2009686

LEGO education

Investigate
Measure
Predict
Present
Record
Design & Make
Test

Teacher's Guide

education

Table of contents

Introduction

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

Who is it for?

The material is designed for use by teachers of students in Grades 2 through 8. 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 behavior 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:

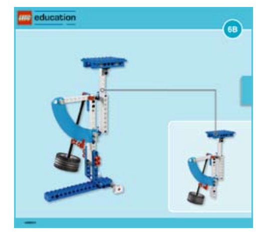
- Think creatively to try to explain how things work
- Establish links between cause and effect
- Design and make artifacts that fulfill specific criteria
- Try ideas using results from observations and measurements
- Ask questions that can be investigated scientifically
- Reflect on how to find answers and imagine new possibilities
- Think what might happen, then try new ideas
- 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 the conclusions 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 color. Some of the Building Instructions booklets are intended for use with other LEGO® Education activity packs.

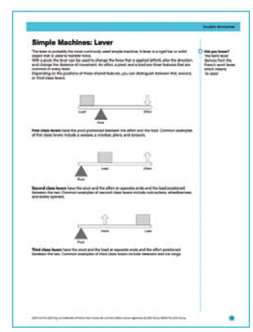
Included is a sorting tray and accompanying element overview showing all the different elements in the set. Everything is stored in a sturdy blue storage box with a transparent lid.

Building Instructions booklets
We have devised the Buddy Building system in which models are designed so two children can build simultaneously – 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.

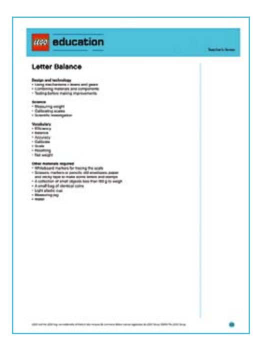
Principle Models
The Principle Models let children experience the mechanical and structural principles normally hidden away inside everyday machines and structures. The many easy-to-build models each present a hands-on demonstration of one of the concepts of simple machines, mechanisms and structures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

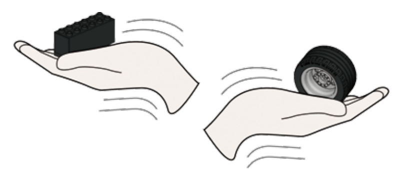


The lessons follow LEGO Education's 4C approach; Connect, Construct, Contemplate, and Continue. This enables you to progress naturally through the activities.

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.

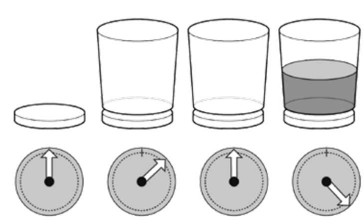
Construct
Learning is best when hands and minds are engaged. In pairs, children build models step-by-step. Two buddies each build half a model using separate booklets (A and B) to create their own subsystems and then collaborate to assemble one complete model.



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.

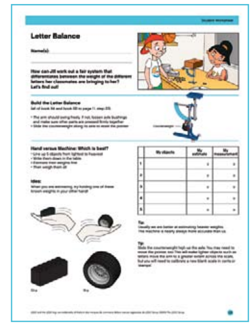
This phase includes the possibility to start evaluating the learning and the progress of the individual child.

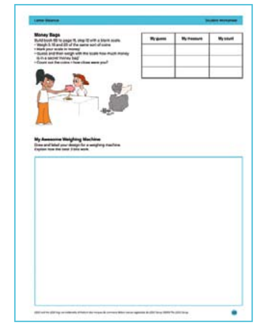


Continue
Learning is always more enjoyable and creative when it is adequately challenging. Maintaining this challenge and the pleasure of accomplishment naturally inspires the continuation of more advanced work. Therefore, extension ideas are provided to encourage the children to change or add features 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
Each worksheet has a focused approach following the 4Cs and includes easy-to-read pictorial guidelines. The children can use and explore their models with little teacher assistance. They will be able to predict, try out, measure and record data, change the models to compare and contrast findings, and draw conclusions.





Let the children work in pairs, predict and test their predictions at least three times to be confident that their results are reliable. Then they record their main data accordingly. At the end of each activity, the children are challenged to design and draw a device that applies the major concepts they have just explored.

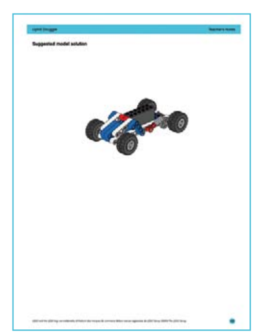
The worksheets are an easy-to-use tool for assessment of the individual child's level and achievement. They can also form a valuable part of the children's log books.

Problem-solving Activities
The six Problem-solving Activities all feature real-life settings with needs that cannot be solved in just one way.

The problem descriptions and the closely-defined design brief are meant to be copied and used by the children. Descriptions of learning focus areas, materials needed, extra challenges and how to progress is teacher information only!

The Problem-solving Activities are realistic and children will be able to test and integrate more than just one principle at a time.
The Teacher's Notes for each challenge provides tips on what and how to measure while at the same time carrying out fair testing of the solutions.

As a support we have included suggested solutions to the problems posed. Use these as 'tips and tricks', or print them and hang them as posters as inspiration for the children. The suggested problem-solving model solutions are only meant as guiding principles for any workable solution the children will come up with themselves.



Classroom management tips

Order of activities
Start out with the principles section: simple machines, mechanisms and structures. Have the children build through some or all of the basic principles to get a hands-on understanding of the concepts involved.

Then choose which theme fits your current teaching programme. You introduce the main activities within the theme and let the children investigate the ideas listed in the Teacher's Notes and in the Student Worksheets.

After each theme a relevant Problem-solving Activity may be introduced to determine how well the children can consult and apply the knowledge they have gained.

How much time do I need?
A 90-minute class period is ideal to be able to explore, build, and test in depth all the extension ideas built into the material and for the children to make any creative variations of their own. However, each main model can be built, tested, and explored by two buddies, and the parts put away again within a 45-minute class period.

How do I handle the Building Instructions booklets?
For easy classroom management we suggest storing the Building Instruction booklets in separate plastic folders in binders so that they are at hand and ready to use at the beginning of each lesson.

What's needed in my classroom?
Tables may be pushed aside to let models roll across a smooth floor. A desk fan may be needed to make a breeze, hair-dryers to make land yacht races, etc. Ideally, a computer or computers should be available for children to explore the Jack and Jill animated activity briefings.

Children need to be able to construct in pairs facing each other or side-by-side. From teachers and classrooms we have learned that cafeteria-type trays are ideal to build on, and to stop elements rolling onto the floor. It is also an advantage to have a cupboard or shelves to store the sets lying flat with any unfinished models on top of them.

Any other materials needed will be very common in all classrooms and are listed at the beginning of each activity.

Enjoy!
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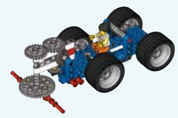
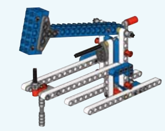
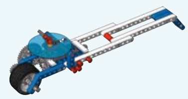
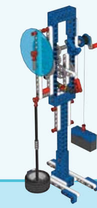
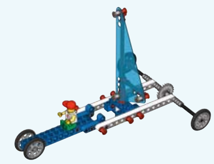
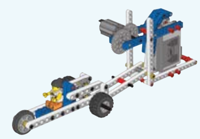
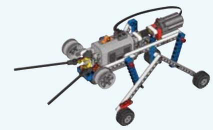
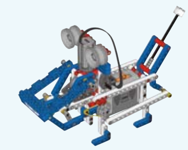
Science and Technology Learning Grid

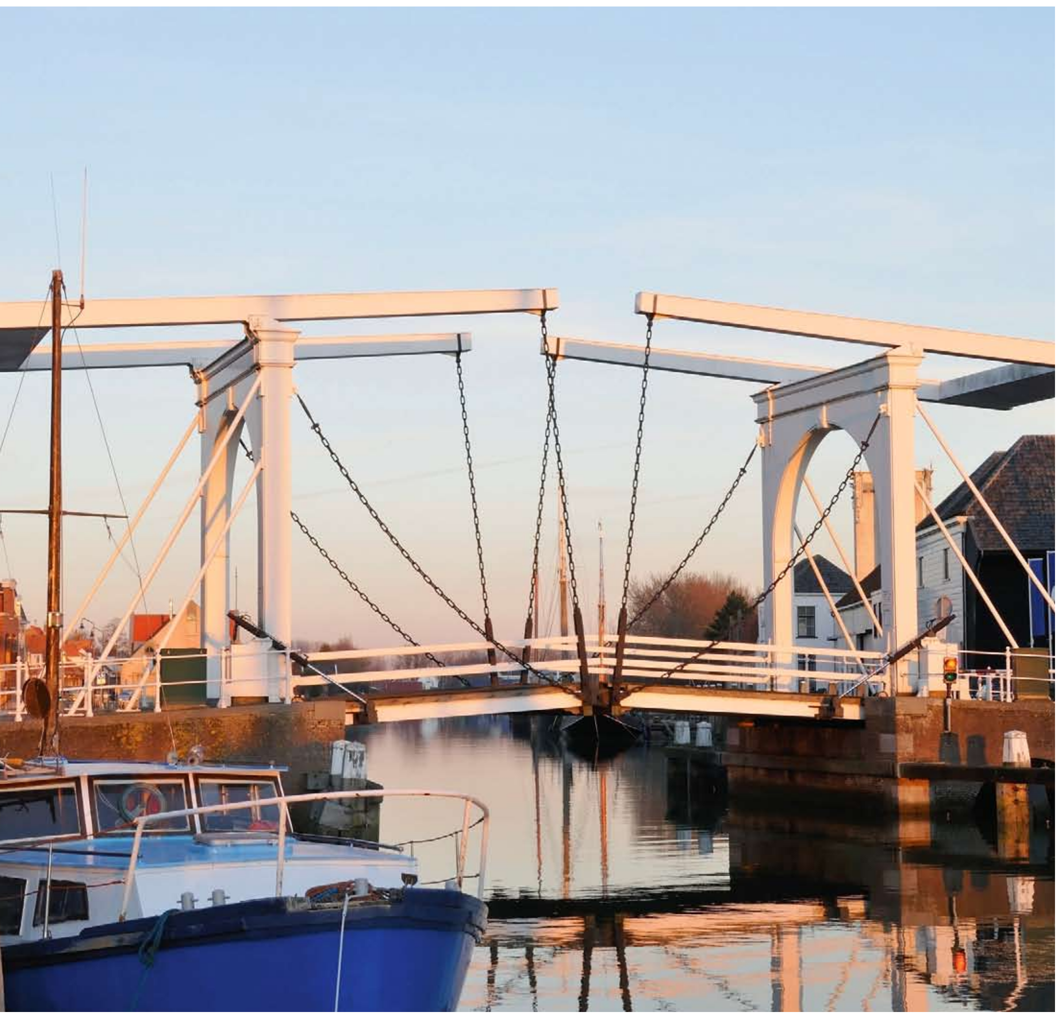
	9686																			
	Sweeper	Fishing Rod	Freewheeling	The Hammer	Trundle Wheel	Letter Balance	Click-Clock	Windmill	Land Yacht	Flywheeler	Power Car	Dragster	The Walker	Dogbot	Uphill Struggle	The Magic Lock	Stamping Letters	Beaten	The Lifter	The Bat
Science																				
Science as inquiry	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Identifying questions to be answered	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Designing and conducting investigations	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Using tools to gather and interpret data	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Developing understanding of forces and motion	■	■	■	■				■	■	■	■	■	■	■	■			■	■	■
Motion, position, direction	■	■	■	■	■		■			■	■	■	■	■	■			■	■	■
Gears and ratios (mechanical advantage)	■		■		■		■			■	■	■	■	■	■			■	■	■
Gearing up and down for speed	■		■		■		■			■	■	■	■	■	■			■	■	
Friction	■		■	■	■				■	■	■	■	■	■	■					
Block and tackle		■									■		■							
Levers, cams		■		■		■	■					■	■	■		■	■			■
Momentum							■				■		■	■					■	■
Balanced and unbalanced forces	■	■		■		■	■	■	■	■	■	■	■		■	■			■	■
Period of swing, pendulums							■													
Developing understanding of energy	■		■				■	■	■	■	■	■	■	■					■	■
Capturing, storing and transferring energy								■	■	■		■		■						
Technology																				
Understanding of attribute designs	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Developing the ability to apply design processes	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Identifying appropriate problems															■	■	■	■	■	■
Designing solutions and products	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Evaluating products	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Properties of materials			■	■	■	■	■	■	■					■						
Counting systems			■		■		■									■	■			
Controlling and timing actions							■			■			■	■						■
Transportation	■		■		■				■	■	■	■	■		■				■	
Reasoning with evidence	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Engineering																				
Describe and explain a purpose															■	■	■	■	■	■
Identifying goals, inputs, processes, outputs and feedback	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Developing understanding of engineering designs	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Test and evaluate	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Math																				
Making reasonable estimates	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Understanding metric systems			■		■				■		■	■	■		■				■	
Understanding ways of representing numbers			■		■	■	■		■			■								
Transferring 2D representations to 3D models	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Visual discrimination	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Informal and formal measuring of distance/time			■		■		■	■	■	■	■	■	■	■	■		■		■	■
Informal and formal measuring of weight/mass		■		■		■		■			■	■				■	■		■	
Solving problems involving scale factors			■		■	■	■													
Sorting and classifying	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Selecting appropriate methods for estimating and measuring		■	■		■		■	■	■	■	■	■	■		■		■		■	■
Using fractions and decimals			■	■	■	■					■	■	■			■			■	
Collecting and handling data	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Critical and logical thinking	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Cooperating and using teamwork	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Logic, reasoning and proof	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Fair testing															■	■	■	■	■	■

