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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. 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 to know what the end product of a challenge should be – a finished product that the students can take home. However, inquiry-based lessons in engineering design and the scientific process will go in whatever direction students take them. Give students just enough information and scaffolding, and they will surprise you!

* Two Kinds of Challenges *

The challenges in this book provide just the right amount of structure and scaffolding to set students up for success, but not so much as to stifle creativity and productive struggle. 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 the given problem is solved.

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 they are deciding what to test and how to test it. Students will 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 (many primary 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. But, give too much direction, and students won't really internalise the concepts.

Prompt students 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, you might say, "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?
- Maybe you could strengthen the base of your tower. Could you put more spaghetti on that side or add more marshmallows?

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 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 *

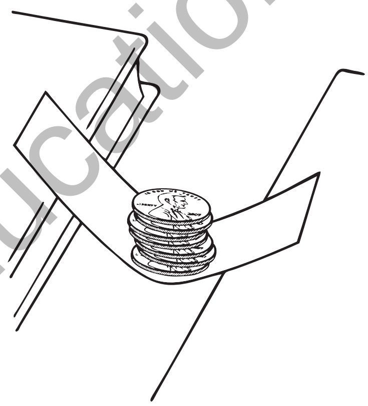
Collaboration is a big part of 21st-century learning and STEM (science, technology, engineering, maths), but not all students work well together. Flexible grouping is important, as is student choice. If a student insists on working alone, that's perfectly acceptable, as long as he or she participates in a 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 often wrong in their predictions – 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.

FAILURE is a step along the way.

The *MythBusters* tested 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. 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 and 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 practise listening to, comparing and evaluating competing ideas based on merit. By looking at data and concrete evidence, e.g. the fan-folded paper bridge held more weight than the rolled-paper 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.

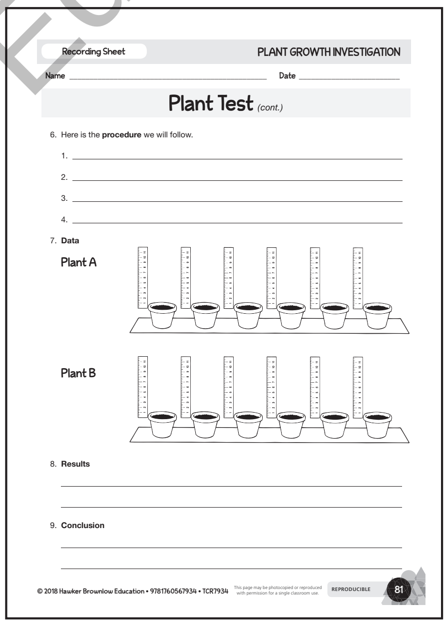
Develop specific routines for how students will access materials, and practise them before each activity. Also, be sure to review safe practices with items like scissors and pushpins. The consequence for not using materials safely should be loss of those materials for the activity in addition to your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



Recording Sheet — PLANT GROWTH INVESTIGATION

Name ____ Date ____

Plant Test *(cont.)*

6. Here is the **procedure** we will follow.
   1. ____
   2. ____
   3. ____
   4. ____
7. **Data**

   Plant A

   Plant B
8. **Results**
9. **Conclusion**

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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, 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 visually represent those concepts.

* Assessment *

Check for understanding in each challenge through formative assessment. This will give you 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 the next steps in instruction.

Build a Beam Bridge

Objectives

Students will learn about the forces of compression and tension through a hands-on activity. Students will then work in pairs to complete bridges using only paper, and will test to see how much weight each bridge can hold. They will improve each design, complete a second bridge, test again and then compare their two bridges.

Setup

For Mini Challenge

- Students will need large index cards.

For Main Challenge

- Make copies of *Building a Beam Bridge* and *Reflections – Building a Beam Bridge* for each student.
- Collect index cards, paper clips, cups, weights and tape for each student or group.
- Set up abutments (platforms) for students to build bridges on. The abutments should be roughly 8 cm high and 12 cm apart. Some ideas for abutments include stacked books or building blocks, upside-down cups or boxes with weights. If the abutments are not heavy enough, tape them to the work area so they will not move.
- Collect small items for weights to test the strength of the bridges. Coins of a single value work well, but any heavy, small objects of consistent weight will do, such as nuts or bolts or decorative glass pebbles.

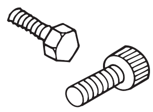
Materials

Mini Challenge

- large index cards or sheets of cardstock cut in half

Main Challenge

- *Beam Bridge Information* (page 29)
- *Building a Beam Bridge* (pages 30–31)
- *Reflections – Building a Beam Bridge* (page 32)
- materials for abutments (See Setup.)
- paper clips (5 per team)
- paper or plastic cups
- coins, bolts or other weights (See Setup.)
- rulers
- scissors
- tape (15 cm per team)



Time Frame

The Introduction and Mini Challenge can be completed in one class session of about 20 minutes.

