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Introduction

Challenges

Challenges vs. Lessons

The activities in this book are referred to as challenges, not lessons. They are quite different from traditional science lessons that tell students what to do and how to do it. The goal of these challenges is for students to experience phenomena for themselves, which requires a bit of letting go on the part of the teacher. Instead of lecturing or demonstrating, we are putting materials into the hands of students, setting them up for success, and turning them loose to discover new concepts. Teachers are facilitators, laying out the challenge for students, scaffolding when necessary, providing guidance, and checking in with groups in order to offer encouragement, advice, correction, and support.

Students CAN meet the challenge!

Once students understand how the challenges work, they really dive into them. The students become fully engaged in working together on their own terms, manipulating materials, and solving a compelling problem or answering an intriguing question, with their hands and minds occupied and on task. And these challenges are not conducive to silence – a low buzz of purposeful conversation indicates that students are actively engaged. Your biggest problem may be getting them to wrap things up!

Keep in mind that we, as teachers, have to change our approach, too. We tend to want an endpoint; to know what the end product of a challenge should be – a finished product that the students can take home. But inquiry-based lessons in engineering design and the scientific process will naturally go in whatever direction students take them. Give students just enough information and scaffolding, and they will surprise you!

* Two Kinds of Challenges *

Each challenge is designed for students to experience either the engineering design process or scientific inquiry.

- In the ***engineering challenges,*** students create a solution to a problem and evaluate the effectiveness of their solutions. They use the engineering design process – ask, imagine, plan, build, test, improve – to arrive at the best solution they can under the *constraints of the challenge*. Constraints include the rules, limitations and restrictions students must follow. In these challenges, students must think creatively, meaning that their solutions will (and should) vary widely; there are no "right" answers. Solutions are evaluated by the class based on how well they solve the given problem.
- For ***scientific-inquiry challenges***, scaffolding is provided to give students experience in exploring questions, testing hypotheses, recording data and evaluating evidence. Although not as student-driven or open-ended as the engineering challenges, scientific inquiry challenges encourage students to ask questions and create hypotheses (within the parameters of the challenge), so the students are deciding what to test and how to test it. Students work with *variables* instead of *constraints* in these challenges. They set up and carry out their planned tests, record and analyse data and come to their own conclusions, which are then evaluated by the class.

Meeting the Challenges

* Productive Struggle *

Inquiry challenges give students a certain amount of freedom, but they should not be free-for-alls. These types of challenges can be overwhelming to students if they aren't provided with enough structure.

When you begin these types of inquiry-based activities, you will most likely encounter a lot of "I can't do it" and "Can you help me?" Outside of actual physical incapability (some students really have trouble blowing up balloons), encourage students to try things on their own at least three times and then ask other students for assistance before coming to you. Freedom may be new to some students, and they may be unsure about how to proceed.

Prompt them with the constraints and goals of the challenge, and if they really are stuck, ask leading questions and offer a few choices of next steps they can take.

For example, "I see that your tower is leaning to one side". Then follow up with questions such as:

- – Where do you think the weak points might be? How could you make them stronger?
- – How could you support your bridge or change its structure at those weak points?

Once they get the hang of it, they will stop asking for help and run full speed ahead into each challenge.

* Give Them an Envelope *

In each Main Challenge, you will set constraints, or rules, that students must follow. The more specific the constraints, the better, and be sure that students understand them. Then, if a student asks if he or she can do something, you can reply, "What do the constraints of this challenge allow?"

Build a very clear envelope for them to work within, and give them complete freedom within it. If students levy a charge of "cheating" at a new idea, have a group discussion about the constraints and whether the new idea falls within them.

* Collaboration *

Collaboration is a big part of 21st-century learning and STEM (science, technology, engineering, maths), but not all students work well together. Flexible grouping is important, as is student choice. If a student requests to work alone, that's perfectly acceptable, as long as they participate in the debrief with the class. You will find that even those lone wolves, once they see how much fun the other students are having, will most likely choose to work with others at some point. And if they don't, remember – Einstein and Tesla usually worked alone.