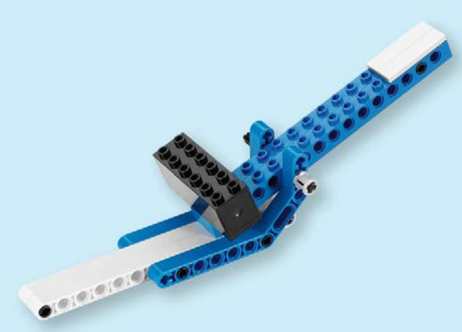
	Sweeper	Fishing Rod	Freewheeling	The Hammer
				
FORCES & MOTION				
Technology curriculum: Identifying a need and developing ideas. Working as individuals and in teams. Use materials and components as well as modular construction kits to design and make high-quality working prototypes. Use appropriate 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 tire 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 inquiry including predicting and measuring the effect of variables on the performance of simple machines. Careful observation, measurement, and recording.	• Balanced and unbalanced forces • Friction • Force and motion • Gear ratio	• Reducing speed and increasing force using string and pulleys (block and tackle) • Force and motion	• Inclined planes • Friction • Force and motion	• Inclined planes • Friction • Force and motion
Math curriculum: Using and applying mathematical ideas. Calculations using all number operations. Calculate and use notions of area, averages, and ratios. Measure time, distance, force, and 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	• Reading and calibrating scales • Measuring distance, mass • Working with negative numbers (at bottom of hill, rolling the car backwards to zero) • Exploring limits to accuracy • Calculating averages	• Measuring number of 'impacts' per unit time • Estimating and comparing LEGO® element grip forces • Expressing relative grip forces using mathematical terms

	Trundle Wheel	Letter Balance	Click-Clock	
				
MEASUREMENTS				
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 inquiry 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 • Force and motion • Gear ratio	• Balancing forces • Calibrating and reading scales • Measuring weight to limits of accuracy • Force and motion	• The pendulum • Calibrating and reading scales • Measuring weight to limits of accuracy • Force and motion	
Math curriculum: Using and applying mathematical ideas. Calculations using all number operations. Calculate and use notions of area, averages, and ratios. Measure time, distance, force, and 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	

	Windmill 	Land Yacht 	Flywheeler 	
ENERGY				
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	• Investigating sail shape, area, and angle to wind for effectiveness in capturing wind energy • Investigating mechanisms for efficient energy for use in transport • Designing and making: the most efficient omni-directional wind powered vehicle	• 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	
Science curriculum: Scientific inquiry including predicting and measuring the effect of variables on the performance of simple machines. Careful observation, measurement, and recording.	• Capturing wind energy to run machines • Storing and transferring energy; kinetic to potential energy transformations • Balanced and unbalanced forces • Force and motion	• Capturing wind energy for transport • Transforming energy by gearing down • Forces and wind resistance • Balanced and unbalanced forces • Force and motion	• Storing kinetic/ moving energy • Friction • Balanced and unbalanced forces • Force and motion • Gear ratio	
Math curriculum: Using and applying mathematical ideas. Calculations using all number operations. Calculate and use notions of area, averages, and ratios. Measure time, distance, force, and 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 force in time and area • Estimating and comparing speed and efficiency related to sail shape and area	• Estimating and measuring distance, area, time, and angle • Expressing speed and efficiency, related to the angle to wind. • Expressing speed and efficiency, related to the shape and area of the sail	• Measuring distance and time • Expressing speed and distance travelled related to the mass of the flywheels	

	Power Car	**Dragster**	**The Walker**	**Dogbot**
				
POWERED MACHINES				
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 tire 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	• Investigating gearing up • Designing and making: a dragster that will travel the furthest when released from a launcher	• Investigating cranks, levers, and linkages on stability and stride distance to produce walking or reciprocating movements • Investigating ratchets to control slippage and create one-way movement • Investigating relative positions of cranks to produce a variety of life-like 'gaits' • Investigating the worm gear for extreme gearing down • Designing and making: a walker that can tackle the steepest hills and most difficult terrain	• 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 'skin' for a dynamic model • Designing and making: an 'animatronic' creature that simulates dog-like behavior
Science curriculum: Scientific inquiry including predicting and measuring the effect of variables on the performance of simple machines. Careful observation, measurement, and recording.	• Investigating the effects of load on friction; reducing friction • Inclined planes and work • Force and motion • Gear ratio	• Investigating the transfer of movement and energy • Investigating relationship between speed and mass; momentum and kinetic energy • Force and motion • Gear ratio	• Careful observation of the way a person moves in order to compare with the way a walker actually moves • Force and motion • Balance and load	• Careful observation of the way a dog moves to compare with Dogbot's movements • Force and motion
Math curriculum: Using and applying mathematical ideas. Calculations using all number operations. Calculate and use notions of area, averages, and ratios. Measure time, distance, force, and 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 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 (behavior), qualitatively and quantitatively

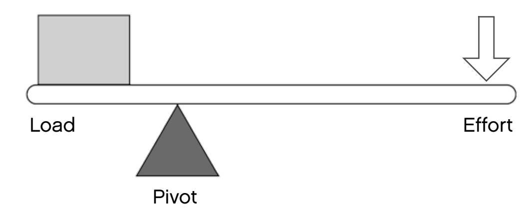




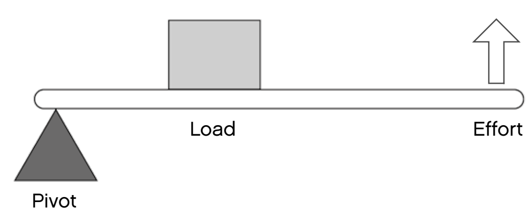
Lever

Simple Machines: Lever

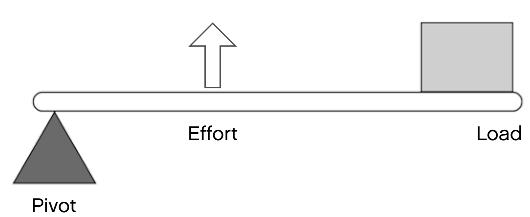
The lever is probably the most commonly used simple machine. A lever is a rigid bar or solid object that is used to transfer force.
With a pivot, the lever can be used to change the force that is applied (effort), alter the direction, and change the distance of movement. An effort, a pivot, and a load are three features that are common in every lever.
Depending on the positions of these shared features, you can distinguish between first, second, or third class levers.



First class levers have the pivot positioned between the effort and the load. Common examples of first class levers include a seesaw, a crowbar, pliers, and scissors.



Second class levers have the pivot and the effort at opposite ends and the load positioned between the two. Common examples of second class levers include nutcrackers, wheelbarrows, and bottle openers.

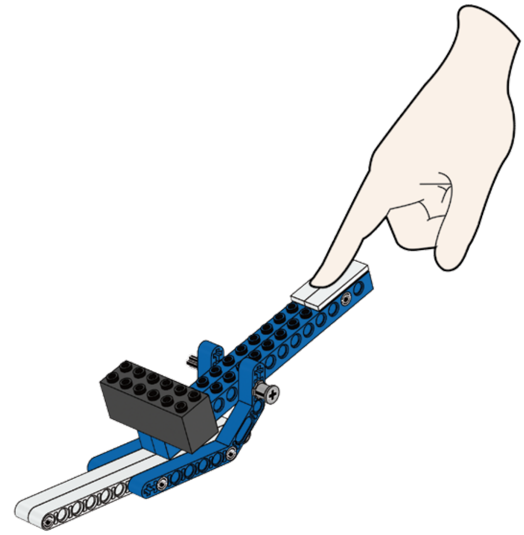


Third class levers have the pivot and the load at opposite ends and the effort positioned between the two. Common examples of third class levers include tweezers and ice tongs.

Did you know?
The term lever derives from the French word *levier* which means *'to raise'.*

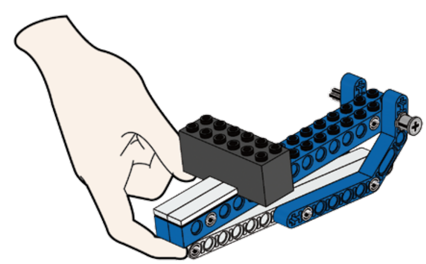
A1

Build A1 book I, pages 2 to 3
Press down on the lever to lift the load.
Describe how hard or easy it was to lift the load.
Circle and label the pivot, load, and effort.
Which class of lever is this?



