.

Finally, we were ready for our first visit to the Exploratorium. Once inside, the kids were given an hour to play with exhibits and pick one they wanted to replicate. This exploration time was essential, since each person was expected to build a different exhibit. As students made their decisions, they came right back to me: They knew that it was first come, first served.

TIP

Hone your scavenging skills! Most Snacks can be done with familiar materials that are inexpensive and easily available. In fact, students can help keep the classroom stocked. Make finding materials fun by assigning bonus points for bringing in items or by organizing a swap meet or treasure hunt. Get parents involved, and see what you can stockpile for your classroom.

Over the course of three visits to the museum, each student chose three different exhibits that demonstrated many different scientific principles, but several favorites came from sections of the Exploratorium that demonstrated perspective, vision, color, and light. Two favorites were Bird in the Cage and Blue Sky. If you look at the Bird in the Cage Snack (page 11), you can see its potential flexibility: A variety of colors and shapes can be used to demonstrate the concept of afterimages. The Blue Sky exhibit (page 123) is appealing because it's easy for the kids to figure out what they will need: essentially, water and some kind of light source. Besides this relatively simple assembly, Blue Sky answers a question that fascinates them: "Why is the sky blue?"

Once choices had been made, I asked students to tell me how they would design the exhibit for the classroom. It was important to assess whether their plans were feasible; occasionally, I had to make suggestions to help simplify the process. I also had to direct one or two students to do different, less complicated exhibits.

While at the museum, I left students alone so they could sketch preliminary designs and write notes from the information at each exhibit. I asked them to think about how other people would use their model and to consider the science their model would illustrate. Before we left the museum, I checked each student's designs and notes at least once. Many had to return to an exhibit to clarify some point or get more information. My class and I were at the Exploratorium approximately four hours during each of these three field trips.

Back at school, several class sessions were devoted to building science projects. We all brought in a variety of materials. Like most long-term science teachers, I have lots of stuff. I asked each child to get a sturdy shopping bag with handles so they could easily carry "in process" exhibits from school to home and back. Of course, this presented its own problems. Some of my students ended up misplacing their half-built exhibits; some left their projects on the bus. Other projects and materials just sort of "disappeared." None of the materials were expensive or irreplaceable, but it was no fun for those unfortunate students to start over again.

In the classroom, students selected the materials they needed and helped each other with the construction of the exhibits. I was amazed at how little they needed my help. These sessions were chaotic but wonderful. We had materials all over the room and at least three conversations going at once. We might start with a question like "What color should I make this part of my spinning disk?" and end up with a complex examination of how cones in the human eye actually work. Not everything went perfectly, of course. But, all in all, these sessions were very productive. The kids were committed to building with care. If something didn't work the first time, they pitched in to help each other.

Besides the time spent building the models, finishing details were sometimes done at home, and homework included doing a rough draft of a paper explaining each exhibit. As for the math part of the curriculum, it taught itself. The kids were so busy calculating, counting, and measuring, they hardly even noticed how much they were learning.

Finally, we had Evaluation Day. The students presented their projects and let their peers play with the finished exhibits. This display generated the kind of peer support I was hoping for. The majority of my kids were so invested in their work that each one came away with something they were proud of and thoroughly comprehended.

Their classmates were genuinely impressed. They had all seen the prototypes in various stages and now got to play with a finished model. I didn't have to use an inadequate textbook or workbook: I had a kid-directed course that was highly productive, encouraged peer support, and built the self-esteem of every student.

I encourage any teacher to give these hands-on experiments a try. Once you have a set of these demonstrations in your classroom—whether you do it by working with a local museum or by building the Snacks in the *Snackbook*—you'll have a student-built museum of your own.

TIP

It's great to have lots of Snack materials around, but don't forget the tools! Have simple tools available, and take the time to help students understand tool safety and use.

Building a Mini-Exploratorium

Before he joined the Exploratorium's Teacher Institute staff, Modesto Tamez found a variety of unconventional ways to use Snacks—in the classroom and out.

One of the true joys of teaching is when you see the "lights go on" in a student's eyes: the lights of curiosity, wonder, and understanding. That's what I see when the tools for teaching are hands-on experiments that students choose and build themselves. With a little organization and effort, these projects can form the basis of a science museum in a classroom, a resource that can be shared with the entire school.

