Why is riding a bicycle faster than running? The teacher guide

Whybricks
Giving physical science form

microbric
motivate • create • educate

Contents

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About Whybricks

Whybricks is an education-focused construction system consisting of 2,100 pieces (210 pieces per student). Each Whybricks kit contains everything needed to enable 10 students to work individually.

Each Whybricks kit contains interlocking building blocks, beams, pegs, gears and other parts. The individual Whybricks pieces are designed with studs and holes which are compatible with any LEGO brick compatible building system.

Why use Whybricks?

The Whybricks kit, along with the supporting lessons, can help students tangibly access topics that can otherwise feel abstract. Whybricks allow students to explore physical science and engineering phenomenon in a hands-on and engaging way. By enabling students to explore topics through physical activity, students engage in kinaesthetic learning, allowing them to experiment with productive trial-and-error and bridge potential gaps between theory and practice.

The Whybricks lessons use the Whybricks kit to help to support or elevate understanding for any type of learner. The Whybricks kit offers a way to bring hands-on learning in as a functional part of each Whybricks lesson plan.

Managing Whybricks in your classroom

Whybricks offers educators flexible teaching options. Both the Whybricks kit and lessons are intentionally versatile to allow teachers the freedom to implement the materials however best suits their classroom's needs.

The components of each Whybricks kit are supplied with the intention of being a 'pool of parts' for the teacher to use as you see fit. The parts can be organised and stored as best suits your classroom and students. Some ideas for managing the Whybricks kits in your classroom include:

- Create individual 210-part student kits for each student.
- Make up packs with just the parts needed for a specific lesson activity or project.
- Make 'STEM boxes' with instructions and pieces for a challenge for rotation stations.

- Divide up the full kit, arranged by part type, into a storage tray-style storage system, allowing students to find and use the parts they need.
- Provide only a selection of parts in a mixed pack for semi-open and open-ended projects, limiting students from being overwhelmed or distracted by other parts and providing an engineering constraint.
- Keep all the parts mixed together in a single pile free-for-all.

About the 'But, Why?' lessons

This lesson is a *But, Why?* Whybricks Lesson. What does that mean?

Try this.

Ask 10 students the question 'why do people use wheelbarrows?' You will likely end up with 10 versions of the answer 'because it makes it easier.' And they are right, of course!

Your students already know a lot about how the world works. They know that when they let something go, it falls down. They know that riding a bicycle is faster than walking. What they might not know, or may not be able to articulate, is why these things are true.

Now imagine the conversation again:

> You: Why do people use wheelbarrows?
>
> Student: It makes it easier.
>
> You: It makes what easier?
>
> Student: … Doing… the work. You know, carrying heavy stuff, or big stuff.
>
> You: But, why?

These lessons will help you flip the script

The *But, Why?* Whybricks Lessons are designed to help teachers transfer agency over learning to students. These lessons help you take your students on a learning journey by asking them 'why?' and supporting them in discovering and presenting their answers using sound engineering and scientific practices.

These Whybricks investigations start by getting students to communicate what they already know about observable phenomenon. By asking students 'why?' up front, the Whybricks investigations help educators determine and celebrate what students already understand. This intuitive understanding is then built upon inside the investigation. Each lesson supports students in growing their grasp of the reasons that underpin the 'why' of what they have already discovered.

The *But, Why?* investigations help students invest in their learning through active and hands-on sciencing (because science is a verb now!) and engineering. The 'why' question format drives the inquiry nature of each investigation, exploring different aspects of physical science and engineering.

Pedagogy approach

The pedagogy behind the *But, Why?* Whybricks lessons set is to deliver physical science education holistically. Through the investigations, students will:

- encounter facts (for example, Newton's second law is mathematically expressed as F=ma),
- exercise a scientific mindset (for example, making observations by answering 'what do you notice?' and developing questions by considering 'what do you wonder?'),
- participate in scientific and engineering practices (for example, by planning and carrying out an experiment or by developing and iterating a design), and
- make real-world connections between the world around them and the material they are learning.

The methodologies used in the investigations are inspired and informed by:

- The PQRST approach developed by DaNel Hogan and Brooke Meyer https://stemazing.org/pqrst/
- The inquiry in the classroom approach as codified by Trevor Mackenzie https://www.trevormackenzie.com/

With great appreciation and heart-felt thanks for your collaboration for constructive disruption.