When pairing students or placing them in small groups, allowing them to choose with whom they want to work is often the best option, especially during the first few challenges. The activities are engaging enough that hijinks are rare; they are too busy to cause trouble.

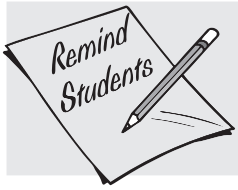
As students get used to the procedures, you can mix it up and still offer student choice by specifying that everyone must work with someone they haven't worked with before. But always keep an eye on things – forcing students to work with others who make them uncomfortable is counterproductive because social interaction takes their focus off the challenges.

* Copying Allowed *

Let students know that, because there are no right answers, copying is allowed! If a group is struggling with a task, one strategy they can employ is to observe the work of others. If students see someone else's great idea, encourage them to use it… with a twist or in a new way to make it their own. Even if they're really stuck and choose to copy another group exactly, they will still have their own experiences. Of course, if a particular student or group copies others in every activity, intervention is warranted.

* Failure Is Always an Option *

Talk with students about the word "fail". It has a very different meaning in science and engineering than it does in school! Failure is not the end of an experiment or project – it is merely a step along the way. When students are asked to make predictions about what will happen in an experiment, be sure to let them know that it does not matter whether their predictions match what happens. Scientists are wrong in their predictions much of the time – it's part of conducting experiments.



Every failure provides an opportunity for improvement. Scientists and engineers look at why they think something happened and how they can fix or improve it. Then, they try again and again and again.

I often tell students the story of *MythBusters* testing whether elephants are afraid of mice (look it up online – the video is great!). They were absolutely sure that this was just a silly tale – why in the world would a giant elephant be afraid of a little mouse? But lo and behold, the elephants cautiously avoided the mice every time. Were the researchers upset that their prediction did not match the outcome? No! They were astonished and thrilled. *MythBusters*' Adam Savage summed it up: "I'm always pleased to be completely wrong".

* Making Connections *

We want students to understand why things happen, but instead of telling them, we want them to discover for themselves. At the end of each challenge, bring the class together for a wrap-up session to debrief and analyse their results. This is important – this is where students make connections to internalise scientific processes and engineering concepts.

Students will share and compare their ideas, experiences, data, constructions and most importantly, evidence. Because it can be difficult for students to let go of their own ideas, they need to practice listening to, comparing, and evaluating competing ideas based on merit. By looking at data and concrete evidence, e.g. the arch bridge held more than the beam bridge, students build the ability to discern evidence-based fact from opinion.

Bringing the whole class together to share data and observations and analyse outcomes lets us lead students toward discovery and understanding at their level and in their words. They will grasp and remember concepts much better when it comes from them instead of from us.

* Materials *

STEM challenges do not always need specialized tools and equipment. These challenges rely on classroom supplies you probably already have, recycled materials (think paper-towel tubes and scratch paper), and sometimes, a few items from the dollar store. For many of the challenges, the material choices are quite flexible, making it easy to use materials you have available.

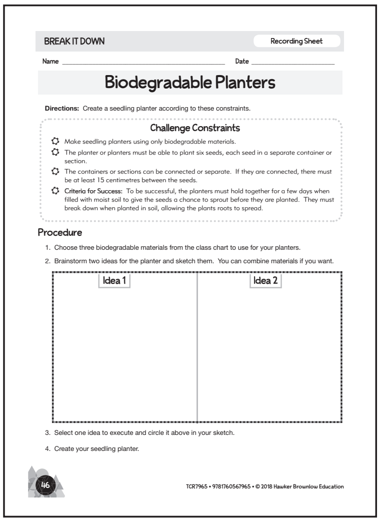
Develop specific routines for how students will access materials, and practice them before each activity. Also, be sure to review safe practices with items like scissors and pushpins. The consequence for not using materials safely should be loss of those materials for the activity in addition to your established classroom consequences.