Creating a miniature science museum is easier and cheaper than you might think. I recently organized two science classes to build fifty-five exhibits. The exhibits took us a little over a month to complete and cost about $300. The rewards in student pride and knowledge—and the attention the mini-Exploratorium garnered for the school's science program—were well worth the time, effort, and expense. You can do it, too, with help from the *Exploratorium Science Snackbook.*

I start by building ten or twelve Snacks to demonstrate. I choose easy-to-handle projects and show them to my students, stressing how quick they were to assemble. On the first one or two Snacks, I go slowly through the demonstrations and spend some time helping students figure out the science behind what they're seeing.

For example, I recently used a modified version of the Fog Chamber Snack (page 97) to introduce the concept of air pressure. I stretched a rubber glove over the opening of a glass jar so the fingers of the glove dangled inside the jar. I chose one of the larger boys in the class to help demonstrate and asked him to put his hand all the way inside the glove. Much to the amusement of the rest of the class, he couldn't force his hand in. After they stopped giggling, I asked the students to guess why: What was already in the jar that might keep someone's hand from going in? They answered: "air." This is a very simple experiment, but with it I introduced a fundamental scientific principle to a class that had had no previous instruction in any of the physical sciences.

Sometimes I take a completely different approach to a Snack, as I did recently when I demonstrated the Doppler effect (page 249) to four separate science classes. The students assembled on a grassy knoll outside the classroom while I ran to get my car. For the next few minutes I zoomed past them—back and forth—blaring my horn as they cheered and waved. The students said they could clearly hear the Doppler effect: the pitch of the horn got higher when the car moved toward them and lower when it moved away. The experiment worked great until the fourth and final class. As I was cruising down the street with my hand jammed on the horn, I saw the flashing red lights of a police car in my rear-view mirror. The students, of course, were delighted. Peering into my car, a puzzled officer inquired, "What are you doing?" A school security guard, familiar with my antics, finally came to my rescue. "It's okay," he explained, "he's just a crazy science teacher."

After one or two demonstrations, I give my students some time to play with the completed Snacks. Don't worry if you can't answer all their questions or if some Snacks don't work the way they should. If something goes wrong, tell the class that trial and error is part of the scientific process. Tinker with the Snack and have the students help you figure out what's wrong. Pitching in and working together to solve a problem is a crucial part of doing hands-on science.

Once the students have been introduced to Snacks, it's time for them to build one of their own. I usually select a range of Snacks that I think are appropriate for my class level, pass them out, and have each student choose several favorites. If other students choose the same Snack, I may have to give some of them an alternate choice. Sometimes I opt for one of the harder Snacks if I want to challenge a student I know is capable of handling a more difficult assignment.

After the students know which Snacks they're building, I give them a week to gather materials. Some materials will be in the classroom; others they'll have to find for themselves. I also tell them it's okay if their Snack isn't exactly the same as the one in the book—it just has to make the same point. Then it usually takes three to four weeks for the students to assemble their Snacks and put on the finishing touches. If they run into problems or want to try a different approach, I talk it over with them. I'm always amazed at the creative solutions my students come up with; often, a modified Snack is an improvement over the original.

TIP

Snacks offer great team-building opportunities. Have groups help one another, and let the strengths of each student shine.

TIP

Keep common Snack supplies and materials and simple tools in the classroom for students to use, and give them time to experiment. Watch for opportunities for students to test out their own questions and ideas.

As the students experiment, they also work out the science behind their projects. The final step is writing and producing "graphics," the instructions and explanations that accompany each project.

Once the Snacks are built and the graphics completed, it's time to unveil the mini-Exploratorium. The Snacks are assembled on long tables in the classroom, and I assign four students at a time to be "Explainers," science guides who answer visitor questions. This means that students must be familiar with all the Snacks, not just their own. You can invite the whole school to the mini-Exploratorium. I'd also suggest a special parents' night exhibition. If you invite school administrators to the event they might be so impressed with the students' work that they loosen the purse strings for other innovative science programs!

Finding a New Approach to the Science Fair

Eric Kielich, science department head and teacher at the Mount Tamalpais School in Mill Valley, California, sees the creativity and ingenuity involved when his students build Snacks to be an important part of the learning experience.

