# LEGO Education

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Introduction

LEGO® Education is pleased to bring you ‘2009686 Introducing Simple & Powered Machines’.

Who is it for?
The material is designed for use by non-specialist teachers of key stage 2 and lower 3. Working in pairs, children of any academic background from eight years and up can build, investigate and learn from the models.

Check the grid in the curriculum section to see which themes match your current teaching program.

What is it for?
The ‘Introducing Simple & Powered Machines’ activity pack enables children to work as young scientists, engineers and designers providing them with settings, tools and tasks that promote design technology, science and mathematics.

Using our activity pack children are encouraged to involve themselves in real world investigations and problem-solving. They make assumptions and predictions. They design and make models and then observe the behaviour of these models; they reflect and re-design, and then record and present their findings.

The ‘Introducing Simple & Powered Machines’ activity pack enables teachers to cover the following overall curriculum skills:

• Think creatively to try to explain how things work
• Establish links between cause and effect
• Design and make artefacts that fulfil specific criteria
• Try out ideas using results from observations and measurements
• Ask questions that can be investigated scientifically
• Reflect on how to find answers also imagining new possibilities
• Think about what might happen, or try things out
• Make fair tests by changing single factors and observing or measuring the effects
• Make systematic observations and measurements
• Display and communicate data using diagrams, drawings, tables, bar charts and line graphs
• Decide whether conclusions agree with any predictions made, and whether they enable further predictions
• Review work and describe its significance and limitations
What is it and how to use it?

The 9686 building set
The set has 396 elements, including a motor, and Building Instructions booklets for 14 main models and for 37 Principle Models – all in full colour. Some of the Building Instructions booklets are intended for use with other LEGO® Education activity packs.

Included is also a sorting tray and accompanying element overview showing all the different elements in the set. Everything is stored in a sturdy blue storage box with a transparent lid.

Building Instructions booklets
We have devised the Buddy Building system in which models are designed so two children can build simultaneously – also saving time. Each child (Buddy) builds his or her own subsystems using separate booklets (A and B). Working in pairs the subsystems are then built together to become one complete model.

Further progression for both children is suggested in booklet B in red number sequences.

Principle Models
The Principle Models let children experience the mechanical and structural principles normally hidden away inside everyday machines and structures. The many easy-to-build models each present a hands-on demonstration of one of the concepts of simple machines, mechanisms and structures in a clear, straight-forward manner.

By progressing sequentially through the activities, using the Student Worksheets and Building Instructions, children will experience and discover the principles at work and be challenged to apply their knowledge when recording their results. In the Teacher’s Notes you will find suggested answers to the questions posed in the Student Worksheets.

The Principle Models are a pathway for children to understand and integrate mechanical and structural principles applied in their own models.

Teacher’s Notes
In the Teacher’s Notes you will find all the information, tips and clues you need to set up a lesson. Each model the children build has specific key learning focus areas, vocabulary, questions and answers, and further ideas for investigations.

The lessons follow LEGO Education’s 4C approach; Connect, Construct, Contemplate and Continue. This enables you to progress naturally through the activities.
Connect
You add to your brain’s knowledge when you connect a new learning experience to those you already have or when an initial learning experience is the seed stimulating the growth of new knowledge. Ideas are provided for helping the children identify a problem and for helping Jack and Jill, our two cartoon friends who help guide us through the activities. Show the flash animation with Jack and Jill and have the children define the problem and investigate how best to come up with a solution. Another approach is to read the story in connection with the flash animation.

Please also draw on personal experience and from current events both near and far to set the scene for the children. The more easily the children identify with the situation in which Jack and Jill find themselves, the more easily they will come to grips with the technology, science, and mathematics embedded in them.

Construct
Learning is best when hands and minds are engaged. In pairs, children build models step-by-step. Two buddies each build half a model using separate booklets (A and B) to create their own subsystems and then collaborate to assemble one complete model.

Contemplate
When you contemplate what you have done, you have the opportunity to deepen your understanding. As you reflect, you develop connections between previous knowledge and new experiences. This involves children reflecting on what they have observed or constructed, and deepening their understanding of what they have experienced. They discuss their results, reflect on and adapt ideas, and this process can be encouraged by asking relevant scientific and technical questions.

Questions are included in the material to encourage children to carry out relevant investigations, predictions and rationales, and to reflect on how to find answers – also imagining new possibilities.

This phase includes the possibility to start evaluating the learning and the progress of the individual child.

Continue
Learning is always more enjoyable and creative when it is adequately challenging. Maintaining this challenge and the pleasure of accomplishment naturally inspires the continuation of more advanced work. Therefore extension ideas are provided to encourage the children to change or add features to their models and to investigate further – always with the key learning area in mind. This phase allows the children to operate at different speeds and levels conducive to their individual capabilities.

It is OK if there is too little time to complete Continue phases within the class period. Working through the first three phases of the process covers the curriculum skills listed for any one activity. You may omit the Continue phase at your discretion, or postpone it until the next lesson.
Student Worksheets
Classroom management tips

Introduction

Schools are places where students spend a lot of their time, and the classroom is the heart of these institutions. A classroom can be a place of learning, growth, and development for students, but it can also be a place of confusion, frustration, and conflict for teachers. Effective classroom management skills are crucial for teachers to create a positive learning environment and ensure that students are engaged and motivated to learn.

There are a variety of classroom management strategies that teachers can use to create a supportive and structured learning environment. These strategies can include creating a clear set of rules and expectations, establishing routines and procedures, using positive reinforcement, and providing opportunities for students to take ownership of their learning.

How do I handle the building materials left on the floor?

Buildings can quickly become cluttered with building materials if not properly managed. To prevent this, it's important to establish a clear system for storing and organizing materials. This can include designating specific areas for different types of materials and implementing a system for returning materials to their proper places after use.

What's needed in my classroom?

Classrooms should be equipped with the necessary materials and resources to support learning. This can include books, writing materials, and technology tools. It's important to ensure that the classroom is well-stocked with these materials and that students have easy access to them.

I need to be able to ask students to work on class projects, but they keep asking for help. How can I get them to work independently?