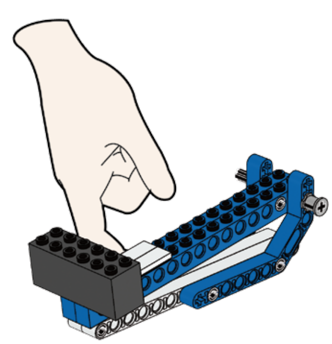
A2

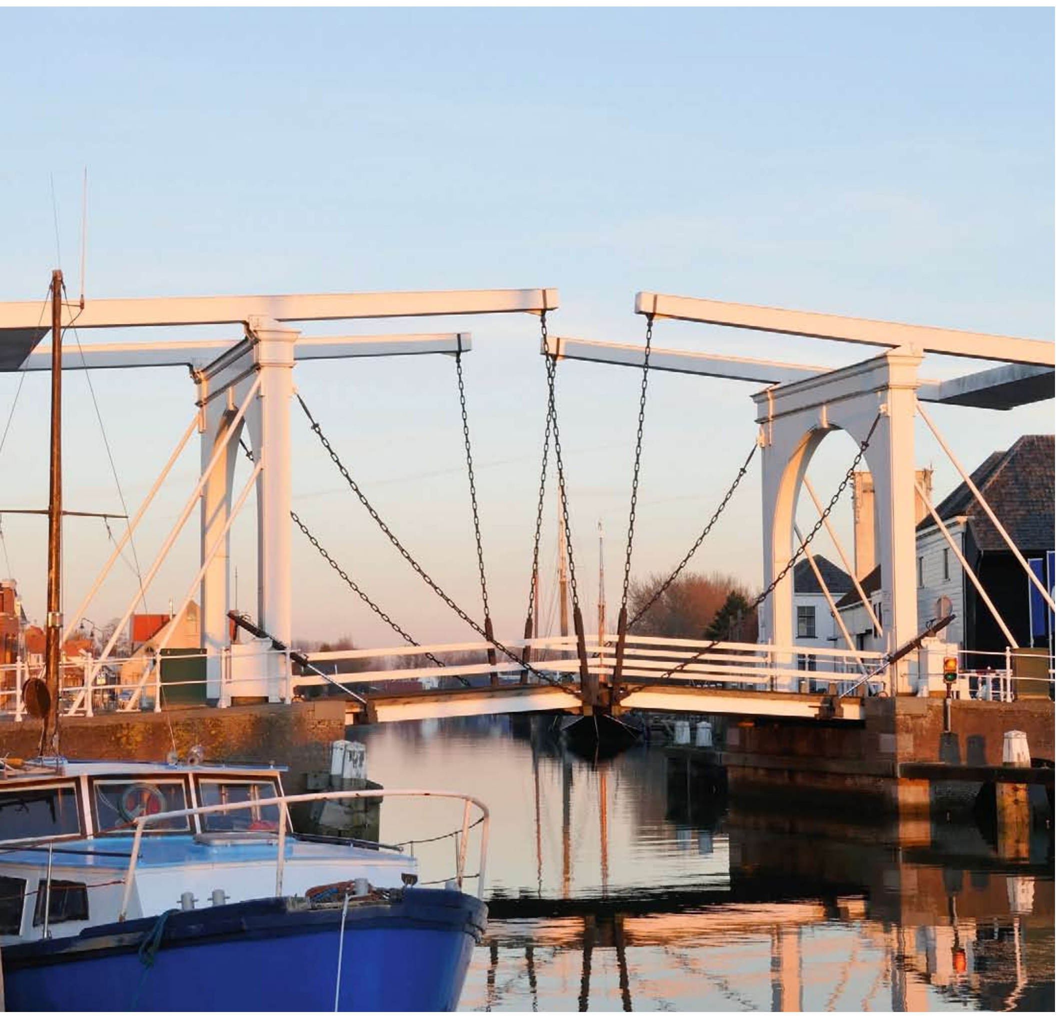
Build A2 book I, page 4 to 5
Raise the lever.
Describe how hard or easy it was to lift the load.
Circle and label the pivot, load, and effort.
Which class of lever is this?

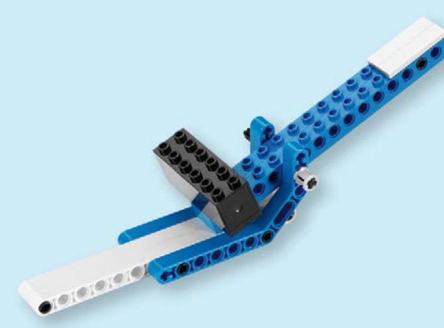


A3

Build A3 book I, page 6 to 7
Raise the lever.
Describe how hard or easy it was to lift the load.
Circle and label the pivot, load, and effort.
Which class of lever is this?







Lever

Simple Machines: Lever

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Depending on the positions of these shared features, you can distinguish between first, second, or third class levers.

Did you know?
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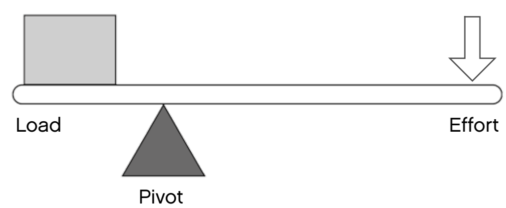

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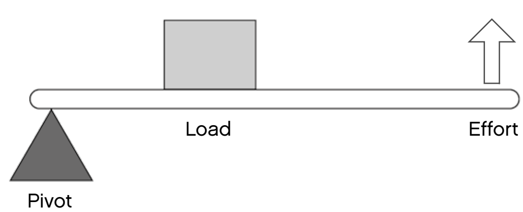
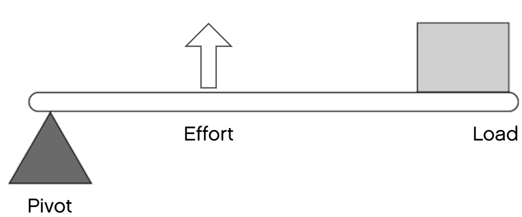


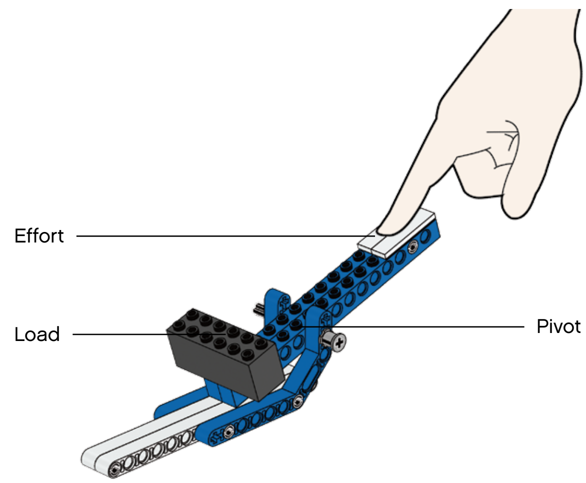
Second class levers have the pivot and the effort at opposite ends and the load positioned between the two. Common examples of second class levers include nutcrackers, wheelbarrows, and bottle openers.



Third class levers have the pivot and the load at opposite ends and the effort positioned between the two. Common examples of third class levers include tweezers and ice tongs.

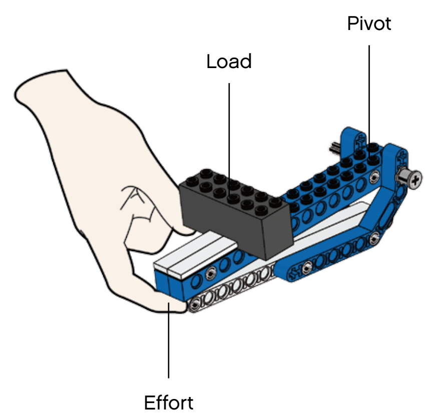
A1

This model shows a first class lever. It has the effort and load at opposite ends with the pivot in between.
This model uses the least effort to move the load.



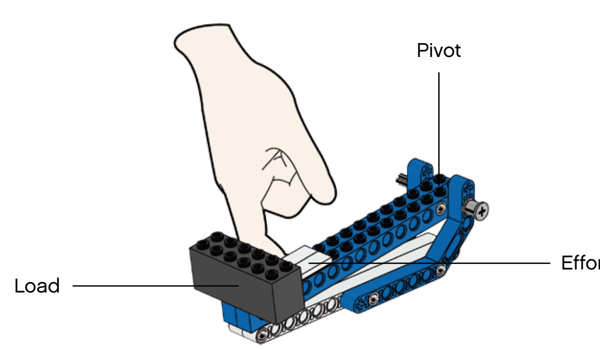
A2

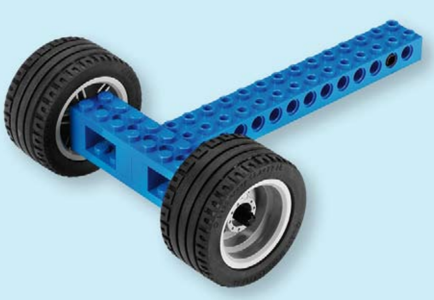
This model shows a second class lever. It has the effort and pivot at opposite ends and the load in between. The effort needed to move the load is about half the load force.



A3

This model shows a third class lever. It has the pivot and load at opposite ends and the effort in between. Even though the effort required is greater than lifting the load directly, the advantage of using a third class lever is that the load is moved a further distance than the length of the lift of the effort.

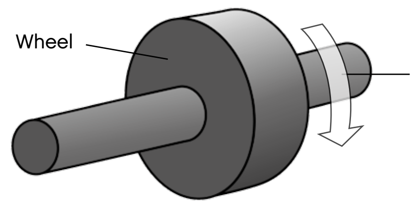




Wheel and Axle

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.



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.

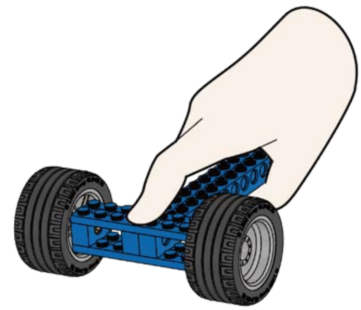
Placing a load on a wheeled vehicle almost always reduces friction compared to dragging it over the ground. Wheels in science and engineering are not always used for transport. Wheels with grooves are called pulleys and wheels with teeth are called gears.

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.

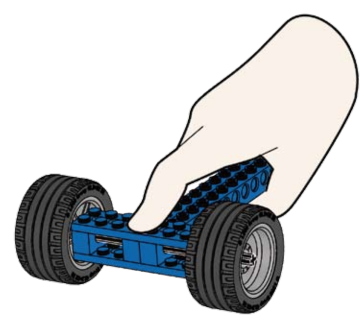
B1

Build B1 book I, page 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.



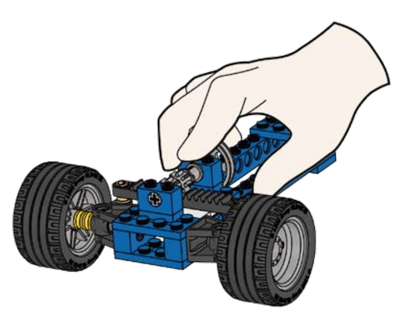
B2

Build B2 book I, page 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.



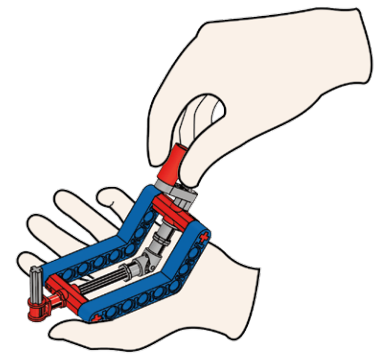
B3

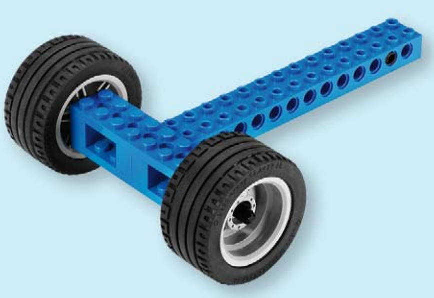
Build B3 book I, page 12 to 15
Push the model along the table in a straight line.
Describe what happens.
Now try driving it in a zigzag pattern with sharp turns.
Describe what happens and compare with the models above.



B4

Build B4 book I, page 16 to 17
Describe what happens and the movement of the universal joint when you turn the handle.

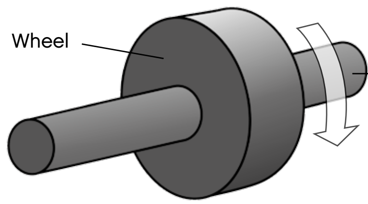




Wheel and Axle

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.



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.

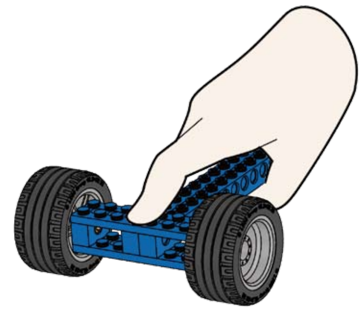
Placing a load on a wheeled vehicle almost always reduces friction compared to dragging it over the ground. Wheels in science and engineering are not always used for transport. Wheels with grooves are called pulleys and wheels with teeth are called gears.

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.