As part of our curriculum, students present a mini-Exploratorium at our Middle School Science Night. Students select their projects from an Exploratorium activity publication, or from Snacks on the Exploratorium Web site, which is available on the computers in our school library. Students are made aware of the expectations and requirements of the assignment, are given a printed sheet that outlines the project for them, and are shown some of the past years' exhibits for ideas. The mini-Exploratorium projects are intended to be interactive and relatively easily constructed with a minimum of time and expense. Parents are encouraged to be supportive, but to keep their role to an advisory one.

Each Snack is to be accompanied by a self-standing display board that provides the necessary information for a person to interact independently with the activity. At the very least, it should include the title, the materials needed to assemble the Snack, and "To Do and Notice" and "What's Going On?" sections. Any additional information about the Snack that provides some insight for the participant is encouraged.

Since this assignment is one that students work on independently and mostly at home, it is important for them to have a definite plan for its completion. Students can ask for advice if they need help. Grades for the mini-Exploratorium Snacks are based on a number of considerations:

- Degree of challenge
- Innovation
- Classroom presentation

• Science night presentation

• Effectiveness of the exhibit and display board

• Meeting all due dates

These criteria are mostly subjective—and are intended to be. This assignment is not like taking a test—effort, ingenuity, and creativity are as much a part of this assignment as the completion of the display. If students challenge themselves and put in the necessary effort, they will do fine. The whole experience has proven to be a very positive one for all involved.

Placing Hands-On Materials Around Your Classroom

Before he "retired," longtime Exploratorium teacher and Snackbook *co-author Don Rathjen liked to leave intriguing tools and materials around his classroom and then watch as his students discovered them.*

Don Rathjen, known to other teachers as Mr. Snack, designs and builds hands-on exhibits, then uses them as demonstrations in his high school physics classroom in Pleasanton, California. Don knows how to grab his students' attention. He breaks a Pyrex stirring rod in half, drops both halves into a beaker filled with Karo syrup, and lets his students watch as they disappear in the fluid. Then he puts his hand in and pulls out a whole rod. Of course, the pieces of the broken rod are still in the beaker—and the unbroken rod was there all along. They just couldn't be seen.

This simple demonstration, called Disappearing Glass Rods (page 145), is one of Don's favorite Snacks. He leaves the beakers and rods and syrup lying around his classroom for months. The students who play with them get sucked into exploring and discovering science on their own.

When you enter Don's classroom, you may come face to face with a book-sized Fresnel lens hanging from the ceiling (see Giant Lens, page 149). Don tells of students who duck under the lens for months, and then suddenly discover it. When Don teaches optics, he uses the Giant Lens as a demonstration. By holding the lens at just the right distance in front of his face, his class sees his head replaced by a giant eye. The students laugh, but they want to try it, too.

Don always has his eyes open for interesting science materials. He find them at plastics stores, toy stores, even flea markets. A Fresnel lens that came from the back window of a delivery van looks just like the one Don has hanging in his class but produces the opposite visual effect. When Don holds it in front of his face, his head appears to shrink. The students love it.

Even if lenses are not a part of your curriculum, says Don, don't let that stop you from leaving them around for kids to experience. Don's classroom is filled with attention-getting materials: a gyroscope fashioned from a bicycle wheel, a pile of blocks used to demonstrate center of gravity, pendulums that swing

TIP

Make sure you know where students can obtain any specialized materials or equipment they might need. That way, their time is not spent in fruitless or frustrating searches. Instead, use even the search for materials as an educational opportunity—helping students with online research skills, for example, or introducing unfamiliar equipment or materials. Each step of building a Snack can be a learning experience.

TIP

Remind students that testing a Snack to make sure it works is part of the process—and be sure they know it's not a problem if things don't work perfectly the first time they're used. Reinforce the idea that science is trial and error, and that it's okay to make mistakes. Solving problems and fixing errors can lead to improvements and insights that might otherwise be missed!

in peculiar ways, and many, many more. These attention-grabbers motivate students. Try them yourself. You may be surprised at the discoveries both you and your students make.

Using Snacks as a Science Library

Teacher Judith Christensen finds a wealth of potential in Snackbook *activities, from helping kids understand science to helping them understand each other.*

In Judith Christensen's physics class, thirty-six high school sophomores are packed around six laboratory tables. The crowded class contains members from a variety of ethnic backgrounds: Asian, African American, white, Latino, and more. The class is popular, but students know they're expected to pitch in and work because, in Ms. Christensen's class, you learn science by doing science.