It's important to establish clear expectations for students to work independently. This can include setting deadlines for assignments and providing opportunities for students to take ownership of their learning. It's also important to create a supportive learning environment where students feel comfortable asking for help when needed.

Why do students lose focus so quickly in class?

Lack of focus can be a result of a variety of factors, including physical discomfort, lack of engagement, or a lack of motivation. It's important to create a comfortable and engaging learning environment that encourages students to stay focused and motivated to learn.

Conclusion

By implementing effective classroom management strategies, teachers can create a positive and supportive learning environment for all students. This will not only help students stay engaged and motivated to learn, but it will also help them develop the skills and knowledge they need to succeed in life.
What are the curriculum highlights?

The process of children actively building, exploring, investigating, enquiring and communicating together benefits their development in innumerable ways over and above the more traditional learning parameters. See the curriculum grid for more details. Here is an overview:

**Design and technology**
Making solutions to match real needs; choosing appropriate materials and processes; designing, making, testing and modifying; exploring systems and subsystems, and safety and control systems; using 2-dimensional instructions; creating 3-dimensional models; working cooperatively in a team, and more.

**Science**
Investigating, collecting, storing and transferring energy; force, speed, and the effect of friction; simple machines, calibrating and reading scales, scientific fair testing, purposeful enquiry, predicting and measuring, collating data, drawing conclusions, and more.

**Mathematics**
Maths in the service of science and technology; measuring distance, time, speed (velocity), and weight (mass); notions of accuracy in calibrating and reading scales; tabulating and interpreting data; informally calculating ratios, and more.

**Curriculum grid**
Grab a pencil and note pad and sit just for a few minutes watching and listening as a pair of your ‘Buddy Builders’ collaborate on any of the LEGO® activities. Note down key knowledge, skills and attitudinal outcomes as they become apparent to you.

We are sure the many valuable academic, creative, problem-solving and social aspects of the activities will speak for themselves.

The major skill and knowledge outcomes most schools require for lesson planning are listed in the Curriculum grid on the following pages.
<table>
<thead>
<tr>
<th>Sweeper</th>
<th>Fishing Rod</th>
<th>Freewheeling</th>
<th>The Hammer</th>
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</thead>
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### FORCES & MOTION

**Design and technology curriculum:**
Identifying a need and developing ideas. Working as individuals and in teams. Use materials and components as well as modular construction kits to design and make high-quality working prototypes. Use appropriate testing to identify improvements. Assembling and disassembling a range of familiar products and testing how well they meet the intended purpose.

- Investigating pulley drives for safety and gears for speed
- Controlling friction and slip
- Designing and making: the most efficient push along cleaning machine

- Investigating the ratchet and pawl as a safety system
- Investigating automatic mechanical control of motion
- Designing and making: a fishing game with easy-to-understand rules and a fair scoring system

- Investigating the effects of different wheel sizes and tyre material on vehicle efficiency (working characteristics of materials)
- Wheels and axles to move loads
- Designing and making: a downhill runner vehicle that rolls as far as possible

- Investigating mechanical control and timing of complex actions by cams and levers
- Investigating how industries test quality of components
- Designing and making: a mechanical toy with as many actions as possible

**Science curriculum:**
Scientific enquiry including predicting and measuring the effect of variables on the performance of simple machines. Careful observation, measurement and recording.

- Balanced and unbalanced forces
- Friction
- Reducing speed and increasing force using string and pulleys (block and tackle)
- Inclined planes
- Friction
- Inclined planes
- Friction

**Mathematics’ curriculum:**
Using and applying mathematical ideas. Calculations using all number operations. Calculate and use notions of area, averages and ratios. Measure time, distance and (force) weight to a suitable degree of accuracy. Use word equations; solve simple equations to calculate speed. Identify patterns in results; collect and handle data in tables. Communicate mathematical ideas in speech, and in written and graphic forms.

- Measuring distance
- Ratios
- Notions of efficiency as a percent or fraction
- Measuring distance
- Estimating and comparing force, speed
- Designing and evaluating fair scoring systems and fair rules for games
- Ratios and fractions
- Measuring distance, mass
- Working with negative numbers (at bottom of hill, rolling the car backwards to zero)
- Exploring limits to accuracy
- Calculating averages

- Reading and calibrating scales
- Measuring number of ‘impacts’ per unit time
- Estimating and comparing LEGO® element grip forces
- Expressing relative grip forces using mathematical terms
### Curriculum Highlights

<table>
<thead>
<tr>
<th>Trundle Wheel</th>
<th>Letter Balance</th>
<th>Click-Clock</th>
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</thead>
<tbody>
<tr>
<td><img src="image1" alt="Trundle Wheel" /></td>
<td><img src="image2" alt="Letter Balance" /></td>
<td><img src="image3" alt="Click-Clock" /></td>
</tr>
</tbody>
</table>

#### Measurements

**Design and Technology Curriculum:**
- Identifying a need and developing ideas. Working as individuals and in teams. Use materials and components as well as modular construction kits to design and make high-quality working prototypes. Use appropriate testing to identify improvements. Assembling and disassembling a range of familiar products and testing how well they meet the intended purpose.
- Investigating gearing down and complex gearing
- Designing scales that are accurate and easily readable by the user
- Designing and making: the most accurate and easy-to-use distance measuring device
- Investigating lever and linkage systems
- Designing scales that are accurate and easily readable
- Designing and making: the most accurate and easy-to-use weighing machine
- Investigating feedback control systems (pendulum and escapement) and gearing up
- Designing scales that are accurate and easily readable
- Designing and making: the longest running and most accurate time measuring device

**Science Curriculum:**
- Scientific enquiry including predicting and measuring the effect of variables on the performance of simple machines. Careful observation, measurement and recording.
- Calibrating and reading scales
- Measuring distance to limits of accuracy
- Balancing forces
- Calibrating and reading scales
- Measuring weight to limits of accuracy
- The pendulum
- Calibrating and reading scales
- Measuring weight to limits of accuracy