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The *But, Why?* Whybricks Lesson Set is comprised of the student materials (including the *But, Why?* lesson activity Whysheets, Notice and Wonder sheets and WOW sheets) and the teacher guides. The collection is licensed under a Creative Commons Attribution-ShareAlike 4.0 International (CC BY-SA 4.0)[1].

Using the guides and the lessons

Each *But, Why?* Whybricks investigation is slightly different. As every investigation explores different physical science and engineering topics, the layout and activities of each one differs to best enable meaningful learning to be achieved. There is no set order in which the investigations should be explored and no wrong-way of adjusting an investigation to suit your students or curriculum.

This guide offers support for educators to get the most out of this lesson.

Overview of the student materials

Each *But, Why?* Whybricks investigation is intended to be student-centred and led. With the exception of the teacher guides, the educational materials are all 'student materials' and are designed for independent use by students.

The student materials for this lesson can be downloaded from https://whybricks.com/lesson-set/but-why/

There are three types of interrelated printable student materials:

- Whysheets
- Notice and Wonder sheets
- WOW sheets

An overview of each type of document follows.

About the Whysheets

The core of each *But, Why?* Whybricks investigation is its Whysheet. Much more than a worksheet, a Whysheet is the students' (and educators') guide for the investigation.

[1] Creative Commons licence information can be viewed at http://creativecommons.org/licenses/by-sa/4.0/

Every Whysheet starts with the ‘why’ question the investigation is centred around. Students answer the question to the best of their ability, drawing on what they already know. The goal isn’t to get it ‘right’ but to codify what they already understand and, over time, get them to think about what they don’t understand as well.

The Whysheet will then walk the students through the investigation step-by-step.

Any WOW sheets related to the investigation will be referenced in the Whysheet as will suggestions for when to use the Notice and Wonder sheets. If there is a set Whybricks build, step-by-step build instructions will also be included as an appendix to the Whysheet. You can also encourage students to improve on the set builds, further exploring and applying aspects of physical science and engineering.

The Whysheets, along with the Notice and Wonder sheets, are designed to capture learning evidence as it happens during the investigation, rather than be a ‘now that you have finished everything, write in the correct answer’ style worksheet. Encouraging students to view the Whysheet as their tool to help them through the investigation will help them take ownership over their learning.

About the Notice and Wonder sheets

The Notice and Wonder sheets are templates designed to work alongside any *But, Why?* investigation. These sheets offer places for students to note observations ‘I notice …’ and capture questions ‘I wonder …’ throughout the investigation. The Whysheets will indicate key opportunities in an investigation when students will benefit from making notes in a Notice or Wonder sheet, but students should feel free to use these sheets throughout their learning journey, especially for capturing new questions they begin to wonder about as they progress.

Along with the Whysheet, the Notice and Wonder sheets form an important part of capturing learning evidence and empowering student agency in each investigation. All of the Notice and Wonder sheets serve the same purpose, but different versions are available to offer educators flexibility in adapting these to their students’ needs.

The Notice and Wonder sheet set includes an educator’s overview and recommendation section with additional information.

About the WOW sheets

The WOW in the WOW sheets stand for ‘Why? Oh, Whoa!’.

WOW sheets are a way of inserting teaching into an investigation flexibly. For example, you might choose to provide copies of the WOW sheets for students to read in-depth or just reference to find the answers they need. You can also replace WOW sheets with your own lecture or other fact-delivery method on the topic, explaining and exploring as deeply as you see fit.

These sheets are basically reference cards. Each WOW sheet contains information about a specific topic or fact. The WOW sheets help students to discover and understand key information, enabling them to apply what they learn back into the investigation. Examples of the content covered in WOW sheets includes definitions of terms (e.g. 'What is mass?'), explanations of facts (e.g. Newton's third law) and formulas in context (e.g. calculating acceleration, part of the 'What is acceleration?' WOW sheet).

WOW sheets can be used in several ways. You can use them to help guide class-wide explanation sessions or allow students to access them independently when and if they need the information. The WOW sheets can introduce concepts, serve as quick 'refresher' reference cards or be used retrospectively to demonstrate broader applications of elements encountered inside an investigation.