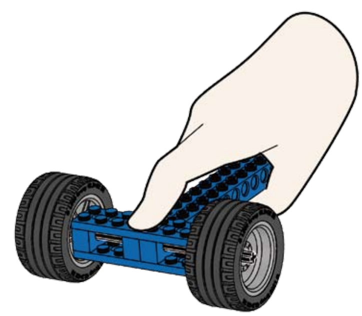
B1

This model shows a cart with split axles. It is very easy to steer both when driving in a straight line or when following zigzag patterns involving sharp turns. The split axles allow the wheels to turn at different speeds.



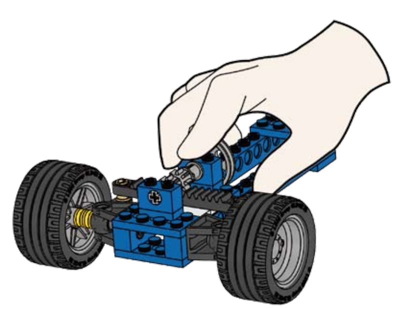
B2

This model shows a cart with fixed axles. It is very easy to steer when driving in a straight line. However, it is hard to steer when following zigzag patterns involving sharp turns as the wheels cannot turn at different speeds. One wheel will always skid when turning corners.



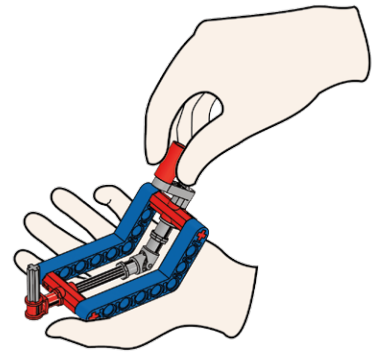
B3

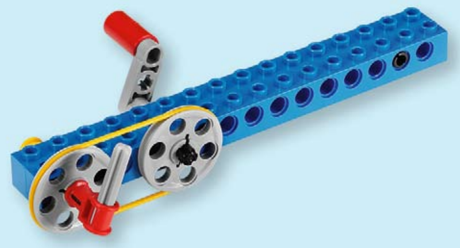
This model shows a cart with a steering system. It is very easy to steer both when driving in a straight line or when following zigzag patterns involving sharp turns. The split axles allow the wheels to turn at different speeds and the steering wheel provides good control.



B4

This model shows a universal joint. When the handle is turned the rotary motion is transmitted through the universal joint at an angle to the output. The speed ratio between input and output is 1:1.

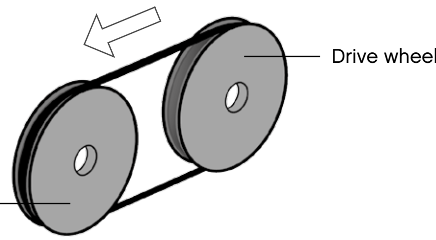




Pulley

Simple Machines: Pulley

Pulleys are wheels that are moved by ropes, chains or belts around their rims.

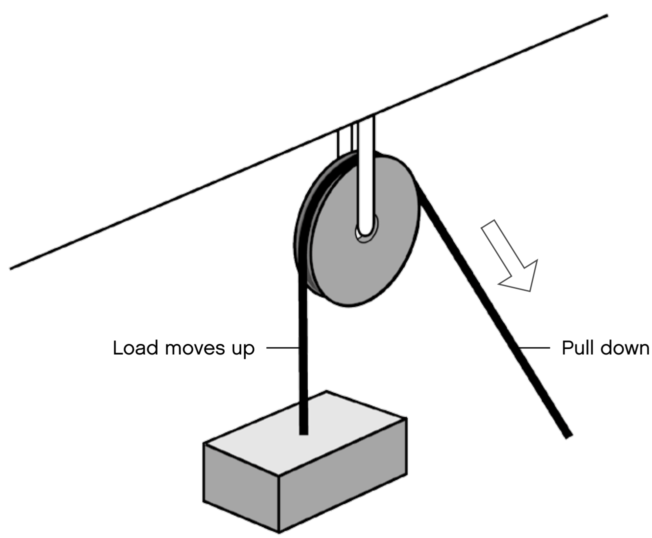


In a belt driven pulley a continuous belt joins two pulley wheels. The wheel to which an external force is applied (effort) is called the drive wheel, and the other the driven wheel. The drive pulley wheel provides the input force and the driven pulley wheel delivers the output force. When the drive wheel turns the belt moves and causes the driven wheel to turn in the same direction. If the drive wheel is smaller than the driven wheel, the driven wheel will turn more slowly than the drive wheel.

Belt driven pulleys rely on belt friction to transmit motion. If the belt is too tight the belt will create wasteful friction forces on the pulley axle and bearing. If too loose the belt will slip and the effort is not used efficiently. Slip is an overload protection safety feature of belt-operated machinery.

For heavy lifting jobs; multiple pulley wheels can be combined into a lifting system that makes lifting heavy objects easier.

Did you know?
Pulleys started the age of mass production in England, when they were produced at the beginning of the 19th century to supply the British Royal Navy with pulley blocks for their war ships during the Napoleonic Wars.

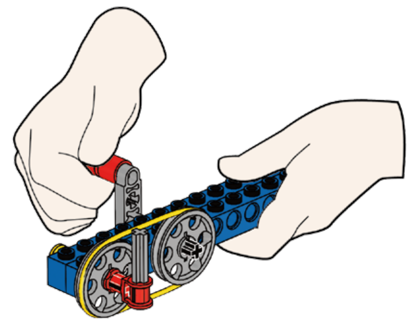


Using a single pulley to lift a load doesn't make it easier, but it changes the direction of motion without any gains in speed or required effort. It only allows you to lift a load up by the pulling of the rope. Pulleys can be either movable or fixed. The difference between fixed and movable pulleys are that fixed pulleys do not move up or down when the load is being moved.
A fixed pulley is often fixed to an overhead beam or rafter and will only be able to rotate around its own axle. The use of multiple pulley wheels on one axle, in a lifting or dragging system, is called a Block and Tackle.

Common examples of pulleys are found in window blinds, curtains and flagpoles.

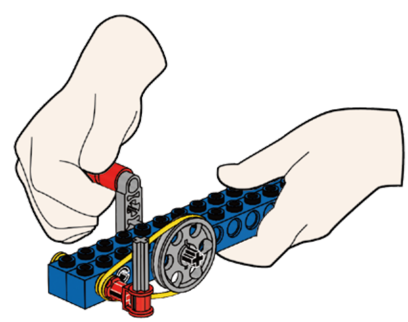
C1

Build C1 book I, page 18
Turn the handle and describe the speeds of the drive and the driven pulley wheels.
Then gently increase your grip on the output pointer and describe what happens.



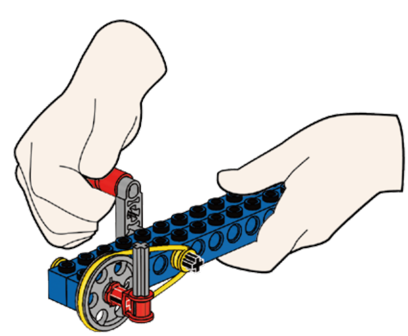
C2

Build C2 book I, page 19
Turn the handle and describe the speeds of the drive and the driven pulley wheels.
Then gently increase your grip on the output pointer and describe what happens.



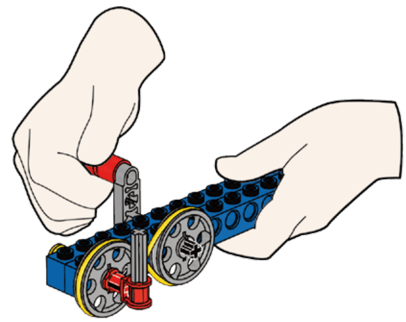
C3

Build C3 book I, page 20
Turn the handle and describe the speeds of the drive and the driven pulley wheels.
Then gently increase your grip on the output pointer and describe what happens.



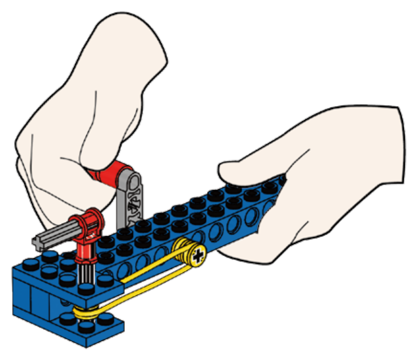
C4

Build C4 book I, page 21
Turn the handle and describe the speeds of the drive and the driven pulley wheels. Then gently increase your grip on the output pointer and describe what happens.



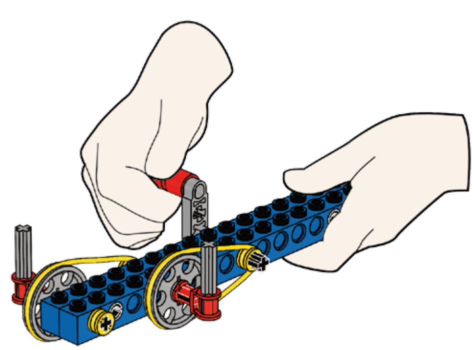
C5

Build C5 book I, page 22 to 23
Turn the handle and describe the speeds of the drive and driven pulley wheels. Label the drive and driven pulley wheels. Use a circle to show exactly where each one is.



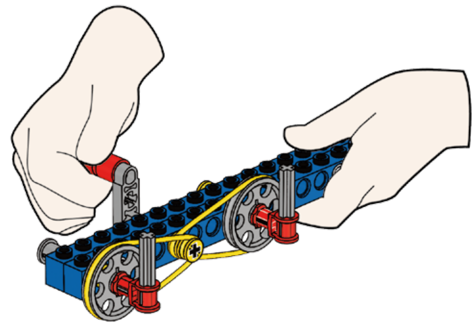
C6

Build C6 book I, page 24 to 25
Turn the handle and describe the speeds of the drive and driven pulley wheels. Label the drive and driven pulley wheels. Use a circle to show exactly where each one is.



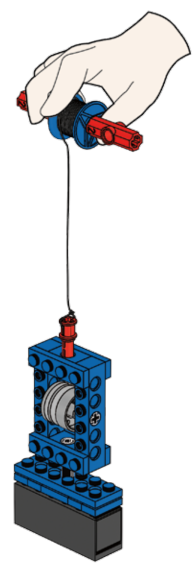
C7

Build C7 book I, page 26 to 27
Turn the handle and describe the speeds of the drive and driven pulley wheels.
Label the drive and driven pulley wheels. Use a circle to show exactly where each one is.



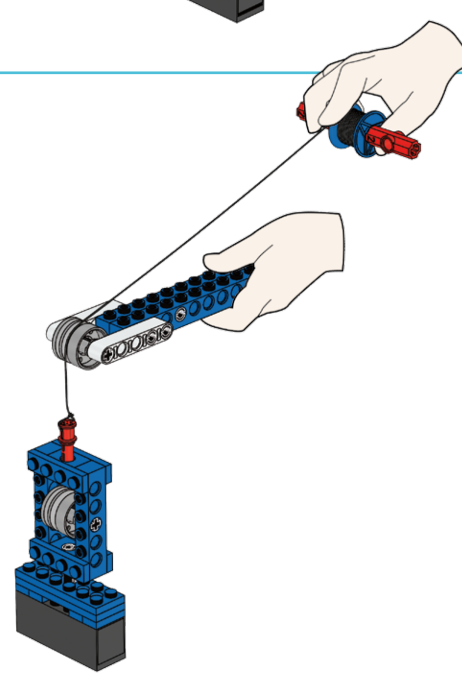
C8

Build C8 book I, page 28 to 31
Lift the string to lift the load. Describe what happens.



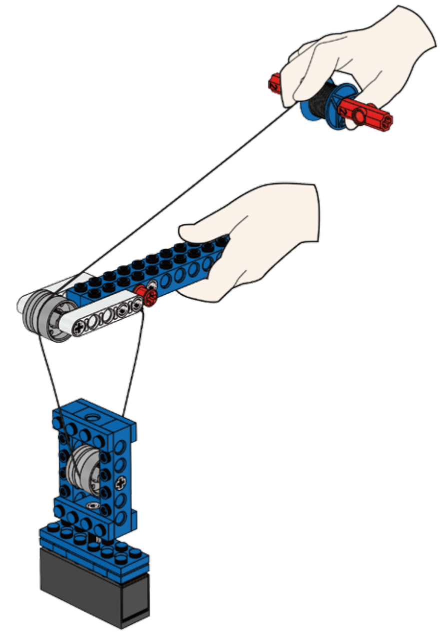
C9

Build C9 book I, page 32 to 35
Pull the string to lift the load. Describe what happens.



