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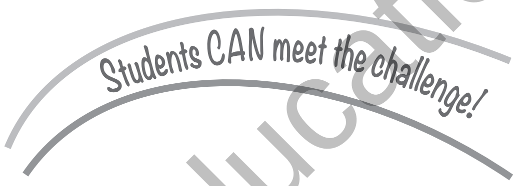
Introduction

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 students up for success and turning them loose to discover new concepts. Teachers are facilitators, laying out the challenges for students, scaffolding when necessary, providing guidance and checking in with groups to offer encouragement, advice, correction and support.

Once students understand how the challenges work, they really dive into them. They 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 students to wrap things up!



Keep in mind that we, as teachers, have to change our approach, too. We tend to want 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 solutions to problems and evaluate the effectiveness of their solutions. They use the engineering design process – *ask, imagine, plan, create (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 the final 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 in order 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 to create hypotheses (within the parameters of the challenge), so that 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 and suggestions such as:

– Where do you think the weak points might be? How could you make them stronger?

– Maybe you could strengthen the base of your tower. Could you use the cups in a different way?

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 they can do something, you can answer, "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, math), 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; students are often too busy to cause trouble.

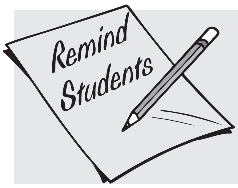
As students get used to the procedures, you can mix it up and still offer student choice by specifying that everyone must work with someone whom they haven't worked with before. But always keep an eye on things – forcing students to work with others who make them uncomfortable is counterproductive because 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 from the one heard 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 all 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 internalize 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 their merits. By looking at data and concrete evidence, e.g., the shelters with wider bases remained upright longer during the "earthquakes," (*Make It Move!* unit), students build the ability to discern evidence-based fact from opinion.

Bringing the whole class together in order 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 that you have available.

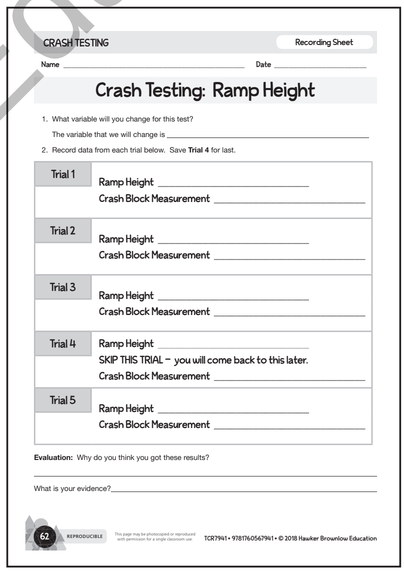
Develop specific routines for how students will access materials and practice them before each activity. Also, be sure to review safe practices with items like scissors and pushpins. The consequence for not using materials safely should be loss of those materials for the activity in addition to your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


CRASH TESTING — Recording Sheet

Name ______________________ Date ____________

Crash Testing: Ramp Height

1. What variable will you change for this test?

   The variable that we will change is ______________________

2. Record data from each trial below. Save **Trial 4** for last.

Trial 1	Ramp Height ______________ Crash Block Measurement ______________
Trial 2	Ramp Height ______________ Crash Block Measurement ______________
Trial 3	Ramp Height ______________ Crash Block Measurement ______________
Trial 4	Ramp Height ______________ SKIP THIS TRIAL – you will come back to this later. Crash Block Measurement ______________
Trial 5	Ramp Height ______________ Crash Block Measurement ______________

Evaluation: Why do you think you got these results?

____

What is your evidence?______________________

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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'll find that even students working alone often have discussions with other students). These discussions allow students to work out their thoughts and observations aloud, which makes writing easier. This is particularly helpful for English language learners who practice vocabulary and sentence structure as a natural part of their challenge work time. Encourage students to use their natural language during challenges in order 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 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 to label their ideas. Sketching helps students to get their ideas on paper quickly and forces them to think through the relationships of the parts to each other and to the whole. Drawings are similarly great for assessment, as you can easily see how well students understood the challenge concepts by how they visually represent those concepts.

* 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 constraint will force students to be thoughtful about the materials they choose, and it brings an extra mathematical element to the challenge.

Pricing Ideas

- Price all of the available materials and give students a total budget.
- Materials that are in short supply or that are easier to use in solving the challenge can cost more.
- 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 encourage them to add with decimals or to 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 *Shelters* challenge using small amounts of money. (See page 74.) The amounts are specifically chosen to be easy to add and multiply.

The budget is $5.00.	
Item	**Price**
cut-up garbage bags	50 cents each
fabric pieces	50 cents each piece
foil	25 cents per sheet
paper	25 cents per sheet
pipe cleaners	25 cents each
rubber bands	25 cents each
string	20 cents per 30 cm
skewers	10 cents each
straws	10 cents each
pushpins	5 cents each
ice cream sticks	20 cents each
uncooked pasta	25 cents per dozen
toothpicks	20 cents per dozen

Here is a sample price list for the *Animal Adaptations* challenge using millions of dollars. (See page 24.) Keep the amounts easy to work with and just add "million" onto the end.