* Recording *

"The only difference between messing around and science is writing it down."

– **Adam Savage of** *MythBusters*

Scientists and engineers do a lot of writing in order to turn data into information. Every step of the scientific process is recorded so that other scientists in other places and at other times can replicate experiments. Engineers write procedures, reports, funding requests and more. And STEM professionals write not only to communicate with others but also to clarify their thinking, to explore new ideas and to come to conclusions.


BREAK IT DOWN — Recording Sheet

Name ____________ Date ____________

Biodegradable Planters

Directions: Create a seedling planter according to these constraints.

Challenge Constraints

- Make seedling planters using only biodegradable materials.
- The planter or planters must be able to plant six seeds, each seed in a separate container or section.
- The containers or sections can be connected or separate. If they are connected, there must be at least 15 centimetres between the seeds.
- **Criteria for Success:** To be successful, the planters must hold together for a few days when filled with moist soil to give the seeds a chance to sprout before they are planted. They must break down when planted in soil, allowing the plants roots to spread.

Procedure

1. Choose three biodegradable materials from the class chart to use for your planters.
2. Brainstorm two ideas for the planter and sketch them. You can combine materials if you want.

Idea 1 | Idea 2

3. Select one idea to execute and circle it above in your sketch.
4. Create your seedling planter.

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Throughout the challenges in this book, students will be recording their thoughts, ideas, procedures, data, and more on paper. In some cases, they will answer questions that help lead them through an investigation or set them up for success in a challenge. At other times, they will record data as they collect it, and then analyse it to arrive at a conclusion or a result. And in engineering challenges, they will do their planning and evaluating on paper. At the end of each challenge, students will write about their experience by answering reflection questions in order to pull everything together.

Both speaking and writing give students an opportunity to articulate their thinking. As they work on a challenge, they discuss what's going on with other students (yes, you will find that even students working alone often have discussions with other students). These discussions allow students to work out their thoughts and observations out loud, which makes writing easier. This is particularly helpful for English language learners who practise vocabulary and sentence structure as a natural part of their challenge work time. Encourage students to use their natural language during challenges to communicate their ideas, even if grammar isn't perfect. The same goes for writing – don't worry so much about spelling and punctuation – focus on the ideas.

Drawing is also a big part of recording in these challenges. Visual and symbolic representations such as diagrams, blueprints, technical drawings, schematics and models are an integral part of science and engineering. In every challenge, students are asked to sketch and label their ideas. Sketching helps students get their ideas on paper quickly and forces them to think through the relationships of the parts to one another and to the whole. Drawings are similarly great for assessment, as you can see how well students understood the challenge concepts by how they represent those concepts visually.

* Assessment *

As students work through the challenges in this book, teachers should check for understanding along the way through formative assessment. This will give teachers a coherent picture of what students know and can do. To help you formatively assess students' understanding of the ideas, concepts and practices during each challenge, examine the following evidence:

- Observations of and discussions with students during work time. It is recommended that you take notes during these observations.
- Class sharing and discussions
- Writing Reflection pages

These formative assessments provide multiple sources of evidence to guide you in making inferences about what students know and are able to do and also point toward next steps in instruction.

Budgets

In all challenges, constraints are specified or, at least, outlined. An extra constraint you can add is a budget. This will force students to be thoughtful about the materials they choose, and it brings an extra mathematical element to the challenge. Some challenges include suggested costs and budgets, and others will need to be established.

Pricing Ideas

- Price all of the materials available, and give students a total budget.
- Materials that are in short supply or that are of easier use in solving the challenge can have higher prices.
- It doesn't matter what the prices are, but students really love high prices – they love to pretend that they're spending millions!
- Connect the prices to your maths lessons. Use prices that will force them to add with decimals or to multiply by 10.