C10

Build C10 book I, page 36
Pull the string to lift the load. Describe what happens.



Pulley

Simple Machines: Pulley

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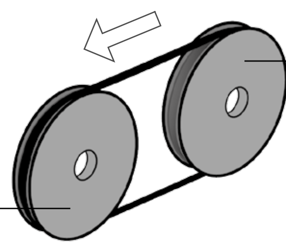

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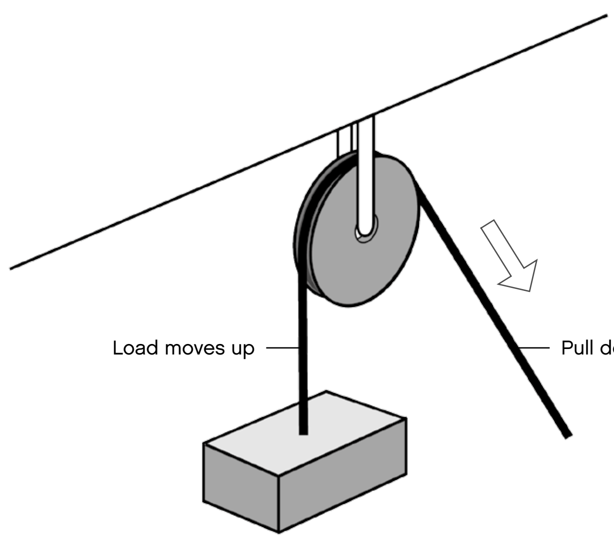

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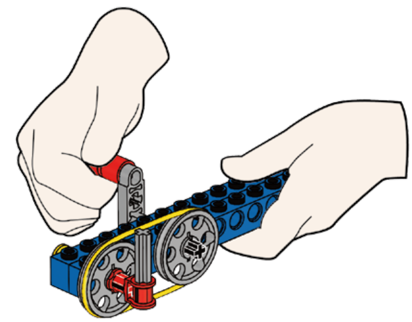
Common examples of pulleys are found in window blinds, curtains and flagpoles.

Did you know?
Pulleys started the age of mass production in England, when they were produced at the beginning of the 19th century to supply the British Royal Navy with pulley blocks for their war ships during the Napoleonic Wars.

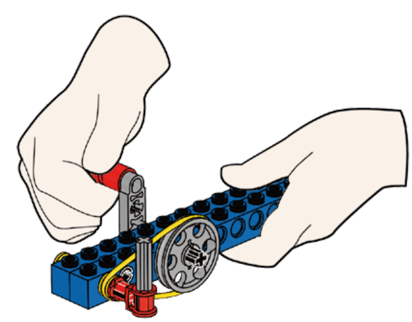
C1

This model shows a belt driven pulley where the speed and direction of the drive and driven pulley wheels are the same. A light grip on the output pointer will stop the driven pulley wheel from turning, as this causes the belt to slip.



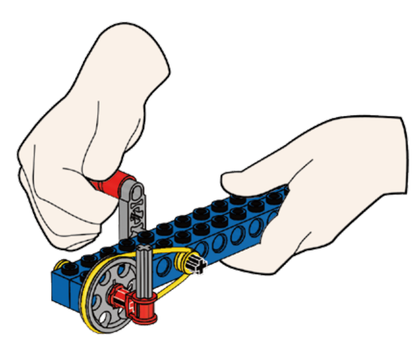
C2

This model shows a belt driven pulley where there is an increase in speed. The driven pulley wheel turns faster than the drive pulley wheel, but the output force is reduced and the belt can slip.



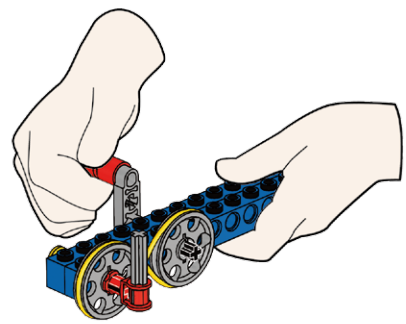
C3

This model shows a belt driven pulley where there is a decrease in speed. The driven pulley wheel turns slower than the drive pulley wheel. This increases the output force, but the belt slips with increasing load.



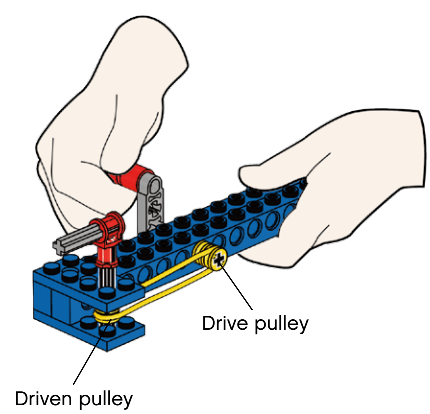
C4

This model shows a belt driven pulley where the speed of the drive and driven pulley wheels are the same, but they turn in opposite directions because the belt crosses over.



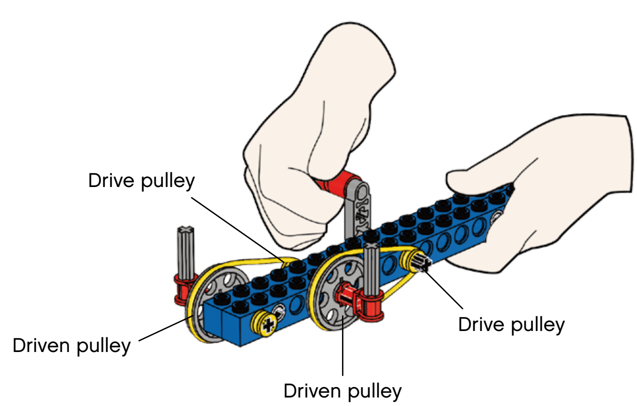
C5

This model shows a belt driven pulley where the speed of the drive and driven pulley wheels are the same, but there is a change in the angle of motion caused by the twist in the belt.



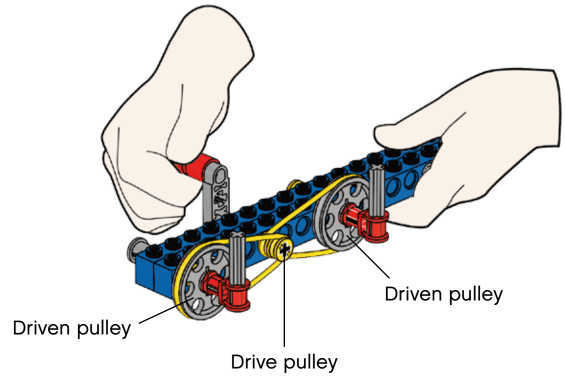
C6

This model shows a belt driven pulley using a compound pulley system. This reduces speed significantly, but at the same time significantly increase the output force. The smaller drive pulley wheel causes the larger driven pulley wheel to move slower. The small drive pulley wheel on the same axle as the larger driven pulley wheel becomes the drive pulley wheel of the second, large driven pulley wheel.



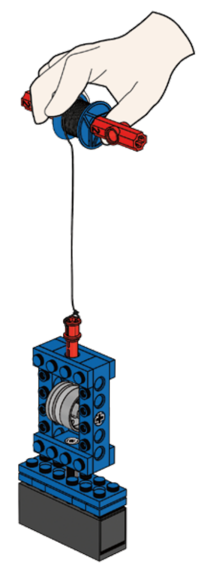
C7

This model shows a belt driven pulley where one drive pulley drives two driven pulley wheels, creating double output. The difference in size of the drive and driven pulley wheels causes a reduction in speed, but an increased output force.



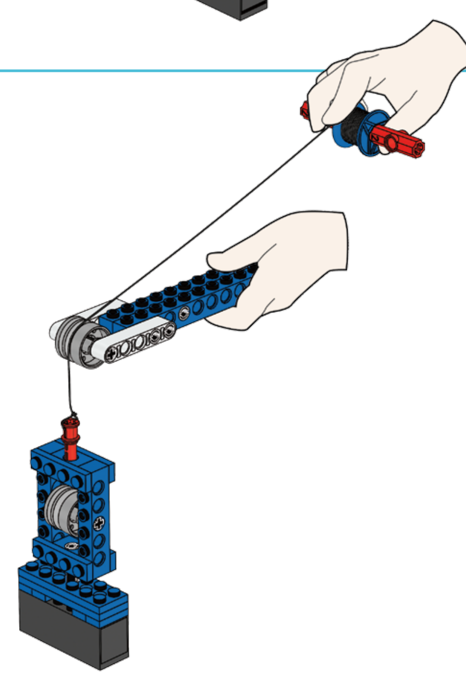
C8

This model generates no increase or reduction in the required effort, speed or distance. The full load of the LEGO® weight element is simply lifted or lowered.



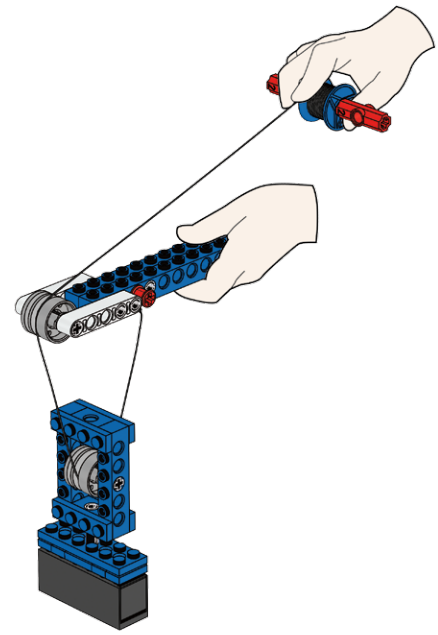
C9

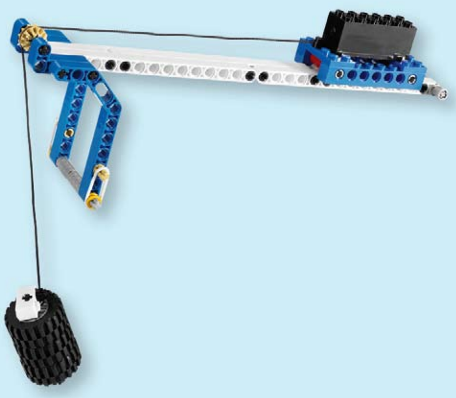
This model shows a single fixed pulley. It generates no increase or reduction of required effort or speed, but merely changes the direction of motion.



C10

This model shows a fixed and a movable pulley. It halves the effort needed to lift the load, but also reduces the speed at which the load is lifted. You must pull twice the length of string to lift the load.

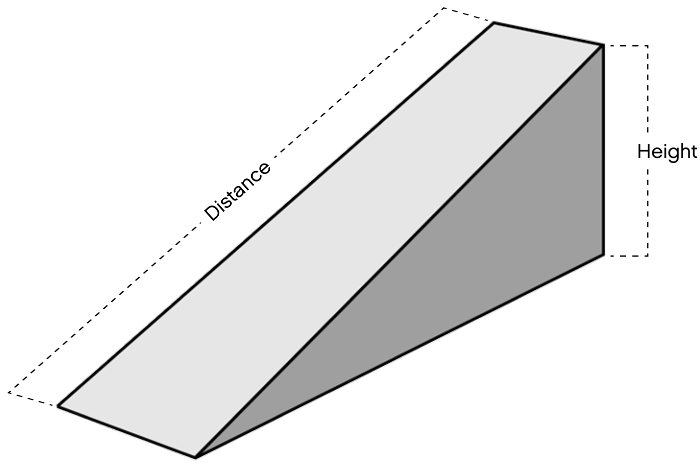




Inclined Plane

Simple Machines: Inclined Plane

An inclined plane is a slanted surface used to raise objects. One example is 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 raise straight up.
It is 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. That means the same amount of work is done.