The Whysheets will indicate key moments in an investigation when students may benefit from using a specific WOW sheet. You may also find it helpful to have the WOW sheets available for students to access at any time.

Overview of the teacher guide

This teacher guide offers overview information plus per-investigation support for educators to get the most out of each lesson.

Remember that the *But, Why?* lesson set is intentionally flexible. There is no set order in which the investigations should be explored. Likewise, while the teacher notes offer additional support for educators, by design they are not overly prescriptive.

The *But, Why?* investigations aim to inspire students to 'think like a scientist' or 'think like an engineer'. Rather than simply explaining how something works, the lessons encourage active participation in learning by conducting experiments and problem-solving. Armed with these experiences, the students are the ones doing the sense-making.

As you might expect, trial-and-error is an inherent part of this approach. To get the most out of their Whybricks lesson, you should support your students as they work through productive struggles without jumping in and 'saving them' from these exciting learning opportunities. Give students a chance to impress you, and themselves, with the thinking they can do. However, you know your students best! Always feel free to adjust any investigation to suit your students or curriculum as you see fit.

For each *But, Why?* investigation you will find teacher notes specific to the investigation that include:

- An overview of the investigation
- A list of the topics covered
- A list of the WOW sheets needed (both those explicitly noted in the student Whysheet plus any additional recommendations)
- Recommendations for running the investigation
- Additional notes specific to the investigation (including sample answers to specific Whysheet questions)

Love these lessons? Hate them? Have an idea for a lesson activity?

The team behind Whybricks would love to hear from you! You can share your feedback and ideas with us through the contact form on our website at https://whybricks.com/support/contact-us/

Why is riding a bicycle faster than running?

Overview

This project is focused around gears. Often mistakenly added to lists of simple machines, gears are actually compound machines. A common component in many mechanical devices, developing an understanding of how gears work allows students to better understand how devices in their lives work, and to tackle interesting engineering challenges.

In this investigation, students explore the fundamentals of how gears work, including mated gears of different sizes. They then work through the engineering design process as they iterate and test a design that utilises gears to change the speed, the size, or the direction of an input force to perform a task of their choosing.

Topics covered

- Gears
- Engineering design

WOW sheets

Explicitly noted	Also recommended
• Gears	• Wheel and axle • Lever • Mechanical advantage • What is force? • Friction

Additional equipment

- Additional Whybricks, especially additional gears, and other building materials for part 2.
    - Student designs will determine the supplies required.
    - Alternatively, you can decide on the available supplies in advance. Show students the available building materials and explain that these are the only options for use in their designs. This is an excellent way of introducing the idea of constraints into the engineering design process.
    - Depending on what tasks students want to perform with their creations, materials to track or measure different objectives may be needed.

Delivery recommendations

The Why question

Before you begin the investigation, have students think about and answer the 'why' question. Offering everyone quiet independent thinking time to start is a good way to ensure all students have the chance to consider what they already know. You can then have students share with a partner, a group or the class if you like. If students start to raise questions, encourage them to capture them on a Wonder sheet.

Students may write down 'gears' or 'wheels' but not initially offer definitions of what a gear or a wheel is. Encourage them to explain gears and wheels in their own words. While these devices are common, there is a lot of physics and engineering wrapped up in them. Help draw some of that science out of your students using their experiences and intuition.

Part 1

The first part of this investigation invites students to explore how gears work. Students first build the uniform gearbox using two 40-tooth gears. They then create the mixed gearbox, removing one of the 40-tooth gears and replacing it with an 8-tooth gear instead.

By tinkering with both builds back-to-back, students are able to observe what using gears of different sizes does to a system. They explore why these effects might be useful inside machines, setting the stage for developing their own gear-based invention.

Part 2

The second section of the investigation invites students to apply what they've learnt to an engineering design challenge. The goal of the challenge is to engineer a device that uses gears to change the speed, the size, or the direction of the input force to perform a task of the student's choosing. This section is laid out in three steps:

1. Brainstorm
2. Test design
3. Iteration (i.e. 'Build, test, learn, repeat')

When it comes to 'engineering', there's a temptation to jump straight into building. However, engineers are problem solvers first and foremost. Understanding what the goal is, what constraints there are and how success will be measured are important parts of the engineering design process. The three steps of part two of this investigation are designed to help students work through the engineering design process in a painless but meaningful way.