Judith organizes her class into six multiethnic groups. Each group builds its own equipment, does a scientific investigation using that equipment, and then presents oral and written reports based on its explorations. The students also evaluate each other's work. This day, the class is building the Electroscope Snack (page 95). Once the electroscopes have been constructed, the students will use them to investigate electrostatics.

For this lab, all the teams have successfully built electroscopes by draping charged strips of tape over bent soda straws stuck into film cans full of clay. Judith found the tape in administrative supplies; the straws were donated by a local fast-food restaurant; the film cans came from a neighborhood camera store; and the clay came from Judith's own collection of supplies. The resulting electroscopes are not black boxes made by some science supply house; there are no hidden or mysterious parts. The students have built them, and so "own" them. If an electroscope breaks, the students fix it or build a new one.

To build the exhibits, each team draws on the talents of all its members. Some students are better at figuring out how to build the equipment from the illustrations and photos, some are better at reading, others are better at making things work. If you listen carefully, you'll hear discussions in Cantonese, Vietnamese, and Spanish, but English is the *lingua franca* of this classroom. Students who are better at English become language teachers for the others in their group. Students who are better at science become science teachers, even if they're just learning English. The final result is a team effort.

In addition to science and English, students in this classroom are learning about different cultures. Judith finds that when students from different backgrounds work together, they become more understanding of each other. As a spur to participation, she requires that the groups give each member a group cooperation grade.

Judith doesn't have all the answers for her students' questions, but she admits when she doesn't know them and encourages her students to help her find the answers. Each year, she and her students learn more about science. And each year, the students guide Judith toward becoming more comfortable and adept at helping them to find their own answers.

Offering Hands-On Science in Nontraditional Classrooms

Snacks can be used in many different learning environments. Here, Vivian Altmann, director of the Exploratorium's Educational Outreach Department, takes one exploration to a community center and leads kids in a friendly competition that keeps them thinking and working together.

TIP

Experiment with Snacks. Don't be afraid to make adjustments, changes, and alterations, and see what happens. Modify and improve Snack designs yourself, and encourage your students to do the same.

Vivian Altmann and her team regularly visit the Whitney-Young Community Center in Hunters Point, in San Francisco, with boxes of hands-on activities. The boxes contain parts for the Stripped-Down Motor Snack (page 117). The teenagers in the room are labeled at-risk and underserved, but once they get going, it's hard to tell them from any other group of energetic kids.

After the usual introductions, Vivian divides the kids into teams. She gives each group a length of insulated wire, a paper cup, twenty cents' worth of small magnets, two paper clips, a battery, and a rubber band.

The teams immediately initiate a friendly competition to see who can build the "best" motor. Soon, one team has its motor turning, then another team. The groups compare motors to see whose is fastest. When one group can't get their motor to run, Viv gets the "experts" from another team to help. The kids decide to swap parts between motors: the problem turns out to be a dead battery! The motor construction is just fine, after all. The kids razz the Exploratorium team for bringing them a dead battery, and then turn back to their motors. The room is buzzing.

TIP

Encourage improvisation and innovation. Once students understand that they can find science-rich materials all around them, challenge them to design their own Snacks and devise their own experiments.

Without even noticing it, these kids are learning about electricity, magnetism, and motors. When the kids make guesses about what will make their motors run better, and then test them, they are doing science. Will twice as many magnets make the motor turn twice as fast? Vivian answers by giving the team more magnets. The motor turns faster, but not twice as fast. What about using two batteries? The questions and suggestions come thick and fast, and the kids get the satisfaction of making discoveries on their own. They're learning important techniques for answering questions and solving problems; they're working cooperatively, making new friends, showing off their skills, and succeeding in science.

Building an Interactive Science Museum

Charles Reynes, a science teacher at Creekside Middle School in Castro Valley, California, takes a different approach to using Snacks. By adapting the instructions in the

Snackbook*, he's built his own traveling museum, which he uses in demonstrations for students throughout the area.*

Using the *Exploratorium Science Snackbook* as a resource, I built twenty exhibits and set up a museum. Since durability was a concern, I beefed up each Snack whenever possible. My water spinner, with its acrylic tank and three-quarter-inch plywood turntable, has survived for more than twelve years. I used the write-ups in the *Snackbook* to create exhibit signs. The *Snackbook* also provided a template for me to use when I created my own Snacks. My museum currently has about forty exhibits.