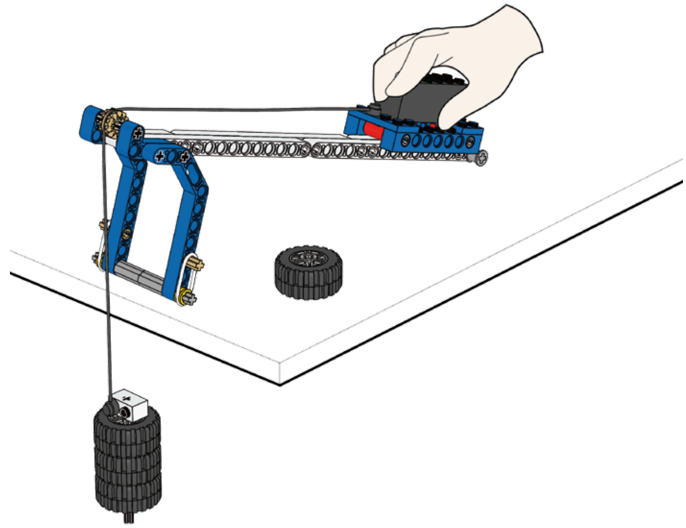
Common examples of inclined planes are ramps, ladders, and stairs.

Did you know?
The advantage of using an inclined plane has been known and used for thousands of years. The ancient Egyptians used inclined planes made of earth to ease the transport of their giant stone blocks to the top of the pyramids.

D1

Build D1 book II, page 2 to 12

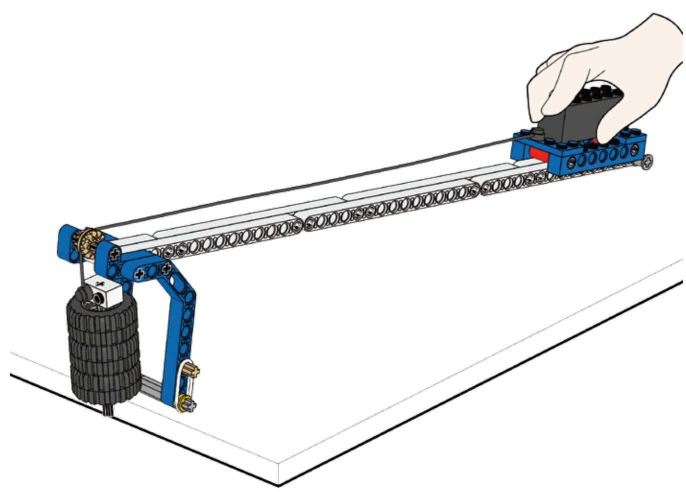
Release the load. Describe what happens.

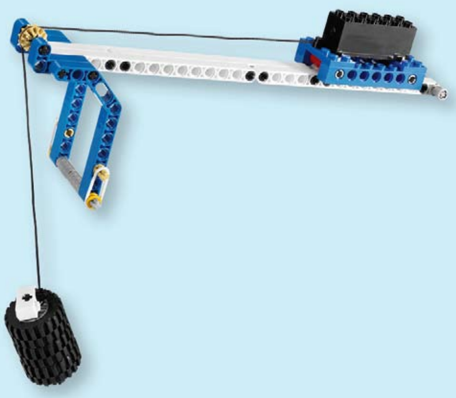


D2

Build D2 book II, page 13 to 15

Release the load. Describe what happens.





Inclined Plane

Simple Machines: Inclined Plane

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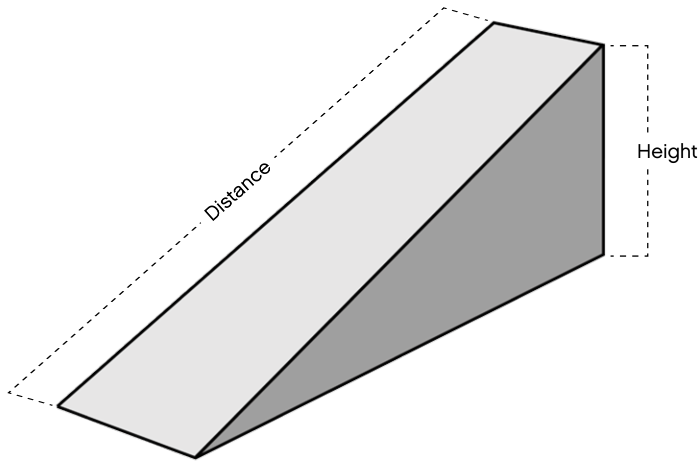

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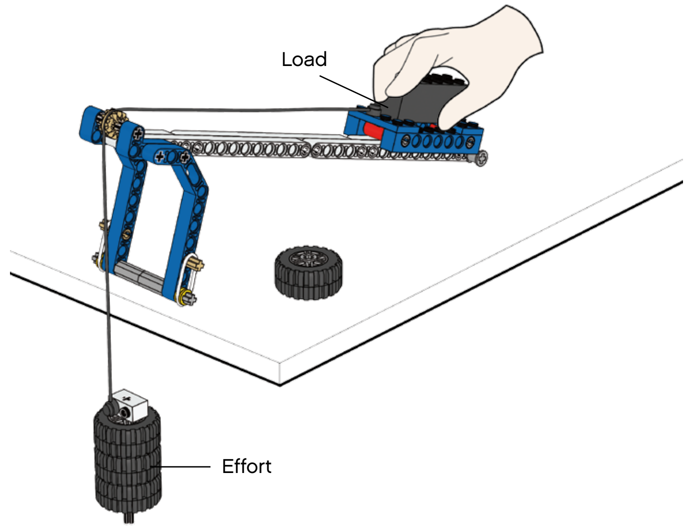
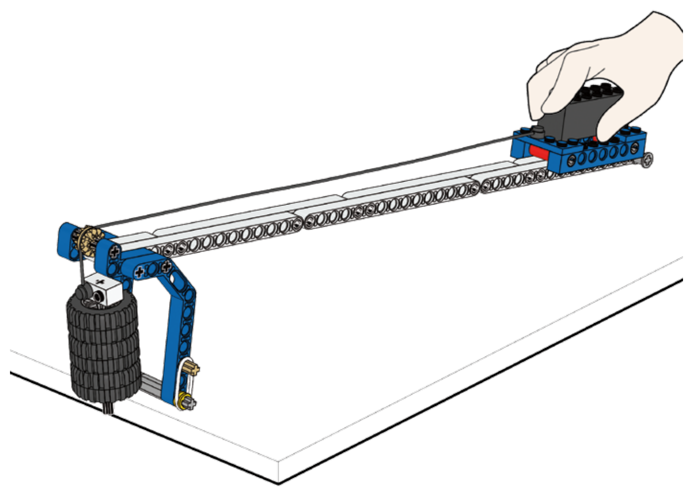
D1

This model shows a short inclined plane. Nothing happens when the load is released. The effort is not enough to raise the load to the top of the inclined plane. If another wheel is added, the effort is able to raise the load.



D2

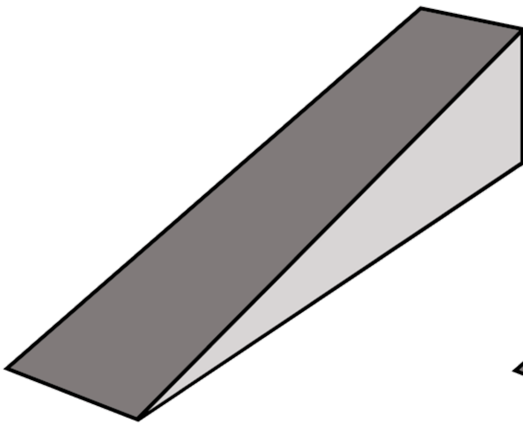
This model shows a long inclined plane. Because of the added distance to this inclined plane, that reduced angle of the ramp, the effort is able to raise the load to the top of the inclined plane.



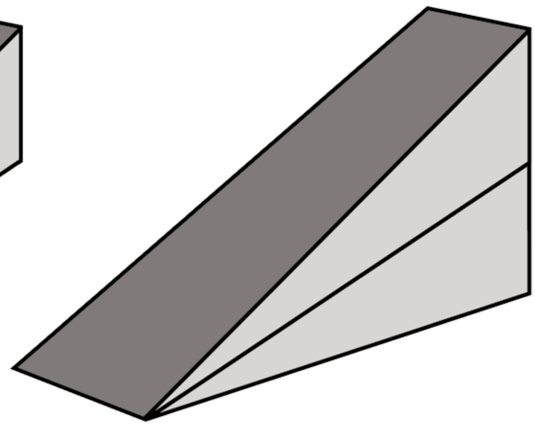
Wedge

Simple Machines: Wedge

A wedge is a modification of the inclined plane. Unlike an inclined plane a wedge can move.



Single wedge



Double wedge

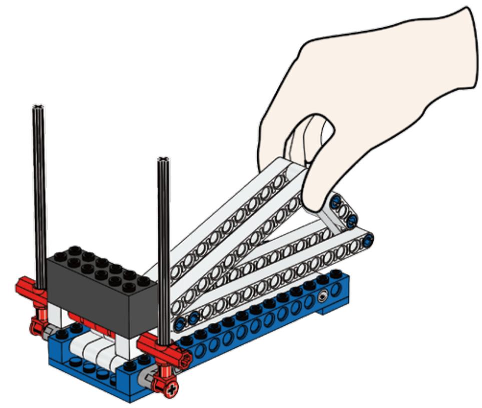
A wedge can have a single or two sloping surfaces. The effort you need depends on the relationship between the length and width of the wedge and consequently the sloping surface.

Common examples of wedges include axes, knifes and doorstops.

Did you know?
Wedges are used to split granite!
A simple device called a wedge and feather can split huge granite blocks.

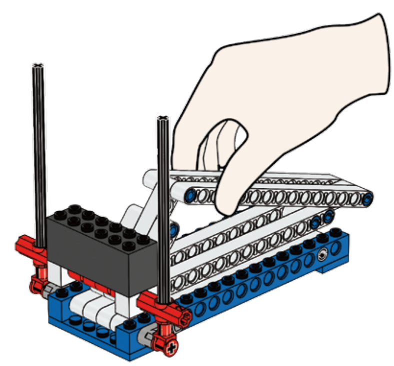
E1

Build E1 book II, page 16 to 25
Push the wedge under the load. Describe what happens.



E2

Turn the wedge around and then push the wedge under the load again. Describe what happens and compare with the model above.



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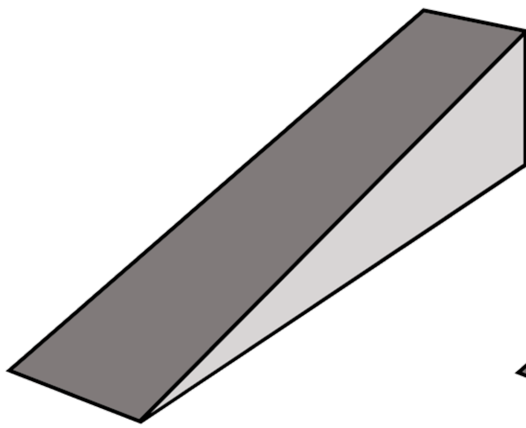
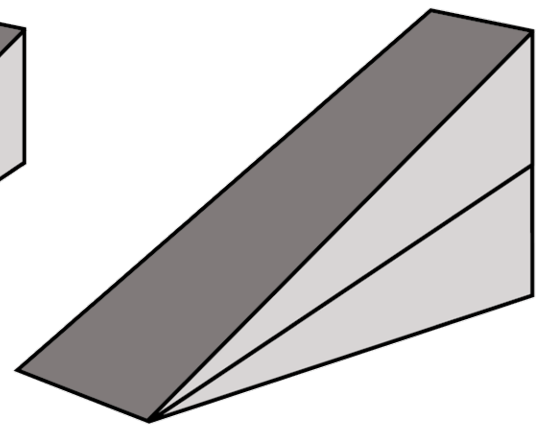
A wedge is a modification of the inclined plane. Unlike an inclined plane a wedge can move.