**Mathematics' Curriculum:**
- Using and applying mathematical ideas. Calculations using all number operations. Calculate and use notions of area, averages and ratios. Measure time, distance and (force) weight to a suitable degree of accuracy. Use word equations; solve simple equations to calculate speed. Identify patterns in results; collect and handle data in tables. Communicate mathematical ideas in speech, and in written and graphic forms.
- Reading and calibrating scales
- Measuring distance
- Counting up, counting down
- Comparing accuracy of different measuring methods
- Ratios and fractions
- Expressing the degree of error
- Reading and calibrating scales
- Measuring mass
- Comparing accuracy of different measuring methods
- Working with negative numbers
- Expressing the degree of error
- Measuring time
- Reading and calibrating scales
- Comparing accuracy of different measuring methods
- Expressing the degree of error
<table>
<thead>
<tr>
<th>Curriculum highlights</th>
<th>Windmill</th>
<th>Land Yacht</th>
<th>Flywheeler</th>
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</thead>
</table>

**ENERGY**

**Design and technology curriculum:**
Identifying a need and developing ideas. Working as individuals and in teams. Use materials and components as well as modular construction kits to design and make high-quality working prototypes. Use appropriate testing to identify improvements. Assembling and disassembling a range of familiar products and testing how well they meet the intended purpose.

- Investigating sail material, shape, and area for effectiveness in capturing wind energy
- Investigating structures
- Designing and making: the most effective energy storage and release system for a windmill

<table>
<thead>
<tr>
<th>Science curriculum:</th>
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<tbody>
<tr>
<td>Scientific enquiry including predicting and measuring the effect of variables on the performance of simple machines. Careful observation, measurement and recording.</td>
</tr>
</tbody>
</table>

- Capturing wind energy to run machines
- Storing and transferring energy: kinetic to potential energy transformations
- Balanced and unbalanced forces

<table>
<thead>
<tr>
<th>Mathematics’ curriculum:</th>
</tr>
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<tbody>
<tr>
<td>Using and applying mathematical ideas. Calculations using all number operations. Calculate and use notions of area, averages and ratios. Measure time, distance and (force) weight to a suitable degree of accuracy. Use word equations; solve simple equations to calculate speed. Identify patterns in results; collect and handle data in tables. Communicate mathematical ideas in speech, and in written and graphic forms.</td>
</tr>
</tbody>
</table>

- Measuring force in time and area
- Estimating and comparing speed and efficiency related to sail shape and area

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<table>
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<tbody>
<tr>
<td>Capturing wind energy for transport</td>
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<tr>
<td>Transforming energy by gearing down</td>
</tr>
<tr>
<td>Forces and wind resistance</td>
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<tr>
<td>Balanced and unbalanced forces</td>
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<tbody>
<tr>
<td>Measuring distance and time</td>
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<tr>
<td>Expressing speed and distance travelled related to the mass of the flywheels</td>
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</table>

- Investigating the flywheel as a speed control (gearing up) and safety mechanism
- Investigating the flywheel as an energy store
- Using gears to increase speed
- Designing and making: the smoothest running vehicle that rolls furthest using its onboard energy store
## POWERED MACHINES

### Design and technology curriculum:
- Identifying a need and developing ideas. Working as individuals and in teams. Use materials and components as well as modular construction kits to design and make high-quality working prototypes. Use appropriate testing to identify improvements. Assembling and disassembling a range of familiar products and testing how well they meet the intended purpose.

- Investigating gearing down, different tyre types and wheel types to give more torque
- Investigating the speed and pulling power of different arrangements of gears and wheels
- Designing and making: a powered vehicle that can pull the heaviest possible load

### Science curriculum:
- Investigating the effects of load on friction; reducing friction
- Inclined planes and work
- Investigating the transfer of movement and energy
- Investigating relationship between speed and mass; momentum and kinetic energy

### Mathematics' curriculum:
- Measuring distance and time of travel
- Measuring and expressing angle of slope
- Notions and calculations of wheel diameter and circumference related to distance travelled per rotation

- Measuring distance and time of travel
- Noticing patterns of distance travelled related to wheel mass

- Measuring distance, time
- Calculating speed
- Noticing pattern of stride length related to crank length
- Measuring and expressing angle of slope

- Measuring and expressing the degree and direction of movement of body parts, and number of actions per unit of time
- Noticing patterns of eye movements related to fulcrum position in cams
- Evaluating and expressing model performance (behaviour), qualitatively and quantitatively

### Dogbot
- Investigating levers, linkages, cams and cranks to produce complex timed and controlled movements
- Investigating pulleys and slip for safety
- Using a variety of materials to create a ‘skirt’ for a dynamic model
- Designing and making: an ‘animatronic’ creature that simulates dog-like behaviour

<table>
<thead>
<tr>
<th>Power Car</th>
<th>Dragster</th>
<th>The Walker</th>
<th>Dogbot</th>
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<tr>
<td><img src="image1.png" alt="Image" /></td>
<td><img src="image2.png" alt="Image" /></td>
<td><img src="image3.png" alt="Image" /></td>
<td><img src="image4.png" alt="Image" /></td>
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</table>
Simple Machines: Wheel and Axle

Wheels and axles are usually circular objects, often a big wheel and a smaller axle, rigidly secured to one another.

![Wheel and Axle Diagram]

The wheel and axle will always rotate at the same speed. Due to the bigger circumference of the wheel, the surface of the wheel will turn at a greater speed – and with a greater distance too.

Placing a load on a wheeled vehicle almost always reduces friction compared to dragging it over the ground. Wheels in science and engineering are not always used for transport. Wheels with grooves are called pulleys and wheels with teeth are called gears.

Common examples of wheels and axles are rolling pins, roller skates and pushcarts.

Did you know?
The first constructed wheel found so far was made by the Sumerians some 5,600 years ago.
B1
Build B1 book I, pages 8 to 9
Push the model along the table in a straight line.
Describe what happens.
Now try driving it in a zigzag pattern with sharp turns.
Describe what happens.

B2
Build B2 book I, pages 10 to 11
Push the model along the table in a straight line.
Describe what happens.
Now try driving it in a zigzag pattern with sharp turns.
Describe what happens and compare with the model above.