Building the museum has not been easy. Most of my projects are built with scrap materials, so the size and shape depend on what's in my scrap pile. I collect and save lots of junk. I purposely keep the projects simple because I believe that a slick production sometimes hides the science. Whenever possible, I try to keep the projects small enough so they will fit into those red flip-top storage crates that are sold at Home Depot. In each case, I store the exhibit and the sign explaining it.

After a time, it can become difficult to maintain so many exhibits, so I have had to let some go. I have replaced some and added others. I have several groups that have reimbursed me for expenses or have paid to have me put on a science night for their school. These events energize me and help keep the museum going. I have also set up the museum at California State University Hayward, the lobby of the Tech Museum in San Jose, and at the Union City Science, Earth, and Health Festival. Often, my students serve as docents.

The *Snackbook* has been a valuable resource. As I built Snacks, I began to think more creatively, developing a taste for what motivates and inspires. I like to think of myself as a Snack chef!

Taking Snacks on Tour

Former Teacher Institute staff member Curt Gabrielson takes the idea of the mini-Exploratorium one step further. His classes not only build Snacks but also take them on tour!

When students get the opportunity to create work for an audience beyond the teacher and the classroom walls, the results are truly staggering. The satisfaction and confidence boost that students gain may even outshine the enormous amount of self-led learning that goes on.

Another dimension is added by going on tour. Instead of making arrangements for guests to come to us, we take our mini-Exploratorium to them. Our guests are primarily students at other schools. We go to at least one school and try to hit two or three classes at a minimum. When the introductions have been made, and the small groups of guests are moving from Snack to Snack, there is nothing to do but sit back, smile, and take some pictures. While it is

TIP

Be sure to build some Snacks yourself. Be flexible: Admit it when you don't have all the answers, and be open when your attempts fail. Share the process, not just the product, with your students.

TIP

Keep several copies of the *Snackbook* in the classroom so you have a few that can be signed out to "travel." That way, students can check out copies to take home or use independently.

advisable to have a small tool kit (hot glue, tape, wire, pliers, scissors, spare parts) on hand for emergency breakdowns, these presentations are often classes that run themselves.

This kind of "exhibit on tour" is a win-win-win-win situation. Both sets of students gain enormously, the teacher of the class where you are presenting sees that this is doable and may be inspired to do it in the future, and you have provided exceptional quality education while also getting considerable satisfaction.

Dealing with the logistics of the mini-Exploratorium can be frightening: finding materials, coordinating students and guests, ensuring correct understanding of concepts with each team and making sure everyone is done on time. But, taken a step at a time, it is manageable, and the results are well worth the effort.

The mini-Exploratorium can be a great way to wind up the year or an exciting ice-breaking project with a new class to start the year off right. It constitutes a fantastic science unit for students from elementary through high school and can be focused on any area of science. Of course, a great way to begin or end this unit is with a field trip to your local science museum.

PART ONE THE CHESHIRE CAT AND OTHER EYE-POPPING EXPLORATIONS OF HOW WE SEE THE WORLD

How do you see the world around you? You open your eyes and there it is: your room, your desk, the pictures on the walls, the trees outside your window.

When you take a look at the world, here's what's happening: Light is bouncing off the pictures, the trees, and all the things out there in the world. Some of that light gets into your eye. This light shines through the cornea, the tough, clear covering over the front of your eye, and then through the pupil, the dark hole in the center of your iris, the colored part of your eye. Your eye's lens focuses this light to make an image on your retina, a thin layer of light-sensitive cells that lines the back of your eyeball. The light-sensitive cells of the retina signal the brain, and the brain creates a mental image. Finally, you see the world "out there."

People have compared the eye to a film-loaded camera—and for good reason. Both your eye and a camera have adjustable openings that let in light: the pupil of your eye and the aperture of a camera. Both focus the light to make an image on a light-sensitive screen: the retina of your eye and the film of a camera.

But unlike a camera, your eye doesn't just passively record the image it receives. Working together, your eyes and brain decide what to see and how to see it. They fill in gaps in your visual field, taking limited information and creating a complete picture. They interpret the limited and distorted images that they receive and try to make sense of the world out there, often using past experience as a guide. They constantly filter out and ignore extraneous information.