Single wedge



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Did you know?
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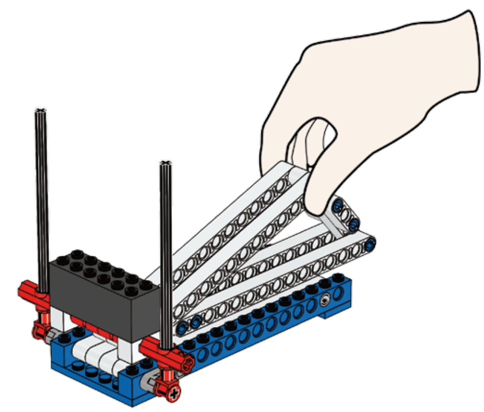
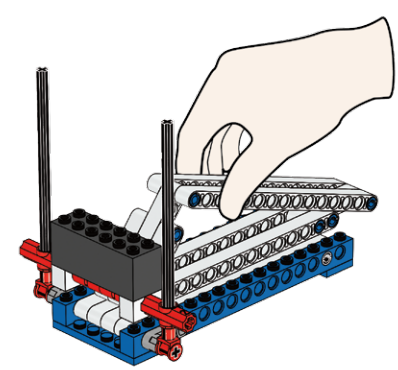
E1

This model shows a single wedge with a long sloping surface. The wedge needs a small effort to lift the load as the wedge has a small angle.

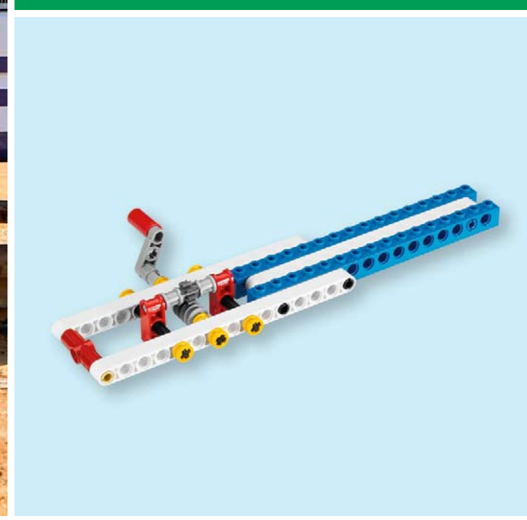


E2

This model shows a single wedge with a short sloping surface. The steep angle of the sloping surface needs a greater effort to lift the load compared to the previous wedge. But it also travels a shorter distance.



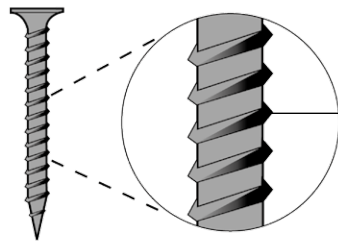
LEGO education



Screw

Simple Machines: Screw

A screw is a modification of an inclined plane. The threads of a screw are like an inclined plane wrapped around a cylinder. The width of the treads are like the angle of an inclined plane.



The finer the pitch of the screw, the more turns are required, but the less effort is needed to drive the screw in. The load is the friction and other forces exerted by the wood on the screw.

When a screw is screwed into a piece of wood, it is like rotating the long inclined plane through the load. The effort of a turning screwdriver is converted into a vertical effort that screws the screw into an object. How far the screw is able to move in one complete revolution is determined by the pitch of the screw.

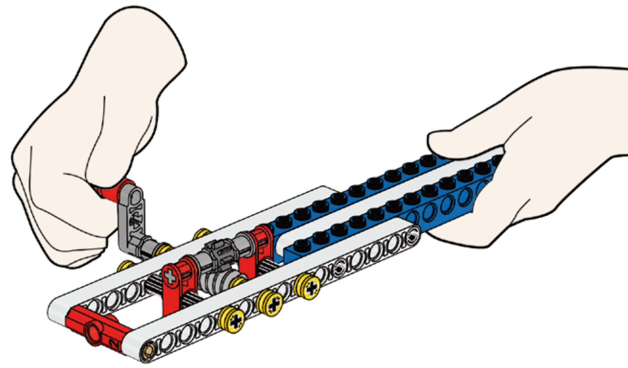
The pitch is the number of threads per cm of screw. If a screw has 8 threads in a cm the screw has a pitch of 1/8. A screw with a pitch of 1/8 will in one complete revolution move a distance of 1/8 of a cm into an object.

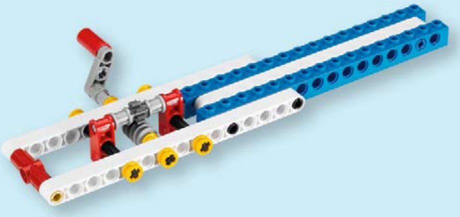
Common examples of screws are screws, cork screws and drills.

Did you know?
Archimedes, the Greek scientist, mathematician and inventor, used a screw as the basis for his screw-pump design to move water for irrigation in the 3rd century BC.

F1

Build F1 book II, page 26 to 32
Turn the handle and describe what happens to the speed and the direction.





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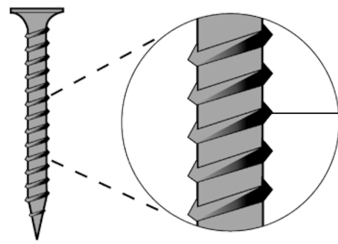

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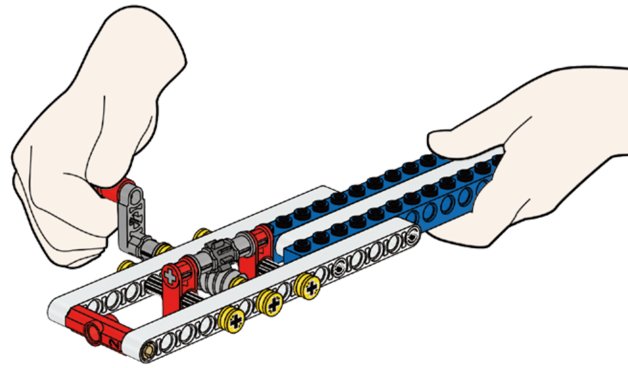
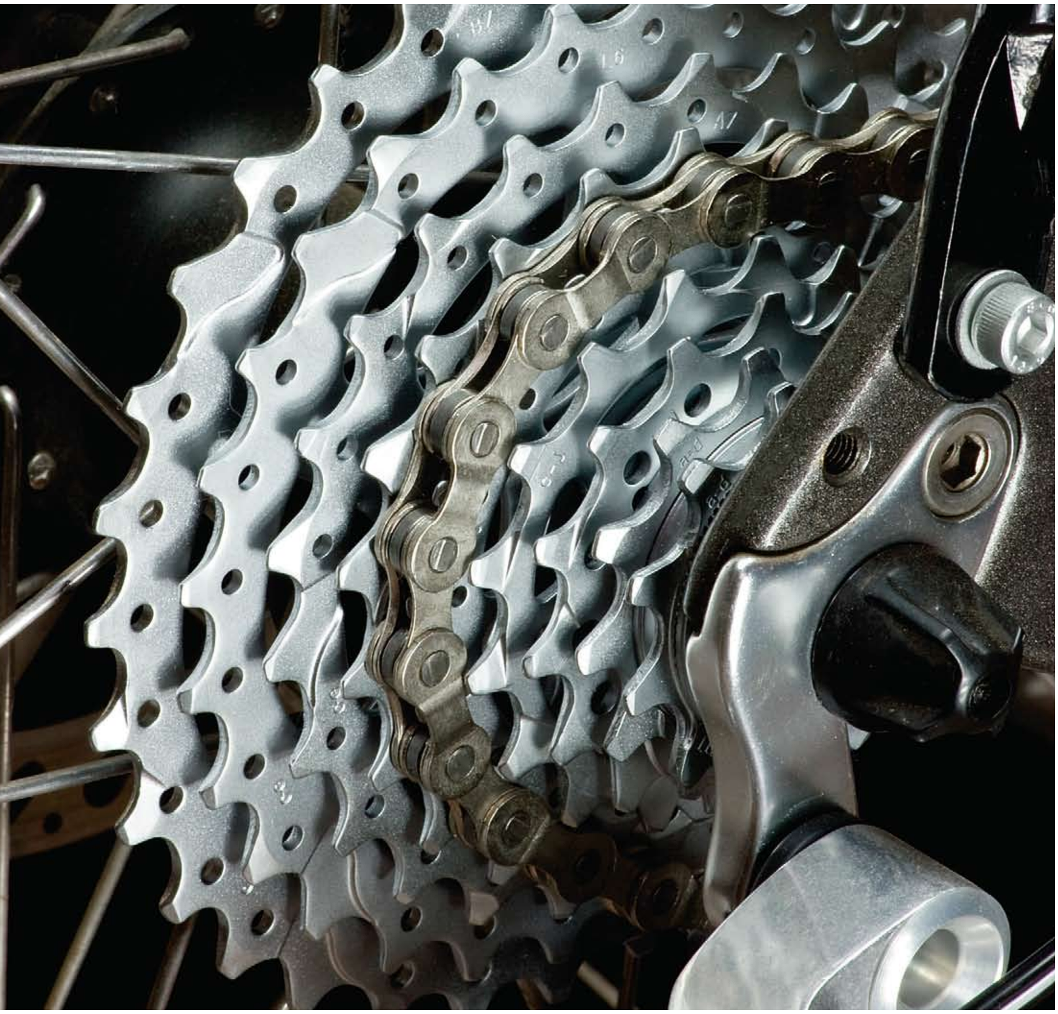
F1

This model uses the threads of the worm gear to demonstrate the principle of the screw. As the handle is turned the screw moves the gear across the screw at a 90° angle. The speed movement is significantly reduced.



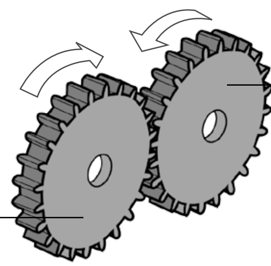
education



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 or follower. 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 cannot have both more output force and an increase in speed at the same time.

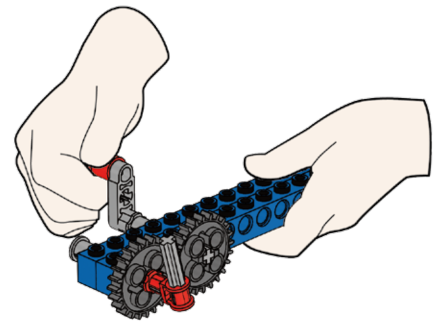
To predict the ratio of which two meshed gears will move relative to each other, divide the number of teeth on the driven gear by the number of teeth on the drive gear. This is called the gear ratio. If a driven gear with 24 teeth is meshed with a drive gear with 48 teeth, there is a 1:2 gear ratio.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

Did you know?
Not all gears are round. Some gears are square, triangular, and even elliptical.

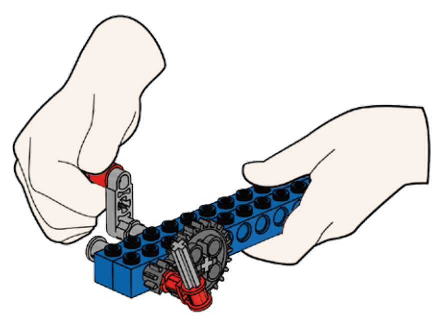
G1

Build G1 book III, page 2
Turn the handle and describe the speeds of the drive and the driven gears. Circle and label the drive and driven gears.