B3
Build B3 book I, pages 12 to 15
Push the model along the table in a straight line.
Describe what happens.
Now try driving it in a zigzag pattern with sharp turns.
Describe what happens and compare with the models above.
B4

Build B4 book 1, pages 16 to 17
Describe what happens and the movement of the universal joint when you turn the handle.
Inclined Plane
Simple Machines: Inclined Plane

An inclined plane is a slanted surface used to raise objects, e.g., a ramp.

Using an inclined plane to raise an object to a given height, the object must be moved a longer distance, but with less effort needed, than if the object was to be raised straight up. It's a trade-off either to use a lot of effort to raise a given load a short distance straight upwards or to apply much less force to raise it gradually over the longer distance of an inclined plane.

Common examples of inclined planes are ramps, ladders and stairs.
D1
Build D1 book II, pages 2 to 12
Let go of the load. Describe what happens.

D2
Build D2 book II, pages 13 to 15
Let go of the load. Describe what happens.
Gear
Mechanisms: Gear

Gears are wheels with teeth that mesh with each other. Because the teeth lock together, they can efficiently transfer force and motion.

The drive gear is the gear that is turned by an outside effort, for instance your hand or an engine. Any gear that is turned by another gear is called a driven gear. The drive gear provides the input force and the driven gear delivers the output force. Using a gear system can create change in speed, direction and force. But there are always advantages and disadvantages. For example, you can not both have more output force and an increase in speed at the same time.

To predict the ratio of which two meshed gears will move relative to each other, divide the number of teeth on the driven gear by the number of teeth on the drive gear. This is called the gear ratio. If a driven gear with 24 teeth is meshed with a drive gear with 48 teeth, there is a 1:2 gear ratio. Meaning that the driven gear will turn twice as fast as the drive gear.

Gears are found in many machines, where there is the need to control the speed of rotary movement and turning force. Common examples include power tools, cars and egg beaters!
G1
Build G1 book III, page 2
Turn the handle and describe the speeds of the drive and the driven gears. Label the drive and driven gears. Use a circle to show exactly where each one is.

G2
Build G2 book III, page 3
Turn the handle and describe the speeds of the drive and driven gears. Label the drive and driven gears. Use a circle to show exactly where each one is.

G3
Build G3 book III, page 4
Turn the handle and describe the speeds of the drive and driven gears. Label the drive and driven gears. Use a circle to show exactly where each one is.
G4
Build G4 book III, pages 5 to 6
Turn the handle and describe the speed and direction of
the drive and driven gears. Label the drive and driven gears.
Use a circle to show exactly where each one is.

G5
Build G5 book III, pages 7 to 8
Turn the handle and describe the speed and direction of
the drive and driven gears. Label the drive and driven gears.
Use a circle to show exactly where each one is.

G6
Build G6 book III, pages 9 to 10
Turn the handle and describe the movement of the driven
gear.
G7
Build G7 book III, pages 11 to 14
Turn the handle and describe what happens.

________________________________________
________________________________________
________________________________________
________________________________________

G8
Build G8 book III, pages 15 to 18
Turn the handle and describe what happens.
What happens if you stop one of the output pointers?
What happens if you stop both output pointers?

________________________________________
________________________________________
________________________________________
________________________________________

G9
Build G9 book III, pages 19 to 22
Turn the handle and describe what happens.
What happens if you try turning the output pointer?

________________________________________
________________________________________
________________________________________
________________________________________
G10
Build G10 book III, pages 23 to 25
Turn the handle and describe what happens.
Freewheeling

Design and technology
- Using mechanisms – wheels and axles
- Assembling components

Science
- Measuring distance
- Reading and calibrating scales
- Forces
- Moving energy
- Energy of position
- Friction and air resistance
- Scientific investigation

Vocabulary
- Mass
- Position
- Friction
- Efficiency

Other materials required
- 4 metres of smooth floor
- Masking tape
- Metre rule or measuring tape
- Plank of wood or shelf at least 1 metre long
- Pile of books or boxes to elevate the plank
- Spare LEGO® bricks for taking measurements
- Whiteboard marker
- Scissors
Connect

Jack and Jill are arguing as usual. They are making carts to see which one can roll the furthest down Launching Hill in their local Greenall Park.

Jill says that if she puts some extra weight on her cart, she will roll further because the cart is heavier. Jack thinks that because heavy loads are hard to move, he will go further. He prefers to go for bigger wheels, but Jill is not so sure this approach will help.

Which will roll further? Heavier or lighter carts, with bigger or smaller wheels? Let's find out!
Freewheeling

Construct

Make Launching Hill
Draw a start line, 1 metre from one end of the plank. Place a support so that the start line is 15 cm from the floor. Why do we need a start line?

We need it because then all tests are fair: all carts roll down exactly the same ramp.

Build the Freewheeler
(all of book 3A and book 3B to page 6, step 12).
- Test the Freewheeler on the ramp. Is the model running smoothly? If not, check all axles and bushings to make sure the wheels are turning smoothly. Also check that all elements are firmly linked to one another.

Trace the scale
Mark on the blue plastic disc or trace around it and cut out a paper copy. Put on scale markings and attach it on top of the blue plastic disc.

Tip:
If the thickness of the plank means that carts bump down from it onto the floor, use a piece of card to make a smooth transition from plank to floor.
Contemplate

Measure how far the empty cart rolls. Measure with a metre rule and compare with the pointer and scale. Record the distance and use a LEGO® brick as a marker of where it stopped. Test at least 3 times to be sure you have made a scientifically correct answer.

An unloaded cart should roll about 160 cm. This is more than once around the scale. The scale is accurate to within a few centimetres.

Trace the 1 m scale divisions on the plastic scale with an erasable whiteboard marker. Let the Freewheeler go down the ramp again and see if it runs approximately 160 cm by looking at the scale and pointer (one full revolution of the disc and a little more than another half). Carry out several tests. There is no need to use rulers or measuring tapes – just use the readings on the scale disc.

Add a weight brick to the cart (page 7, step 13). Predict how far it will roll this time by placing another marker brick along the track. Then test.