You can fill in a *Price Sheet* (See page 11.) and give students *Budget Sheets* (See page 12.) to help them keep track of their spending. Always remind them that their budget must cover their original plan as well as any improvements they make, so students need to keep some money in reserve at first.

Here is an example price list for the *Green Roofs* challenge using small amounts of money. The amounts are specifically chosen to be easy to add and multiply.

The budget is $5.00	
Item	**Price**
potting soil	10 cents per cup
pebbles	5 cents per cup
marbles	5 cents per cup
pipe cleaners	5 cents each
cardboard	10 cents per piece
newspaper	10 cents per page
plastic bags	25 cents each
foil	25 cents per sheet
plastic wrap	50 cents per sheet
cotton balls	75 cents for 5
sponges	$1 each

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Fun with Bernoulli

Objectives

Students will learn about air pressure and the Bernoulli principle through a series of hands-on activities. They will then design and create a toy using what they have learnt.

Setup

Setup For Introduction and Mini Challenge

- Make copies of *Bernoulli's Principle Activity Cards*, *All About Bernoulli's Principle* and *Bernoulli's Principle – Station by Station* as needed.
- Practise the demonstration before classes. (See page 19.)
- Each student should bring a copy of the activity page and a drinking straw to each station to avoid sharing germs.
- Set up two or three stations for each of the four activities (see *Bernoulli's Principle Activities*). Divide students into the same number of groups as you have stations.

Setup For Main Challenge

- Make copies of *Bernoulli Toy Design* for each group.
- Provide tools such as scissors, glue and staplers.
- Gather building materials you have on hand for this challenge.

Suggestions

* balloons
* cardboard tubes
* small battery-operated fans
* hair dryers
* paper or plastic cups
* paper and cardstock
*plastic bottles
* table tennis balls
* straws
* string
* tilting fans

Materials

Introduction and Mini Challenge

- *All About Bernoulli's Principle* (page 25)
- *Bernoulli's Principle – Station by Station* (pages 26–27)
- *Bernoulli's Principle Activity Cards* (pages 23–24)
- a fan that tilts upward
- balloons
- table tennis balls
- sheets of paper
- straws (one per student)
- string
- thick books
- water-bottle funnels (page 21)
- metre rulers

Main Challenge

- *Bernoulli Toy Design* (page 28)
- *Reflections – Fun with Bernoulli (page 29)*
- tape
- building materials (See Setup.)

Time Frame

The Introduction and Mini Challenge takes about 45 minutes.

The first part of the Main Challenge will take about 40 minutes. The second part of the investigation should take about 45 minutes.

Follow up with the Writing Reflection as time allows.

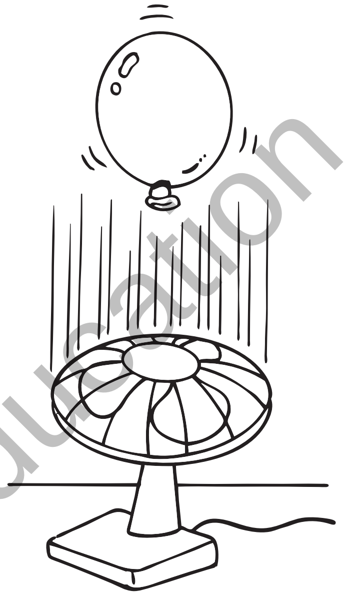
Vocabulary

air pressure
Bernoulli's principle
hover
molecule
theory

BE PREPARED!

1. Find a fan that tilts upward.

2. Blow up three or four balloons and tie them off.



3. Do a test run of the balloon demonstration prior to presenting it to the class. Place the balloon(s) into the column of air coming from the fan. The balloons should stay up, hovering and bumping around a bit in the column of air.

   ➜ If the balloons are different sizes, they may move past each other and switch positions until the smallest balloon is on the bottom.

   ➜ If the balloons don't stay in the air, create a tighter column of air by taping heavy cardstock or poster board into a tube with the diameter of the fan. Tape the column to the front of the fan. This should focus the air enough for the demonstration to work.