You don't believe it? Then close one eye and take a look at the tip of your nose. You can see it clearly if you think about it. It's always in your view. Open both eyes and you can still see it, a shadowy protuberance in the center of your visual field. If you think about the tip of your nose, you can see it—but most of the time you don't notice it (even though it's as plain as the nose on your face).

The experiments in this section will show you some other sights you usually don't notice. Some experiments, such as Blind Spot, Pupil, and Afterimage, will help you understand more about how your eye works—its abilities and limitations. Others, like Vanna and Far-Out Corners, show how prior experience often influences perception: how what you "see" may not be what you "get." Still others, like Persistence of Vision and Jacques Cousteau in Seashells, demonstrate that your eyes and brain work together to make a picture of the world. Finally, some show how your eyes and brain can make mistakes in their interpretation of the world—mistakes that create optical illusions, deceptive pictures that fool your eyes.

Taken together, the experiments in this section let you explore visual perception, a fascinating interdisciplinary topic where biology and psychology overlap.

AFTERIMAGE

A flash of light prints a lingering image in your eye.

Materials

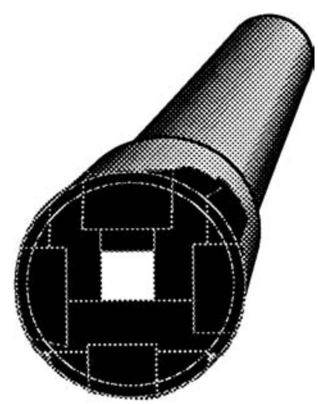
- Opaque black tape (such as electrical tape)
- White paper
- A flashlight

Introduction

After looking at something bright, such as a lamp or a camera's flash, you may continue to see an image of that object when you look away. This lingering visual impression is called an afterimage.

Assembly

(15 minutes or less)



1. Tape a piece of white paper over a flashlight lens.
2. Cover all but the center of the white paper with strips of opaque tape.
3. In the center of the paper, leave an area uncovered where the light can shine through the paper. This area should be a square, a triangle, or some other simple, recognizable shape.

To Do and Notice

(15 minutes or more)

In a darkened room, turn on the flashlight, hold it at arm's length, and shine it into your eyes. Stare at one point of the brightly lit shape for about 30 seconds. Then stare at a blank wall and blink a few times. Notice the shape and color of the image you see.

Try again—first focusing on the palm of your hand and then focusing on a wall some distance from you. Compare the size of the image you see in your hand to the image you see on the wall.

Close your left eye and stare at the bright image with your right eye. Then close your right eye and look at the wall with your left eye. You will not see an afterimage.

What's Going On?

You see because light enters your eyes and produces chemical changes in the retina, the light-sensitive lining at the back of your eye. Prolonged stimulation by a bright image (here, the light source) desensitizes part of the retina. When you look at the blank wall, light reflecting from the wall shines onto your retina. The area of the retina that was desensitized by the bright image does not respond as well to this new light input as the rest of the retina. Instead, this area appears as a negative afterimage, a dark area that matches the original shape. The afterimage may remain for 30 seconds or longer.

The apparent size of the afterimage depends not only on the size of the image on your retina but also on how far away you perceive the image to be. When you look at your hand, you see the negative afterimage on your hand. Because your hand is near you, you see the image as relatively small—no bigger than your hand. When you look at a distant wall, you see the negative afterimage on the wall. But it's not the same size as the afterimage you saw on your hand. You see the afterimage on the wall as much bigger—large enough to cover a considerable area of the wall.

The afterimage is not actually on either surface—it's on your retina. The actual after-image does not change size. The only thing changing is your interpretation of its size.

This helps explain a common illusion you may have noticed. The full moon often appears larger when it is on the horizon than when it is overhead. The disk of the moon is the exact same size in both cases, and its image on your retina is also the same size. So why does the moon look bigger in one position than in the other?

One explanation suggests that you perceive the horizon as farther away than the sky overhead. This perception might lead you to see the moon as being larger when it's near the horizon (just as the afterimage appeared larger when you thought it was on a distant wall), and smaller when it's overhead (just as the afterimage appeared smaller when you thought it was in the palm of your hand).