The cart will roll almost twice as far. The weight brick “falling” with the cart gives it nearly twice as much moving energy. However, note too that extra weight creates extra friction or rubbing on the axles which slows down the cart.

What do you notice about the pointer?

The pointer goes around more than once. You will need to count how many times it goes round.

Test several times to make sure your findings are consistent.

Jack’s Big Wheel Deal

Will big wheels help the cart to roll further than the smaller wheels? Fit them onto the rear axle and test on the ramp (page 7, step 14).

First test unloaded (page 7, step 14), then test loaded (page 8, step 15).

The cart usually rolls further. There are two reasons: more weight = more energy, and the rear axle turns more slowly, which means less friction.

Tip:

Look at the distance the cart travels down the plank. The pointer on the plastic disc passes zero for the first time just as the cart hits the floor. It measures almost exactly 1 m in one rotation.

Did you know?
The empty cart weighs about 58 g. And the weight brick weighs 53 g... almost the same!

Did you know?
The big wheels weigh about 16 g and the small wheels about 8 g.
Continue

**Super Scale**
Build book 3B to page 12, step 12.
Replace the 8-tooth gear wheel with the 24 tooth gear. Predict and then test how far the cart will roll before the pointer completes one revolution.

*It rolls 3 metres. The new gear wheel has 3 times as many teeth as the small one.*
The worm gear has to turn 3 times as often to get the 24-tooth gear wheel to turn once. Now you will need to calibrate the scale to measure distances accurately to 3 metres.

**Super Slope**
Predict first and then test what will happen if you double the height of the hill.

*You double the energy of position, double the moving energy, but do not double the axle friction.*
Freewheeling

Name(s):

Which will roll furthest? Heavier or lighter carts, with bigger or smaller wheels? Let’s find out!

Build the Freewheeler
(all of book 3A and book 3B to page 6, step 12).

• Check all axles and bushings to make sure the wheels turn smoothly
• Let your Freewheeler run down the ramp

Which roll further... heavy or light loads?
• Tip: Place a marker brick next to the track where you predict the cart will stop
• Reset the pointer on the scale after each test run

... and are big wheels better than small?
• Try using big wheels on the back axle

Test accordingly, following the challenges below:

<table>
<thead>
<tr>
<th></th>
<th>My prediction</th>
<th>My measurements</th>
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<tbody>
<tr>
<td></td>
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<td></td>
</tr>
<tr>
<td>Extra weight</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Big wheels</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Big wheels and extra weight</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Larger scales ... and steeper hills
Build book 3B to page 12, step 12.
Change the ramp position to be 30 cm high.
Test your different types of Freewheelers.

What I found out when making the slope steeper:

<table>
<thead>
<tr>
<th>My prediction</th>
<th>My measurements</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</tr>
</tbody>
</table>

My Amazing Downhill Racer!
Draw your favourite Freewheeler design.
Explain how the 3 best bits work.
Glossary

We have tried to make the glossary as understandable and practical as possible without resorting to difficult equations and long explanations.

A

**Acceleration**
The rate at which speed increases.
If a car is accelerating it is moving faster.

**Advantage**
The ratio of the output force to the input force of a machine.
Often a measure of how useful it is to us. This is sometimes called mechanical advantage.

**Air resistance**
The force that air creates by pushing back on a vehicle or object that is trying to push through it.
A streamlined shape creates less air resistance.

**Amplify**
To make larger. For instance a lever can amplify the force from your arm.

**Axle**
A rod through the centre of a wheel, or through different parts of a cam. It transmits force, via a transmission device, from an engine to the wheel in a car or from your arm via the wheel to the axle if you are winding up a bucket on a rope.

B

**Balanced force**
An object is balanced and does not move when all the forces acting on it are equal and opposite.

**Bearing**
Part of a machine which supports moving parts. Most of the holes in LEGO® elements can work as bearings for LEGO axles.
The special plastic is very low friction, so axles turn easily.

**Belt**
A continuous band stretched around two pulley wheels so one can turn the other. It is usually designed to slip if the follower pulley suddenly stops turning.

C

**Calibrate**
To set up and mark out the units on a scale for a measuring instrument. We can use known values like brass weights to mark a letter balance scale in grams or a stopwatch to mark off our new timer in seconds. This is called calibrating.

**Cams**
A non-circular wheel that rotates and moves a follower. It converts the rotary movement of the cam into reciprocating or oscillating the movement of the follower. Sometimes a circular wheel mounted off-centre on a shaft is used as a cam.

**Compression forces**
Forces in a structure that push in opposite directions, trying to squash the structure.

**Control mechanism**
A mechanism that regulates an action automatically. A ratchet stops an axle from turning the wrong way; an escapement stops a clock from running too fast.
### Glossary