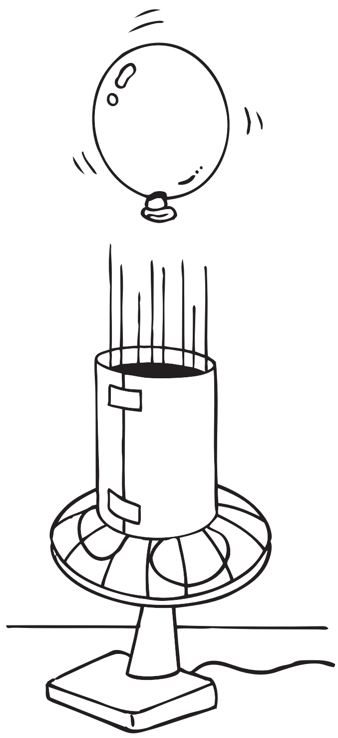
   ➜ If you don't have a fan, you can do the same demonstration with a hair dryer set on cool and a table tennis ball.

INTRODUCTION

1. Point the fan straight up, and turn it on. Ask students:

   – What do you predict will happen when you place a balloon above the blowing fan?

2. Place a balloon into the stream of air.



3. Ask students to talk with a partner and to discuss what they just observed.

4. Then, ask students to share their explanations. Accept all explanations without comment at this time.

5. Add a second balloon, and discuss what happens.

6. Tell students that they just witnessed **Bernoulli's principle** in action.

✏ Write *Bernoulli's principle* on the board. Add student observations as the unit progresses.

7. Explain that Daniel Bernoulli was a mathematician and physicist who lived in Switzerland over 300 years ago! Let students know that in these challenges, they will have some fun learning how Bernoulli's principle works, and then build a toy or a game using this principle.

MINI CHALLENGE

Teacher Preparation

Each station should include the following:

Activity 1: a piece of paper for each student

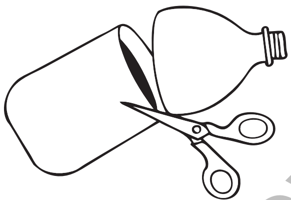
Activity 2: one piece of paper, two thick books

Activity 3: a metre ruler, some string and two blown-up balloons.

Preparation: Tie a string to each balloon, and tie the other ends to the metre ruler. Slide the strings along the ruler until the balloons are about 15.4 centimetres apart.

Activity 4: a table tennis ball, a premade "water bottle" funnel for each student

Preparation: Water-bottle funnels are easy to make – simply cut the tops of the bottles off as shown and recycle the bottoms. If the cut edges are sharp, you can wrap them in duct or masking tape.



STATION ACTIVITIES

1. Distribute a copy of *Bernoulli's Principle Activity Cards* to each group, along with a straw for each student. Remind students – no sharing straws!
2. Point out where each station is located. Have each group move to a station, complete the activity as directed on their recording sheets, and then move to a different station.

   Let students know that there are four different activities that need to be completed, but they can complete them in any order. If another group is busy at a station that they want to access, they should go to a free station that they haven't completed yet or wait patiently until the other group is finished.
3. Once students have competed all four activities, gather the students together and have each group share their results for each activity.
4. Discuss students' **theories** (*possible explanations*) about Bernoulli's principle and how it works.
5. Display or distribute *All About Bernoulli's Principle* and *Bernoulli's Principle – Station by Station* and review them both with students.

Remember the fan and the balloons?

Demonstrate how Bernoulli's principle worked by having students act it out.

1. Have two students stand next to each other at one end of the room.
2. Give one student a straight path to the other end of the room, and give the second student a path that goes around several desks before getting to the other end.
3. Tell the students that they need to arrive at the other end of the room at the same time.
4. Have both students start walking at the same time. (*Notice that the student with the longer path must move faster to keep up with the student with the straight path. In the same way, the air moving around the balloon must move faster than the air further away that is going straight.*)