Negative afterimages do not transfer from one eye to the other. This indicates that they are produced on the retina and not in the visual cortex of the brain where the signals would have been fused together.

Etcetera

For up to 30 minutes after you walk into a dark room, your eyes are adapting. At the end of this time, your eyes may be up to 10,000 times more sensitive to light than they were when you entered the room. We call this improved ability to see "night vision." It's caused by the chemical rhodopsin in the rods of your retina. Rhodopsin, popularly called visual purple, is a light-sensitive chemical composed of retinal (a derivative of vitamin A) and the protein opsin.

You can use the increased presence of rhodopsin to take "afterimage photographs" of the world. Here's how:

Cover your eyes to allow them to adapt to the dark. Be careful that you do not press on your eyeballs. It will take at least 10 minutes to store up enough visual purple to take a "snapshot." When enough time has elapsed, uncover your eyes. Open your eyes and look at a well-lit scene for half a second (just long enough to focus on the scene), then close and cover your eyes again. You should see a detailed picture of the scene in purple and black. After a while, the image will reverse to black and purple. You can take several "snapshots" after each 10-minute adaptation period.

ANTI-GRAVITY MIRROR

It's all done with mirrors.

Materials

- A length of 2 × 4 inch wood and a router tool, or ring stands and clamps to make a stand to hold the mirror upright
- A good-quality flat plastic mirror, 2 × 3 feet (60 × 90 cm) or larger
- A partner

NOTE

It's important to get a good, flat mirror, because distortions will ruin the effect. Plastic mirrors are expensive, but glass mirrors can be dangerous. Look in your local yellow pages for a nearby plastics store.

CAUTION

Be careful with mirrors. Keep yourself and your kids safe by always using plastic mirrors instead of glass. If you must use a glass mirror, tape the edges to minimize the possibility of cuts, and glue one side to a suitable backing of cardboard or wood. Don't just spot-glue the mirror in a few places: The whole surface must be attached to the backing. That way, even if the mirror cracks or breaks, there will be no loose shards of glass.

Introduction

A reflection of your right side can appear to be your left side. With this Snack, you can appear to perform many gravity-defying stunts.

Assembly

(With stand, 15 minutes or less; without stand, 5 minutes or less)

You can make a stand for the mirror from a length of 2 × 4 inch wood. Use a router to cut a groove that is just wide enough to slip the mirror into. To help stabilize the mirror, nail some scrap wood to the ends of the board. You can also hold the mirror in a vertical position using ring stands and clamps, or just with your hands. An assistant might be of help here.

To Do and Notice

(15 minutes or less)

Stand the mirror on the floor. Put one leg on each side of the mirror. Shift your weight to the foot behind the mirror. Lift your other leg and move it repeatedly toward and away from the mirror. To an observer, you'll appear to be flying. If you use this Snack as a demonstration, you can make the effect more dramatic by covering the mirror with a cloth, straddling the mirror, and then dropping the cloth as you "take off."

Etcetera

The cars that seemed to float across the desert in the movie *Star Wars* each had a full-length mirror attached along its lower edge, hiding its wheels. The cars appeared to float above the sand because a camera pointing at a car saw a view of reflected sand and shadow in the mirror, rather than what was really there.

What's Going On?

If you stand with the edge of a large mirror bisecting your body, you will appear whole to a person who's watching. To the observer, the mirror image of the left half of your body looks exactly like the real right half. Or, if you are standing at the opposite edge of the mirror, your reflected right half looks like the real left half.

You look whole because the human body is symmetrical. The observer's brain is tricked into believing that an image of your right side is really your left side. So just straddle the mirror, raise one leg, and you'll fly!

Actually, you can try this out anyplace you find a good-sized mirror you can straddle or stand alongside of—at home, in a department store, or in a dance room with a doorway cut into a mirrored wall. Stand at the edge of the doorway so just half of your body is being reflected for a very convincing flight.