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Counter balance</strong></td>
<td>A force often provided by the weight of an object you use to reduce or remove the effects of another force. A crane uses a large concrete block on the short arm of its jib to counter the unbalancing effect of the load of the other longer arm.</td>
</tr>
<tr>
<td><strong>Crank</strong></td>
<td>An arm or handle connected to a shaft (or axle) at right angles enabling the shaft to be easily turned.</td>
</tr>
<tr>
<td><strong>Driven gear</strong></td>
<td>See Follower.</td>
</tr>
<tr>
<td><strong>Driver</strong></td>
<td>The part of a machine, usually a gear, pulley, lever, crank or axle, where the force first comes into the machine.</td>
</tr>
<tr>
<td><strong>Efficiency</strong></td>
<td>A measure of how much of the force that goes into a machine comes out as useful work. Friction often wastes a lot of energy, reducing the efficiency of a machine.</td>
</tr>
<tr>
<td><strong>Effort</strong></td>
<td>The force or amount of force that you or something else puts into a machine.</td>
</tr>
<tr>
<td><strong>Energy</strong></td>
<td>The capacity to do work.</td>
</tr>
<tr>
<td><strong>Escapement</strong></td>
<td>A control mechanism in a timer that stops energy from, for example, a spring or falling weight escaping too quickly. Usually it ticks!</td>
</tr>
<tr>
<td><strong>Fair testing</strong></td>
<td>Measuring the performance of a machine by comparing its performance under different conditions.</td>
</tr>
<tr>
<td><strong>Flywheel</strong></td>
<td>A wheel that stores moving energy when it is spinning and releases it slowly. The heavier, wider and faster the wheel, the more energy it stores.</td>
</tr>
<tr>
<td><strong>Follower</strong></td>
<td>Usually a gear, pulley or lever driven by another one. It can also be a lever driven by a cam.</td>
</tr>
<tr>
<td><strong>Force</strong></td>
<td>A push or a pull.</td>
</tr>
<tr>
<td><strong>Friction</strong></td>
<td>The resistance met when one surface is sliding over another, e.g. when an axle is turning in a hole or when you rub your hands together.</td>
</tr>
<tr>
<td><strong>Fulcrum</strong></td>
<td>See Pivot.</td>
</tr>
<tr>
<td><strong>Gear</strong></td>
<td>A toothed wheel or cog. The teeth of gears mesh together to transmit movement. Often called a spur gear.</td>
</tr>
<tr>
<td><strong>Gear, crown</strong></td>
<td>Has teeth that stick out on one side looking like a crown. Mesh it with a regular spur gear to turn the angle of motion through 90°.</td>
</tr>
<tr>
<td><strong>Gear, rack</strong></td>
<td>A flat gear with the teeth equally spaced on a straight line that converts rotational motion into linear motion when a spur gear is meshed against it.</td>
</tr>
<tr>
<td><strong>Gear, worm</strong></td>
<td>A gear with one spiral tooth resembling a screw. Mesh it with a pinion to deliver large forces very slowly.</td>
</tr>
<tr>
<td><strong>Glossary</strong></td>
<td></td>
</tr>
<tr>
<td>----------------</td>
<td></td>
</tr>
<tr>
<td><strong>Gear, bevel</strong></td>
<td>Has teeth that are cut at a 45° angle. When two bevel gears mesh, they change the angle of their axles and movement through 90°.</td>
</tr>
<tr>
<td><strong>Gearing down</strong></td>
<td>A small driver turns a larger follower and amplifies the force from the effort. But the follower turns more slowly.</td>
</tr>
<tr>
<td><strong>Gearing up</strong></td>
<td>A large driver turns a smaller follower and reduces the force from the effort. But the follower turns more quickly.</td>
</tr>
<tr>
<td><strong>Gearing, compound</strong></td>
<td>A combination of gears and axles where at least one axle has two gears of different sizes. Compound gearing results in very big changes to the speed or force of the output compared to the input.</td>
</tr>
<tr>
<td><strong>Grip</strong></td>
<td>The grip between two surfaces depends on the amount of friction between them. Tyres grip dry road surfaces better than wet road surfaces.</td>
</tr>
<tr>
<td><strong>I</strong></td>
<td><strong>Idler</strong></td>
</tr>
<tr>
<td><strong>Inclined plane</strong></td>
<td>A slanted surface or ramp generally used to raise an object with less effort than is needed to lift it directly. A cam is a special sort of continuous inclined plane.</td>
</tr>
<tr>
<td><strong>K</strong></td>
<td><strong>Kinetic energy</strong></td>
</tr>
<tr>
<td><strong>L</strong></td>
<td><strong>Lever</strong></td>
</tr>
<tr>
<td><strong>Lever, first class</strong></td>
<td>The pivot is between the effort and the load. A long effort arm and short load arm amplifies the force at the load arm, e.g. when prying the lid off a can of paint.</td>
</tr>
<tr>
<td><strong>Lever, second class</strong></td>
<td>The load is between the effort and the pivot. This lever amplifies the force from the effort to make lifting the load easier, e.g. in a wheelbarrow.</td>
</tr>
<tr>
<td><strong>Lever, third class</strong></td>
<td>The effort is between the load and the pivot. This lever amplifies the speed and distance the load moves compared to the effort.</td>
</tr>
<tr>
<td><strong>Linkages</strong></td>
<td>A mechanical linkage carries movement and forces through a series of rods or beams connected by moving pivot points. Locking pliers, a scissors lift, a sewing machine and a garage door lock all contain linkages.</td>
</tr>
<tr>
<td><strong>Load</strong></td>
<td>Any force a structure is calculated to oppose, such as a weight or mass. It can also refer to the amount of resistance placed on a machine.</td>
</tr>
<tr>
<td><strong>M</strong></td>
<td><strong>Machine</strong></td>
</tr>
</tbody>
</table>
**Mass**  
Mass is the quantity of matter in an object. On Earth, gravitational force pulling your matter makes you weigh say 70 kg. In orbit, you feel weightless – but sadly you still have a mass of 70 kg. Often confused with weight.

**Member**  
The name given to individual parts of a structure, e.g. a door frame is made from two upright members and one cross member.

**Mechanism**  
A simple arrangement of components that transforms the size or direction of a force, and the speed of its output. For instance a lever or two gears meshing.

**Momentum**  
The product of the velocity and mass of an object; velocity not speed because direction is important; mass not weight because it isn’t dependant on gravity.

**Net weight**  
The weight of a substance after the weight of its container has been taken away.

**Pawl and ratchet**  
An arrangement of a block or wedge (pawl) and a gear wheel (ratchet) that lets the gear turn in one direction only.

**Pendulum**  
A weight hung from a fixed point so that it can swing freely back and forth under the influence of gravity.

**Period of swing**  
The time it takes for a pendulum to complete one swing. For our pendulum, lowering the weight lengthens the pendulum and lengthens the time or period of swing and vice versa.

**Pinion**  
Another name for a gear that meshes with a gear rack or worm gear.

**Pitch**  
The distance moved by a screw when the screw is turned through one complete turn (360°).

**Pivot**  
The point around which something turns or rotates, such as the pivot of a lever.

**Potential energy**  
The energy of an object that is related to its position. The higher up it is, the more potential energy it has. See also Kinetic energy.