The Main Challenge can be completed in 45 minutes to an hour.

Follow up with the Writing Reflection as time allows.

Vocabulary

abutment
beam
compression
failure
force
tension

INTRODUCTION

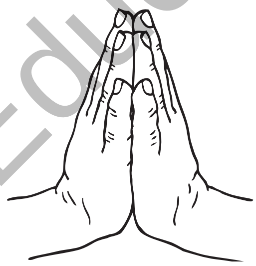
1. Introduce the bridge challenges with the following discussion questions:
   – Have you ever walked or driven over or under a bridge?
   – Can you describe it?
   – Why do we build bridges?
   – What materials have you seen used to build bridges?
2. Tell students they will be building bridges out of nothing but paper!

MINI CHALLENGE

1. Have students put the palms of their hands together in a “praying” position and push their hands together.

   Explain that this type of **force** (strength or energy) is called *compression*.

   Compression is a pushing force.



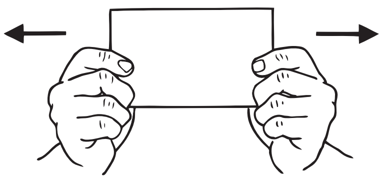
2. Then have them lock their fingers together (*see illustration*) and pull their hands away from each other in opposite directions.

   Explain that this type of force is called *tension*.

   Tension is a pulling force.

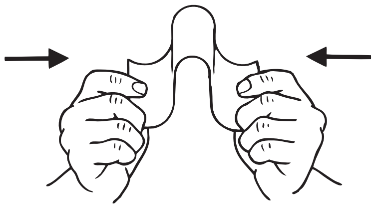
3. Give each student an index card. Have them hold the ends and try to pull the ends away from each other. Ask them to describe what happens. (*Not much! They should not be able to move or break the paper.*)

   Explain that paper is strong in tension, which is a pulling force. That is why they couldn’t pull it apart.



4. Now have them try to push the ends of the paper toward each other. Ask them to describe what happens. (*The paper bends.*)

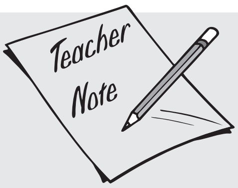
   Explain that the piece of paper is weak in compression, which is a pushing force.



MINI CHALLENGE *(CONT.)*

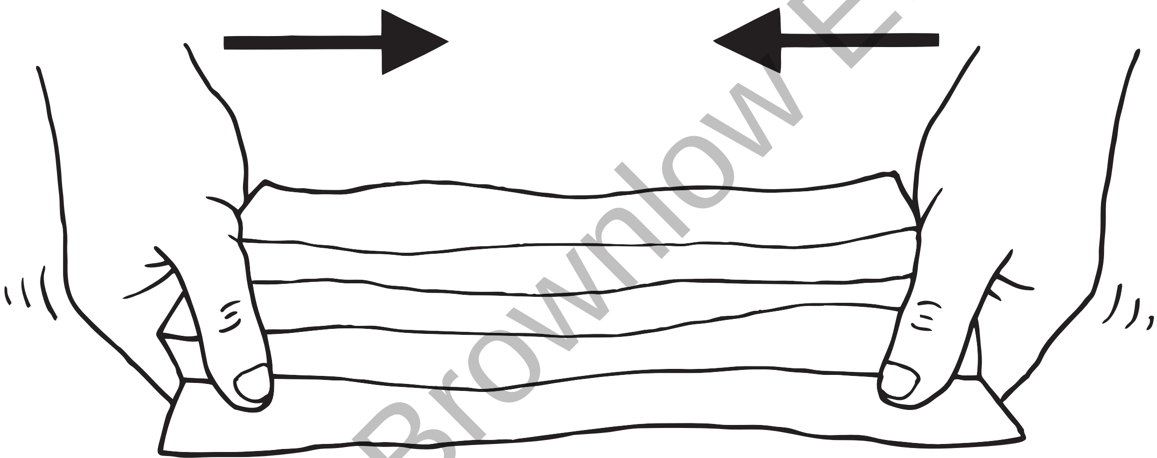
5. Give students several more index cards. Challenge them to fold or roll the paper in ways that will increase its compressive strength so that it's harder to bend.

6. Encourage students to try different types and sizes of folds, and then test each one by pushing the ends of the paper toward each other.