Suggestions on how you can run each step follows, however, feel free to adjust this challenge to suit your class.

Step 1: Brainstorm

Not all students will feel confident about an engineering design challenge. A brainstorming session is a great way to get the creative juices flowing. Tell students that this is just about coming up with ideas, which is all about being imaginative, using their creativity, and thinking about possibilities. Whether or not these will work isn't the current concern – there's a whole other step for that!

Depending on your students' confidence with making, you may want to allow the first few rounds to be completely open: allow them to generate ideas by getting their thoughts to flow freely. Let them know that all ideas are acceptable, no matter what they are. Encourage students not to make decisions about whether the ideas are possible or judge the ideas while they are brainstorming.

One way to do this is to run a timed brainstorming session. Set a timer for 45 seconds – that's all the time students have for the first idea before they must move onto the next. Allow students to capture ideas however they like: draw, write down a description, or a bit of both. Tell them the main rule is that they are not allowed to NOT come up with ideas. Remind them that there are no 'bad' ideas during a brainstorming session! As soon as the timer goes off, reset it and have students move on to the next idea.

After a few rounds, pause. Introduce the materials students will have available to them to use in the engineering challenge. Then start the brainstorming session up again, this time encouraging students to think about possibilities using the available materials. You can keep the timer set to 45 seconds or increase it slightly as you see fit.

Once you have finished brainstorming, give students a few minutes to analyse the ideas they came up with. Looking at all of their ideas together can help students evaluate their ideas, choosing which ones they feel are better than others. This can help students in selecting one idea to use as a starting place in designing their creation.

If you are going to have students work on the rest of the design challenge in pairs or groups, the wrap-up of the brainstorming session is also a good time to get the groups together. Sharing ideas and discussing their thoughts at this stage will help students in the next step as they design their test.

Step 2: Designing the test

There's no way to know whether or not a design is successful without criteria and a test. That's what step two is all about. This step is often overlooked in engineering projects, but is critically important.

A key parameter of the test is established in the goal for this design challenge on the Whysheet (use gears to change the speed, the size, or the direction of an input force to perform a task of their choosing). Students will need to determine what task their creation will perform and how the gears will help. Their test needs to measure the performance of the task in some way.

If, for example, students want to use the gears in their creation to increase the speed of the output, they will need a way of measuring the input and output speeds. Conversely, if they want the output force to be increased, they will need a way of measuring the input and output forces, or comparing the results to an alternative (for example, using no gears).

Remind students also that gear ratio can help them determine the mechanical advantage of their gear system. If students are using multiple gears, they can still calculate the gear ratio for their compound gear train. The easiest way to calculate the gear ratio for a compound gear train is to consider each gear set individually, starting from the input and moving to the output. Use the same formula as the single gear set for each pair, dividing the number of teeth on the driven gear by the number of teeth on the drive gear.

Like all things in engineering, students may encounter issues while designing the test. Whatever test students devise, remind them that it is important that they note the procedure and how they measure carefully so this can be repeated across their designs.

Depending on your students, you may choose to guide your class through this step. In helping students create their tests, noting any dependent and independent variables, materials and equipment that will be used, and the experimental procedure. The experimental procedure should be detailed enough to allow data collection and to be able to be repeated exactly as described.

A note about testing:

It's generally considered good practice to run five (5) trials of a test and then average the results together.

Step 3: Iteration

This step is where students get into the heart of the engineering design process as they build, test, learn, and repeat.

Depending on the materials available to them for use in their designs and the tests that students have created, this step can vary widely even in a single class. Some students' initial iteration may be quite solid and their further iterations are mainly refinements. (Remind students also that they can 'take a step back' to a previous iteration, undoing something they tried to go back to a better result and then iterate from that point.) Other students may decide to switch tactics completely after one or two attempts. Still others may try completely different ideas with each iteration to see what works. These are all valid approaches. If you are looking for students to approach this step in a particular way, offer guidance as students proceed to direct the learning outcomes you are seeking to achieve. Otherwise, allow students the freedom to tinker, experiment, fail, and learn!

A wrap-up section completes this step. Students reflect on all of their designs and explain their most successful design, including why it was the most successful.