**Power**  
The rate at which a machine does work (work divided by time). See also Work.

**Pulley**  
A wheel with a grooved rim used with a belt, chain or rope.

**Pulley, fixed**  
Changes the direction of the applied force. A fixed pulley does not move with the load.

**Pulley, movable**  
Changes the amount of applied force needed to lift the load. A movable pulley moves with the load.

**Pulley block**  
One or more pulleys in a movable frame with ropes or (block and tackle) chains running around them to one or more fixed pulleys. The pulley block moves with the load and reduces the applied force needed to lift the load.
<table>
<thead>
<tr>
<th><strong>R</strong></th>
<th><strong>Rack (gear rack)</strong></th>
<th>A specialized gear in the shape of a flat bar with teeth.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Renewable energy</strong></td>
<td>Energy from a renewable source such as sunlight, wind or</td>
</tr>
<tr>
<td></td>
<td></td>
<td>flowing water.</td>
</tr>
<tr>
<td></td>
<td><strong>Resetting</strong></td>
<td>Turning a pointer on a scale back to zero again.</td>
</tr>
<tr>
<td></td>
<td><strong>Rigid</strong></td>
<td>A rigid material does not easily stretch or bend and does</td>
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<tr>
<td></td>
<td></td>
<td>not deform under load.</td>
</tr>
<tr>
<td></td>
<td><strong>RPM</strong></td>
<td>Revolutions or turns per minute. This is usually the</td>
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<tr>
<td></td>
<td></td>
<td>measure of speed of a motor. The LEGO® motor turns at</td>
</tr>
<tr>
<td></td>
<td></td>
<td>about 400 rpm unloaded (when it is not driving a machine).</td>
</tr>
<tr>
<td><strong>S</strong></td>
<td><strong>Sequencing</strong></td>
<td>Setting up actions to happen in the right order and at the</td>
</tr>
<tr>
<td></td>
<td></td>
<td>correct time intervals. Cams are often used for this</td>
</tr>
<tr>
<td></td>
<td><strong>Sheave</strong></td>
<td>A pulley wheel with a grooved rim. The groove is used to</td>
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<tr>
<td></td>
<td></td>
<td>hold a rope, belt or cable so that it does not slip off</td>
</tr>
<tr>
<td></td>
<td><strong>Slip</strong></td>
<td>A belt or rope slipping, usually on a pulley wheel as a</td>
</tr>
<tr>
<td></td>
<td></td>
<td>safety feature.</td>
</tr>
<tr>
<td></td>
<td><strong>Speed</strong></td>
<td>See Velocity.</td>
</tr>
<tr>
<td></td>
<td><strong>Strut</strong></td>
<td>A member of a structure that is in compression. Struts</td>
</tr>
<tr>
<td></td>
<td></td>
<td>prevent parts of structures from moving towards each other.</td>
</tr>
<tr>
<td><strong>T</strong></td>
<td><strong>Tensile forces</strong></td>
<td>Forces in a structure that pull in opposite directions</td>
</tr>
<tr>
<td></td>
<td></td>
<td>trying to stretch the structure.</td>
</tr>
<tr>
<td></td>
<td><strong>Tie</strong></td>
<td>A member of a structure that is in tension. Ties prevent</td>
</tr>
<tr>
<td></td>
<td></td>
<td>parts of structures from moving apart, i.e. they ‘tie’</td>
</tr>
<tr>
<td></td>
<td></td>
<td>them together.</td>
</tr>
<tr>
<td></td>
<td><strong>Torque</strong></td>
<td>The turning force coming from an axle.</td>
</tr>
<tr>
<td></td>
<td><strong>Transmission</strong></td>
<td>A system of gears or pulleys with an input and one or</td>
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<tr>
<td></td>
<td></td>
<td>more outputs. A gearbox contains a transmission, and so</td>
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<tr>
<td></td>
<td></td>
<td>does a clock.</td>
</tr>
<tr>
<td><strong>U</strong></td>
<td><strong>Unbalanced force</strong></td>
<td>A force that is not opposed by an equal and opposite</td>
</tr>
<tr>
<td></td>
<td></td>
<td>force. An object feeling an unbalanced force must begin</td>
</tr>
<tr>
<td></td>
<td></td>
<td>to move in some way.</td>
</tr>
<tr>
<td><strong>V</strong></td>
<td><strong>Velocity</strong></td>
<td>The speed in a particular direction. To calculate the</td>
</tr>
<tr>
<td></td>
<td></td>
<td>speed of a vehicle, we divide the distance travelled by</td>
</tr>
<tr>
<td></td>
<td></td>
<td>the time taken.</td>
</tr>
<tr>
<td><strong>W</strong></td>
<td><strong>Weight</strong></td>
<td>See Mass.</td>
</tr>
<tr>
<td></td>
<td><strong>Wind resistance</strong></td>
<td>See Air resistance.</td>
</tr>
<tr>
<td></td>
<td><strong>Work</strong></td>
<td>We calculate the work done by multiplying the force</td>
</tr>
<tr>
<td></td>
<td></td>
<td>needed to move an object by the distance it is moved</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(force x distance). See also Power.</td>
</tr>
</tbody>
</table>
LEGO® Element Survey

