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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.

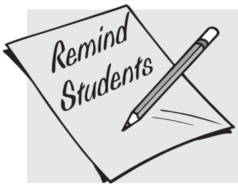
As students get used to the procedures, you can mix it up and still offer student choice by specifying that everyone must work with someone they haven't worked with before. But always keep an eye on things – forcing students to work with others who make them uncomfortable is counterproductive because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

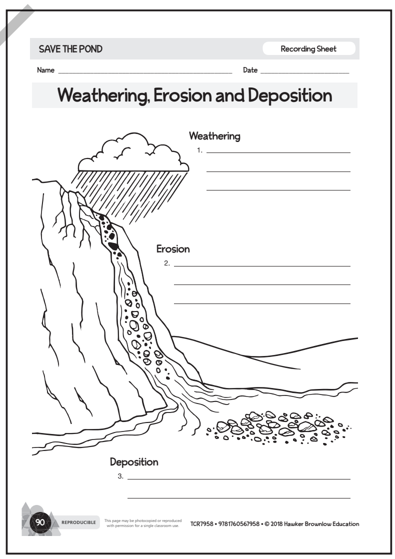
Develop specific routines for how students will access materials, and practice them before each activity. Also, be sure to review safe practices with items like scissors and pushpins. The consequence for not using materials safely should be loss of those materials for the activity in addition to your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



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 similarily 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. Budgets also bring an extra mathematical element to the challenge.

Pricing Ideas

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

You can give students the *Budget Sheet* (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 they need to keep some money in reserve at first. Here are some examples:

Here is a sample price list for the *Collision Contraptions* challenge (page 27) using small amounts of money. The amounts are specifically chosen to be easy to add and multiply.

The budget is $5.00.	
marbles or toy cars	50 cents each
cardboard tubes	25 cents each
funnels	25 cents each
paper cups	25 cents each
boxes	25 cents each
paper plates	20 cents each
index cards	20 cents each
dominoes	10 cents each
pattern blocks	10 cents each
straws	5 cents each

Here is a sample price list for the *Save the Pond* challenge (page 84), using millions of dollars.

The budget is 20 million dollars.	
paper plates	$2 000 000 each
pipe cleaners	$2 000 000 for five
ice cream sticks	$2 500 000 for ten
large plastic bags	$2 050 000 each
large index cards	$1 000 000 each
cotton balls	$3 500 000 per dozen
paper cups	$1 500 000 each
rubber bands	$1 000 000 for five
straws	$500 000 for five
plastic forks	$1 000 000 each
egg cartons	$3 000 000 each

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Send a Message

Objectives

Students will learn about binary codes and practise sending and receiving simple A/B messages. Then they will create a device to send a simple binary-coded pattern across the room.

Setup

For Mini Challenge

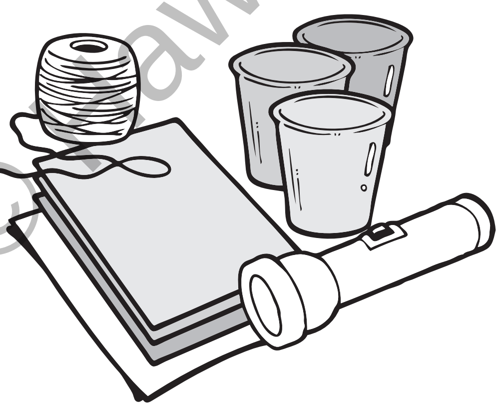
- Make copies of *Our Code* for each pair of students.

For Main Challenge

- Provide building tools such as tape, glue and scissors.
- Make copies of student pages as needed.
- Use any building materials you have on hand for this challenge.

Suggestions

* torches
* paper or plastic cups or containers
* selection of coloured paper
* string



Materials

For Mini Challenge

- *Our Code* (page 22)
- pencils

Main Challenge

- *3 × 3 Grids* (page 23) optional
- *Send a Message* (pages 24–25)
- *Reflections – Send a Message* (page 26)
- pencils and scratch paper
- materials for building (See Setup.)

Time Frame

The Introduction and Mini Challenge can be completed in one class session of about 30 minutes.

The Main Challenge can be completed in 45 minutes.

Follow up with the Writing Reflection as time allows.

Vocabulary

binary
code
transmit
receive

INTRODUCTION

1. Show students a "thumbs up" hand sign, and ask them to tell a neighbour what they think it means. Then show a "thumbs down" sign, and have them tell a different neighbour what they think it means. Have student volunteers share their neighbours' ideas.
2. Tell students that thumbs-up and thumbs-down signs can be considered a **binary code**. Ask:
   – What might the phrase *binary code* mean? Point out that it starts with the prefix *bi-*.
   – What does the prefix *bi-* mean? (*two*) Do they know any other words that start with *bi-*? (*bicycle, bilingual, binoculars, bivalve*)
3. Explain that **binary** means *made up of two things*. A **code** is *a system developed to send messages*.

Write the term *binary code* and its definition on the board.

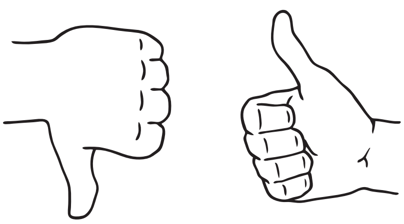
4. Tell students that thumbs up and thumbs down is a binary code that they can use to answer a question. Ask students to answer the following question using the thumbs up/thumbs down binary code.
   – Did you enjoy your breakfast today?
5. Ask students if they can think of any other binary systems in their everyday lives. You can start them off by turning the lights *on* and *off* – a light switch is a binary system because it only has two states: *on* and *off*.

Write examples of binary systems on the board. (*Examples:* yes/no [head nods], true/false, up/down and left/right) Add to the list as more examples are discovered.

Binary Code Basics

Explain that, in binary, there are only two states. We'll call them **A** and **B**. There is no **C** in binary! In order to use a binary code for communication, both the sender and the receiver have to know what the **A** and the **B** stand for. The thumbs-up sign is usually understood to mean *good* or *yes*, and the thumbs-down sign refers to *bad* or *no*.

6. But what if you want to ask a different kind of question? Ask:
   – Do you prefer cereal or toast for your breakfast? Ask students to answer with thumbs up or thumbs down.
   – Ask them to explain why you couldn't understand their answers. (*Because you didn't know which sign meant* cereal *and which sign meant* toast.)



7. It is important to agree on what **A** and **B** stand for before sending a message. Choose a student to decide which thumb position is cereal and which is toast.

Write their choices on the board. For example:

A (*thumbs up*) means cereal. **B** (*thumbs down*) means toast.

8. Ask students the question again, and have them answer in the thumbs code to make certain that each student can now understand the answers.

MINI CHALLENGE

1. Have a pair of student volunteers come up in front of the class. Ask one student to make up a question with only two possible answers.
2. Erase *cereal* and *toast* from the board and write in the answers to the student's new question.
3. Then, allow the first student to ask their question and the second student to answer with the agreed-upon code.
4. Tell students that they will now work with a partner to create a binary code with which they can answer a question. Have students partner up.
5. Distribute a copy of *Our Code* to each pair of students. Let students know that their code can be anything they want (while remaining classroom appropriate).
6. Give students about 5 minutes to work out their codes and practise asking and answering a question.

7. Have a pair of students stand in front of the class. Tell them not to reveal their code! Have one student ask the question and the other student answer. Then, have them switch roles and repeat, giving the other answer this time. Then, ask the class to say what they think the **A** and **B** are for each pair of students.
8. Continue letting each pair of students demonstrate their code and having the class identify the **A** and the **B**.