A note about testing:

It's generally considered good practice to run five (5) trials of a test and then average the results together.

A note on printing step 3 of the Whysheet:

Pages 8-17 of the student Whysheets include ample space for the full note capture of five iterations. You do not need to print all of these pages if students will capture the relevant information in a notebook or similar system elsewhere. Having the template available for students to refer to is recommended.

Additional notes

Build notes

There are two set builds in this investigation: the uniform gearbox and the mixed gearbox, both used in part 1. Students may choose to use either build as the base for their engineering design challenge, or create something entirely different.

The mixed gearbox

- The mixed gearbox removes one of the two gears from the uniform gearbox, replacing it with a smaller gear. The instructions begin with a complete uniform gearbox, then remove one of the gears. Doing the build in this way can help

students see how different gears can mate together in the same machine, which can be helpful for the engineering design challenge.
- If you need to build the mixed gearbox from scratch, follow steps 1-8 from the uniform gearbox build, then continue with the mixed gearbox build from step 4.

Answer key

The sample answers provided are intended to offer guidance only. Student answers will vary depending on their experiences. An answer to the initial 'why' question is not supplied as there is no 'right' answer for this – it is intended to capture a student's initial understanding.

Question	Sample answer
Gear ration using the mixed gearbox	A gear ratio is the measure (ratio) of complete turns two gears make when they are connected together. For example, on the mixed gearbox, the small gear has 8 teeth and the big gear has 40 teeth. When the small gear is the drive gear (and the big gear is the driven gear) the gearbox has a gear ratio of 5 (5 : 1). But when the big gear is the drive gear, the gearbox has a gear ratio of 1/5 (1 : 5). In either case, the small gear will make 5 complete turns for every one turn the big gear makes.
Gears of mixed sizes using the mixed gearbox and uniform gearbox	One reason you might use different sized gears in a machine is to change the speed or the size of the force from the power source. For example, in the uniform gearbox, the second gear turns the same number of rotations and at the same speed as the drive gear because they are the same size. But in the mixed gearbox, the smaller gear turns 5 times for every complete turn the big gear makes. If you want to speed up a force, using a smaller gear as the driven gear will make the force go faster. Bicycles do this by having a smaller gear in the back than the front. The back wheel turns more because of the smaller gear, meaning you don't have to pedal as many times, but you do have to use more force.

Outside resources

These resources can serve as great wrap-ups to this investigation and 'provocateurs' to get students thinking about new questions. As links can disappear over time, a description of the content is included so that you can find a replacement if needed. An example 'I wonder...' question is also provided.

1. **How do bicycle gears work?**
   https://www.youtube.com/watch?v=oauDyIu_swM

   - **About the video:** This made-for-kids video explores why changing gears on a bicycle can make it easier to climb a hill and explores the trade offs between force and output with different gear ratio.
   - **I wonder** if cars also use gear ratios?

2. **The force multiplier: a gear creation**
   https://www.youtube.com/watch?v=U26qzRWj0Eo

   - **About the video:** This short video demonstrates a gear contraption made by a young engineer. The box-shaped contraption uses multiple gears to create a 1:162 gear ratio on the final gear.
   - **I wonder** how many Whybricks gears it would take to create a 1:162 ratio?

3. **Odd shaped gears that work**
   https://www.youtube.com/watch?v=WYcqJ5HdxA4

   - **About the video:** This video demonstrates a variety of square, oval, pentagonal, organic and other unbelievably-shaped gears – all of which really work!
   - **I wonder** what other shapes you can make into gears that work?

4. **Can three gears work together?**
   https://www.youtube.com/watch?v=5Mf0JpTI_gg

   - **About the video:** This video from the *Numberphile* series looks at a common graphic design element of three connected gears, explaining why the design would be unable to move, before looking at non-traditional 3D printed three-gear models that do work.
   - **I wonder** what type of invention could use the three-gear solutions to run?

5. **Newton's three laws explained with a bicycle**
   https://www.youtube.com/watch?v=JGO_zDWmkvk

   - **About the video:** This short, animated TED-ED video looks at how Newton's three laws of motion can all be seen working whenever anyone rides a bicycle, showing how the broader laws of physics are connected to bicycles and our everyday lives.
   - **I wonder** if you could create a working gear ratio so that you could pedal a 10,000-pound bicycle?