- 8x Plate, 1x2, blue 302323
- 10x Connector peg with friction, 3-module, blue 4514553
- 4x Plate, 1x4, blue 371023
- 8x Angular beam, 4x2-module, blue 4168114
- 6x Plate with holes, 2x4, blue 370923
- 4x Angular beam, 4x6-module, blue 4182884
- 8x Plate with holes, 2x6, blue 4114027
- 2x Angular beam, 3x7-module, blue 4112000
- 2x Plate with holes, 2x8, blue 373823
- 4x Studded beam, 1x12, blue 389523
- 4x Studded beam, 1x2, blue 370023
- 4x Studded beam, 1x16, blue 370323
- 4x Studded beam, 1x4, blue 370123
- 4x Studded beam, 1x6, blue 389423
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<thead>
<tr>
<th>Item</th>
<th>Description</th>
<th>Quantity</th>
<th>Set Number</th>
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<tbody>
<tr>
<td>14x</td>
<td>Axle, 2-module, red</td>
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<td>4142865</td>
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<tr>
<td>14x</td>
<td>Connector peg with bushing, red</td>
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<td>4140806</td>
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<tr>
<td>4x</td>
<td>Angular block, 2 (180°), red</td>
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<td>4234429</td>
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<tr>
<td>10x</td>
<td>Angular block with crosshole, red</td>
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<td>4118897</td>
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<tr>
<td>4x</td>
<td>Cross block, 3-module, red</td>
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<td>2x</td>
<td>Tube, 2-module, red</td>
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<td>4x</td>
<td>Studded beam, 1x2 with crosshole, white</td>
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<td>4233486</td>
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<td>2x</td>
<td>Brick, 2x4, white</td>
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<td>300101</td>
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<tr>
<td>2x</td>
<td>Brick, 2x2 round, white</td>
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<td>614301</td>
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<tr>
<td>4x</td>
<td>Roof brick, 1x2/45°, white</td>
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<td>4121932</td>
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<td>2x</td>
<td>Tile, 1x4, white</td>
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<td>243101</td>
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<td>2x</td>
<td>Beam, 3-module, white</td>
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<td>2x</td>
<td>Beam, 5-module, white</td>
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<td>4249021</td>
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<td>Beam, 7-module, white</td>
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<td>4495927</td>
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<td>4x</td>
<td>Beam, 9-module, white</td>
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<td>4156341</td>
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<tr>
<td>8x</td>
<td>Beam, 15-module, white</td>
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<td>4542578</td>
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<tr>
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<td>Steering arm, black</td>
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<td>4114670</td>
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<tr>
<td>2x</td>
<td>Bearing for steering arm, black</td>
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<tr>
<td>4x</td>
<td>Angular block, 1 (0°), dark grey</td>
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<tr>
<td>4x</td>
<td>Angular block, 3 (157°), black</td>
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<td>28x</td>
<td>Connector peg with friction, black</td>
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<td>Tyre, 30.4x4, black</td>
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<td>4x</td>
<td>Tyre, 30.4x14, black</td>
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<tr>
<td>4x</td>
<td>Tyre, 43.2x22, black</td>
<td></td>
<td>4184286</td>
</tr>
</tbody>
</table>
12x Connector peg with axle, beige 4186017

4x Connector peg, 3-module, beige 4514554

16x Bushing, ½-module, yellow 4239601

4x Connector peg, handle, grey 4211688

8x Connector peg, grey 4211807

16x Bushing, grey 4211622

8x Axle extender, 2-module, grey 4512360

8x Axle, 3-module, grey 4211815

4x Axle, 5-module, grey 4211639

8x Axle, 4-module, black 370526

2x Axle, 6-module, black 370626

2x Axle, 8-module, black 370726

10x Axle, 10-module, black 373726

6x Axle, 12-module, black 370826

1x Minifigure, ponytail wig, black 609326

1x Minifigure, cap, red 448521

2x Minifigure, head, yellow 9336

1x Minifigure, body, white with surfer 4275606

1x Minifigure, body, white with flowers 4275536

1x Minifigure, legs, orange 4120158

1x Minifigure, legs, green 74040
<table>
<thead>
<tr>
<th>Quantity</th>
<th>Part Description</th>
<th>Part Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>2x</td>
<td>Gear, 16-tooth, grey</td>
<td>4211563</td>
</tr>
<tr>
<td>4x</td>
<td>Gear, 24-tooth crown, grey</td>
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</tr>
<tr>
<td>2x</td>
<td>Gear, 40-tooth, grey</td>
<td>4285634</td>
</tr>
<tr>
<td>2x</td>
<td>Gear, 10-tooth rack, grey</td>
<td>4211450</td>
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<tr>
<td>2x</td>
<td>Worm gear, grey</td>
<td>4211510</td>
</tr>
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<td>1x</td>
<td>Differential, 28-tooth, dark grey</td>
<td>4525184</td>
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<td>4x</td>
<td>Gear, 24-tooth, dark grey</td>
<td>4514558</td>
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<tr>
<td>6x</td>
<td>Gear, 8-tooth, dark grey</td>
<td>4514559</td>
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<tr>
<td>2x</td>
<td>Gear, 12-tooth double bevel, black</td>
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</tr>
<tr>
<td>1x</td>
<td>Gear, 14-tooth rack, black</td>
<td>4275503</td>
</tr>
<tr>
<td>6x</td>
<td>Gear, 12-tooth bevel, beige</td>
<td>4514556</td>
</tr>
<tr>
<td>2x</td>
<td>Gear, 20-tooth bevel, beige</td>
<td>4514557</td>
</tr>
<tr>
<td>2x</td>
<td>Gear, 20-tooth double bevel, beige</td>
<td>4514555</td>
</tr>
<tr>
<td>2x</td>
<td>Belt, 33 mm, yellow</td>
<td>4544151</td>
</tr>
<tr>
<td></td>
<td>Belt, 24 mm, red</td>
<td>4544143</td>
</tr>
<tr>
<td>2x</td>
<td>Belt, 15 mm, white</td>
<td>4544140</td>
</tr>
<tr>
<td>1x</td>
<td>Universal joint, 3-module, grey</td>
<td>4525904</td>
</tr>
<tr>
<td>4x</td>
<td>Hub, 18x14, grey</td>
<td>4490127</td>
</tr>
<tr>
<td>4x</td>
<td>Hub, 24x4, grey</td>
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<td>4x</td>
<td>Hub, 30x20, grey</td>
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<tr>
<td>6x</td>
<td>Connector peg, 1½-module, dark grey</td>
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<td>4x</td>
<td>Axle with knob, 3-module, dark grey</td>
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<td>4x</td>
<td>Cam wheel, dark grey</td>
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<tr>
<td>1x</td>
<td>Bobbin, dark grey</td>
<td>4239891</td>
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<tr>
<td>2x</td>
<td>½ beam, triangle, dark grey</td>
<td>4210689</td>
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</table>
1x Plastic forms sheet 4500588

2x String, 40-module with knobs, black 4528334

1x String, 2 m, black 4276325

1x Weight element, black 73843

1x Converter cable, black 4514332

1x Battery box, 9V, grey 4506078

1x Motor, 9V, grey 4506083