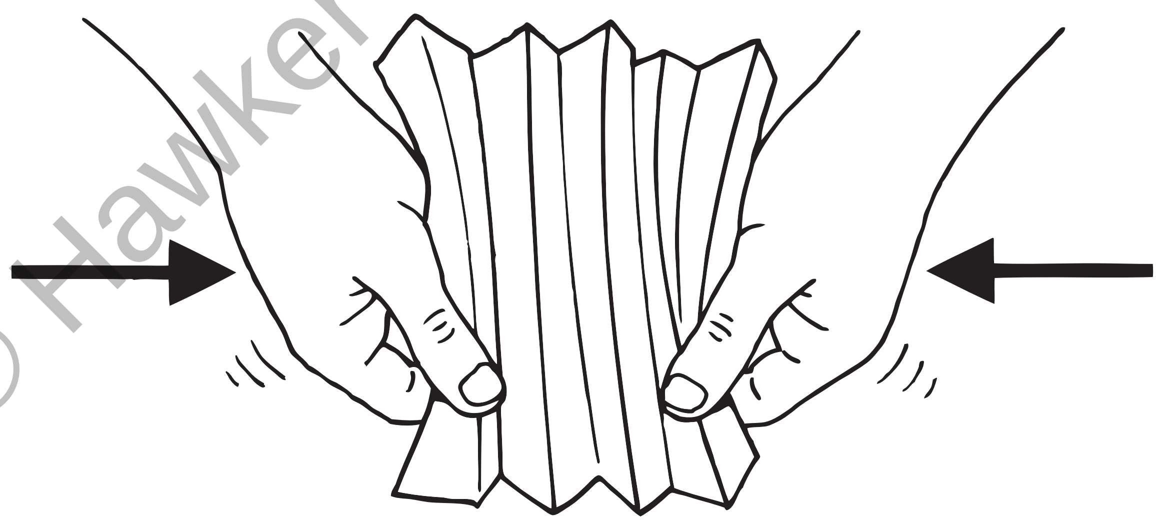


Students should find that folding the paper into an accordion (like corrugated cardboard) will create a lot of compressive strength in one direction, as will rolling it into a tight tube. If they do not make these discoveries on their own, you may want to show them how to fan-fold the paper.

Strong in compression when pushed in this direction.



Weak in compression when pushed in this direction.



MAIN CHALLENGE

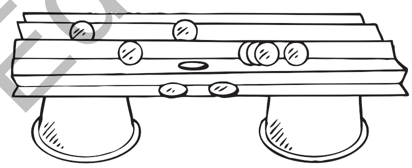
Define the Problem

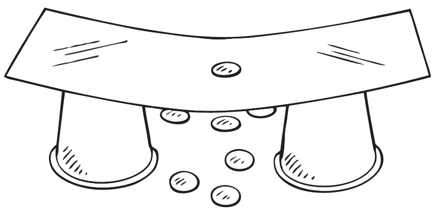
1. Demonstrate a simple bridge for students. Show them one of the abutment setups you created. Tell students that the two platforms are called abutments. **Abutments**, or platforms, hold up a bridge at either end. They will build their bridge on top of the abutments.

2. Lay a card on top of the abutments. Tell students that the part of the bridge that goes across the abutments is called the **beam**.

3. Show students the weights and ask, "How many weights do you think my bridge beam will hold?"

4. Slowly and carefully add one weight at a time while students count the weights. Continue adding weights until the bridge fails.





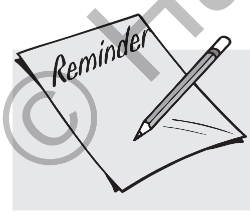
✏ On the board or chart paper, record the number of weights your bridge held just before it failed.

5. Challenge students to use what they learnt about forces to build a bridge that holds more weight than yours did. Have students choose a partner (or assign partners), and give each pair of students a copy of *Beam Bridge Information* (page 29).

6. As a class, read through the information about tension and compression on a bridge beam.
   – Ask students what their beams will be made of. (*paper*)
   – Ask students to share some ideas about how to make their paper bridge beams stronger than your unaltered paper beam.

7. Tell students that in engineering, the rules are called *constraints*. The constraints tell what the engineers can and can not do. With students, review the constraints for the project on the *Beam Bridge Information* sheet.

8. Explain to students that when something breaks, engineers call that a **failure**. Make sure students know this is different from "failing" in school! During design and testing, failure is an expected part of the engineering process.



Engineers use failures to see what went wrong and to improve their designs so that when they build the real thing, it won't fail. Let students know that when their bridges fail, they can learn from what went wrong and try again.

✏ With students, decide on a definition of *failure* for their bridges and have them write it on their information sheets. For example, "The bridge touches the ground", or "The bridge comes off one or both of the abutments".