The budget is 20 million dollars.	
Item	**Price**
paper plates	$2 million each
pipe cleaners	$2 million for five
straws	$2 million for ten
empty containers	$2 million each
large index cards	$1 million each
cotton balls	$1 million per dozen
paper cups	$1 million each
rubber bands	$1 million for five
ribbon, string	$1 million per 30 cm
cardboard tubes	$1 million each
egg cartons	$3 million each
foil	$1 million per sheet
glue, tape	$0 FREE

Animal Life Cycles

Objectives

Students will research the life cycle of an animal from one of five vertebrate groups and then design and build a model of the animal's life cycle. Students will compare and contrast animal life cycles from the five vertebrate groups and identify patterns.

Setup

For Mini Challenge

- Prepare chart paper (optional) and copies of student recording sheets.

For Main Challenge

- Provide some type of base for students to mount their models to, such as sheets of cardboard or foam core.
- Provide tools for assembly, such as tape, glue and staples, etc.
- Provide a variety of building materials. The more that you offer, the more creative students will be!

Suggestions

* aluminium foil
* clothes pegs
* coffee filters
* construction paper
* cotton balls
* modelling clay
* paper clips
* paper or plastic cups
* pipe cleaners
* straws
* string or ribbon

Materials

Introduction and Mini Challenge

- *Vertebrate Categories Game* (page 20)
- *Vertebrate Characteristics* (page 21)
- pencils
- timer
- chart paper (optional)

Main Challenge

- *Life Cycle Models* (page 24)
- *Reflections – Animal Life Cycles* (page 25)
- access to books and/or digital resources about animals
- timer
- building materials (See Setup.)
- building tools (tape, etc.)

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 two segments: about 30 minutes for students to do research, and 45–60 minutes for building and discussion.

Follow up with the Writing Reflection as time allows.

Vocabulary

animal
cycle
model
offspring
reproduction
vertebrates

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INTRODUCTION

Vertebrates
mammal bird reptile amphibian fish

1. Ask students, “What is an **animal**?”

Work with students to make a short list of what makes an animal different from plants and other organisms. The basic differences are:

- ✔ Animals must eat or ingest food but can’t make their own food.
- ✔ Animals can move on their own.
- ✔ Animals sense things around them and respond to them.

On the board or chart paper, write the title *Vertebrates*. Tell students that **vertebrates** are animals that have a backbone.

2. Ask, “Are humans vertebrates?” (*Yes.*) How do you know? (*Have students feel their own backbones, or spines.*)
   – Ask if anyone can name a category of vertebrates.

Under *Vertebrates*, write the five main categories: *mammal, bird, reptile, amphibian* and *fish*.

3. Talk briefly about the characteristics of each category. You may need to explain that **reproduction** refers to the manner in which the animal has **offspring** (*babies*). Some animals lay eggs, others have live births, etc. If students need more support, display or distribute copies of *Vertebrate Characteristics* for further review.

MINI CHALLENGE

1. Tell students that they are going to play a game called “Vertebrate Categories”.
2. Hand out a copy of the *Vertebrate Categories Game* to each group and read the rules together. (See page 20.) Point out that the bottom of the page will be used to fill in the animal names.
3. Divide class into groups of six students or less. Each group will need pencils.
4. Set the timer for three minutes. Call “Begin” and start the timer.
5. Remind students that, when the timer goes off, they must stop writing.

AFTER THE GAME

1. Have a student from each group read out their group’s list of animals. Tell the class that, if they hear an animal they don’t think fits in the category, they can raise their hand and call “Challenge” to show that they do not think it fits in that category.

Write the challenged animals on the board or chart paper.

2. After a group’s list has been read out loud, go back and have a class discussion about any challenged animals. Decide if the challenged animals belong in the category or should be removed from the list.
3. You can use the *Vertebrate Characteristics* information sheet as a resource. Once the challenges have been settled, have each group count how many animals were listed.
4. Discuss students’ experiences.
   – Were some categories more difficult than others? Why?

***** Save the Lists for the Main Challenge. *****

MAIN CHALLENGE

Define the Problem

1. Tell students that scientists often create models. A **model** shows what something is or how it works.

✏ Write the word *model* and its definition on the board.

2. Tell students that each group will build a model of the life cycle of an animal. Each group will choose one animal from the list they created in the *Vertebrate Categories* game.
3. Explain to students that, in engineering, the rules are called “constraints”. The constraints tell what the engineers can and can’t do. *Note:* If you want to challenge students further by assigning costs to the building materials and giving them a budget, add the budget to the list of constraints. (See pages 10–12.)

✏ Write the constraints for the challenge on the board or chart paper, or make copies for students.

Challenge Constraints

- The model must be three-dimensional in some way. It cannot be completely flat.
- The model must show each stage of the animal’s life cycle.
- The stages of the life cycle must be recognisable and labelled.
- The vertebrate category, the animal name and each stage of the life cycle must appear on the model.

Imagine & Plan

1. Distribute a copy of *Life Cycle Models* to each group and review it together. Remind students that a **cycle** is a series of events repeated in the same order.

✏ Write the word *cycle* and its definition on the board.

2. Give groups five minutes to choose the animal for their life cycle models. Use the timer and let students know that any group that is undecided at the end of the time allowed will have to draw straws or play rock/paper/scissors in order to settle disputes.
3. Provide students time to do some research to find out the stages of their animal’s life cycle. Provide access to books or online materials. Explain that they don’t need to go into great detail about their animal – just identify the stages of its life cycle and find some pictures to work from.
4. Show students the available building materials. Provide time for them to explore the materials and to brainstorm ideas for their life cycle models.
5. Direct students to sketch their idea for a model on their *Life Cycle Models* page and to make a list of the materials that they will need.