BENHAM'S DISK

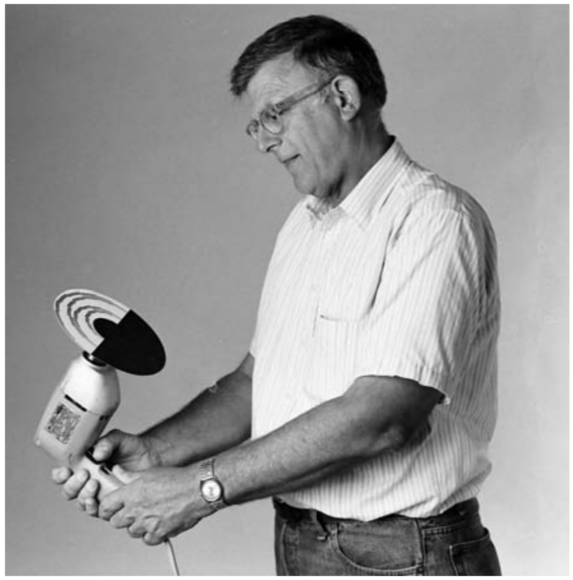
A rotating black-and-white disk produces the illusion of color.

Materials

- Access to a copy machine
- Pattern disk (provided)
- Poster board or cardboard
- Scissors
- Glue stick, tape, or other suitable adhesive
- A black marking pen
- Variable-speed electric drill (works well because it can be reversed) or record turntable
- Double-sided tape, adhesive-backed Velcro, or some other way to attach your disk to your rotator (see Assembly)

BONUS!

You've just done most of the assembly for three other Snacks: Depth Spinner, Squirming Palm, and Whirling Watcher. Now all you need are the pattern disks for those Snacks, and you're good to go.



Introduction

When you rotate this black-and-white pattern at the right speed, the pattern appears to contain colored rings. You see color because different color receptors in your eyes respond at different rates.

Assembly

(30 minutes or less)

1. Make a copy of the pattern disk provided in this Snack.
2. Cut out the disk and mount it on a cardboard backing with the adhesive. If your copier does not make good solid blacks, fill in the black areas with a black marking pen. You can reduce or enlarge the pattern disk if you like.
3. Mount the pattern disk to a rotator and secure it in place with some double-sided tape or adhesive-backed Velcro. If you're using a drill with a chuck, a bolt can be used as a shaft, with two nuts to hold the disk. For something super-simple, you can reduce the size of the disk on a copy machine and then mount it on the flat upper surface of a suitable toy top, or try spinning the mounted disk on a pencil point, or on a pushpin stuck into a pencil eraser. Whatever you can devise to get the disk safely spinning should be fine.

To Do and Notice

(15 minutes or more)

Spin the disk under bright incandescent light or sunlight. Fluorescent light will work, but there's a strobe effect that gives the disk a pulsating appearance and makes it harder to look at. The brighter the light, the better the effect.

Notice the colored bands that appear on the disk. Look at the order the colors are in. What color do you see at the center? What about the next few bands? Reverse the direction of rotation and compare the order of colors again, from the center of the disk to the rim.

Try varying the speed of rotation and the size of the pattern, and compare the results with your initial observations.

What's Going On?

Different people see different intensities of colors on this spinning disk. Just why people see color here is not fully understood, but the illusion involves color vision cells in your eyes called cones.

There are three types of cones. One is most sensitive to red light, one to green light, and one to blue light. Each type of cone has a different latency time (the time in which it takes to respond to a color), and a different persistence-of-response time (the time it keeps responding after the stimulus has been removed). Blue-sensitive cones, for example, are the slowest to respond (have the longest latency time), but they keep responding the longest (have the longest persistence time).

When you gaze at one place on the spinning disk, you are looking at alternating flashes of black and white. When a white flash goes by, all three types of cones respond. But your eyes and brain see the color white only when all three types of cones are responding equally. The fact that some types of cones respond more quickly than others—and that some types of cones keep responding longer than others—leads to an imbalance that partly explains why you see colors.

The colors vary across the disk because at different radial positions on the disk the black arcs have different lengths. As a result, the duration of the flash on the retina is also different.

A complete explanation of the colors produced by a Benham's disk is more complicated than the simple one outlined here (for example, the short black arcs on all Benham's disks must also be thin, or no colors will appear), but this is the basis of much of what you see.

Benham's disk was invented by Charles Benham, a nineteenth-century toymaker who noticed colors in a black-and-white pattern he had mounted on a top. Even now, tops with Benham's disks can occasionally be found in toy stores.

Etcetera

Like the cones of the eye, the three different color sensors in some color-television cameras also have different latency and persistence times. When a color-television camera sweeps across a bright white light in its field of view, it often produces a colored streak across the television screen.