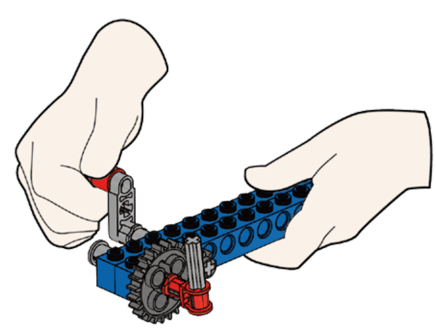
G2

Build G2 book III, page 3
Turn the handle and describe the speeds of the drive and driven gears. Circle and label the drive and driven gears.



G3

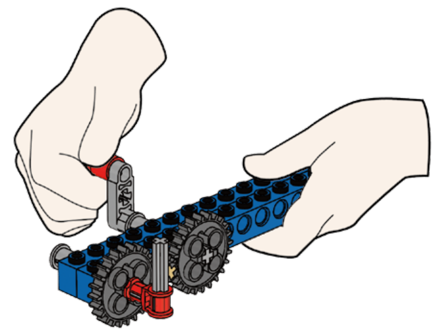
Build G3 book III, page 4
Turn the handle and describe the speeds of the drive and driven gears. Circle and label the drive and driven gears.



G4

Build G4 book III, page 5 to 6

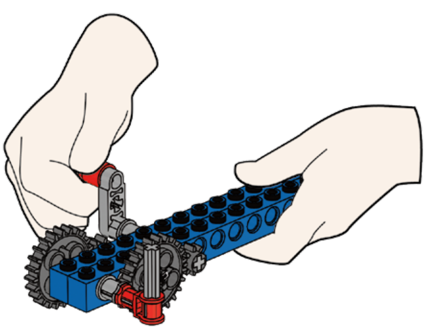
Turn the handle and describe the speed and direction of the drive and driven gears. Circle and label the drive and driven gears.



G5

Build G5 book III, page 7 to 8

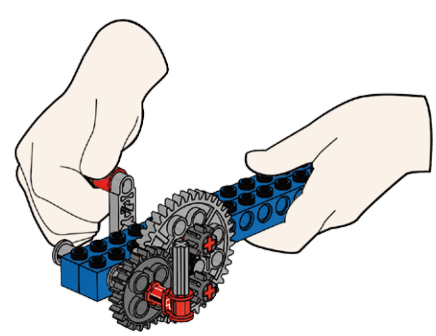
Turn the handle and describe the speed and direction of the drive and driven gears. Circle and label the drive and driven gears.



G6

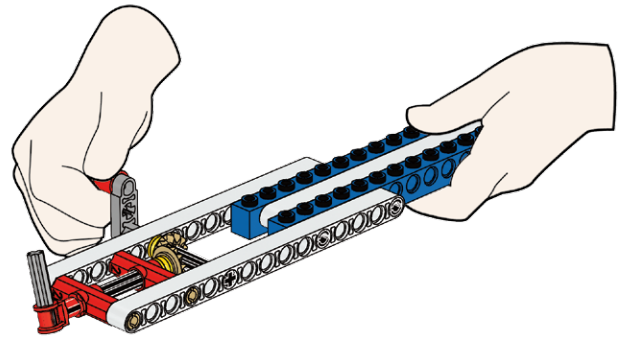
Build G6 book III, page 9 to 10

Turn the handle and describe the movement of the driven gear.



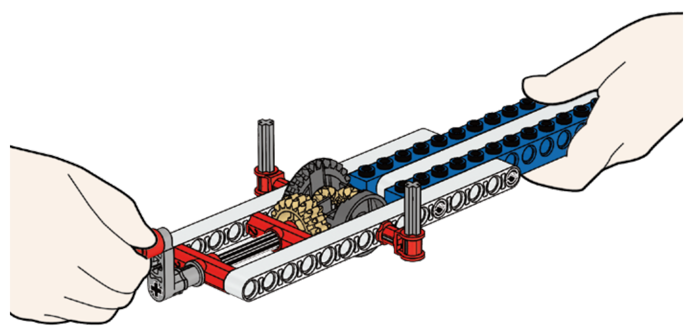
G7

Build G7 book III, page 11 to 14
Turn the handle and describe what happens.



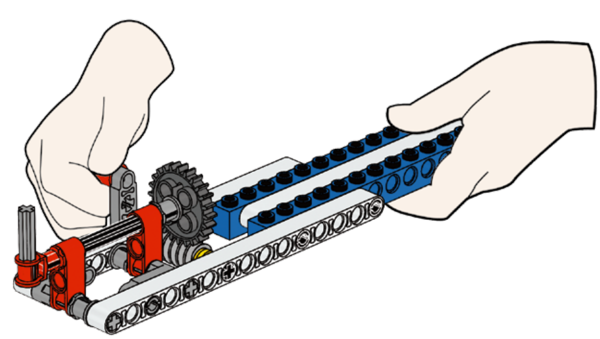
G8

Build G8 book III, page 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

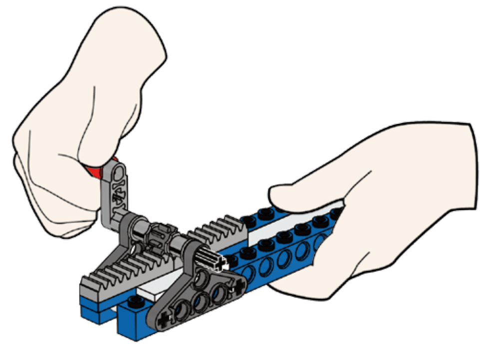
Build G9 book III, page 19 to 22
Turn the handle and describe what happens.
What happens if you try turning the output pointer?

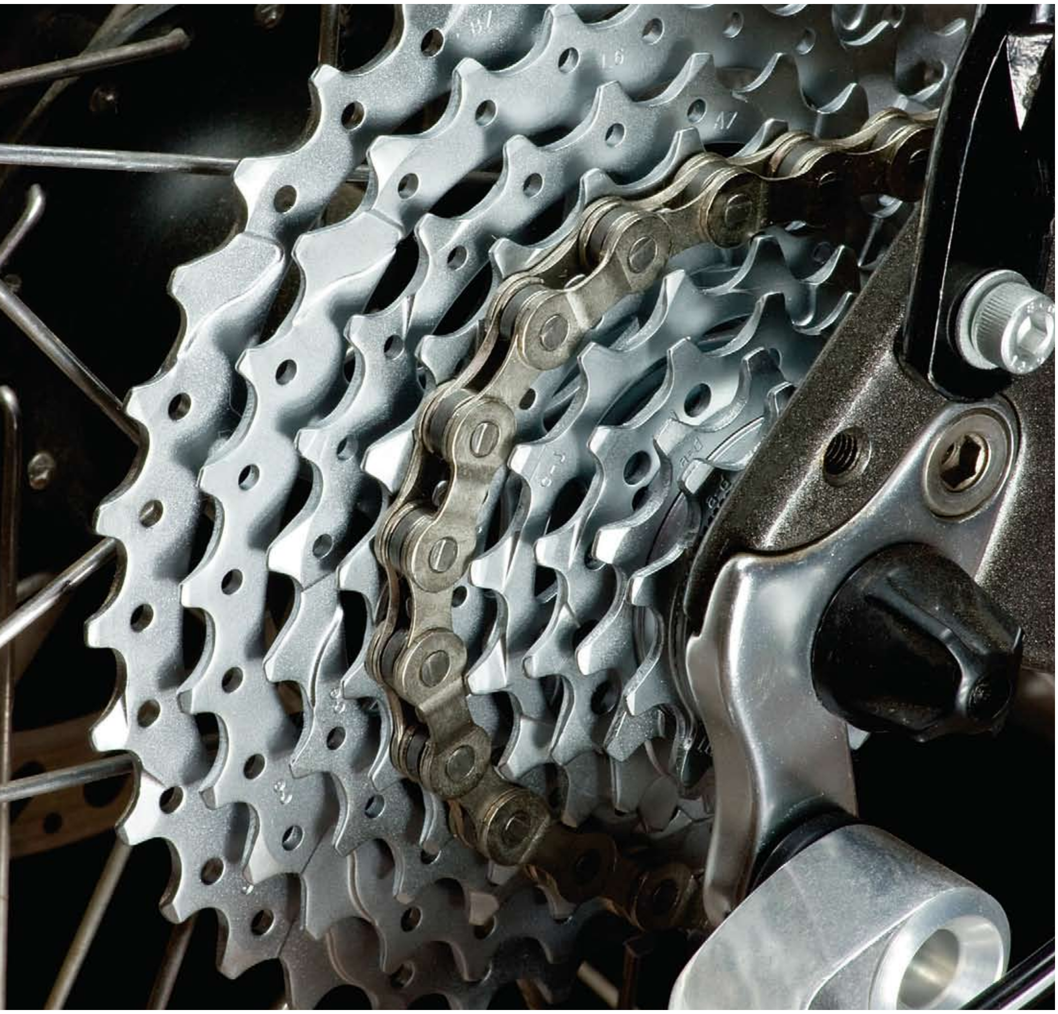


G10

Build G10 book III, page 23 to 25

Turn the handle and describe what happens.





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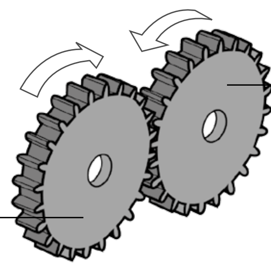

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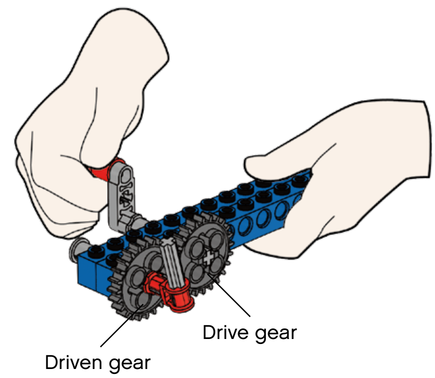
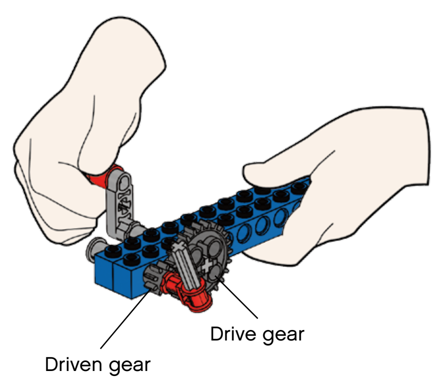
G1

This model shows a 1:1 gear ratio. The speeds of the drive gear and the driven gears are the same, because they have the same number of teeth. The drive and driven gears turn in opposite directions.



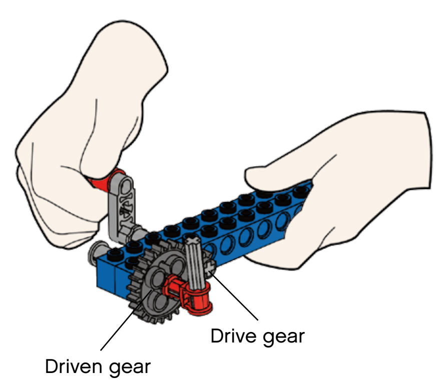
G2

This model shows gearing up. The larger drive gear turns the smaller driven gear, resulting in increased speed, but reduced output force.



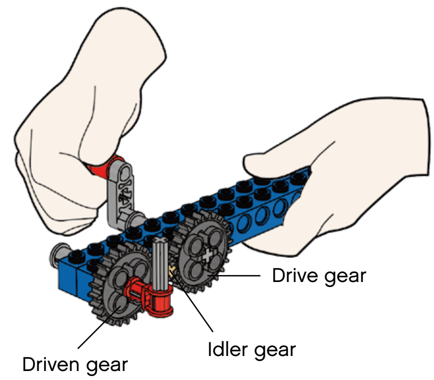
G3

This model shows gearing down. The smaller drive turns the larger driven gear, resulting in reduced speed, but increased output force.



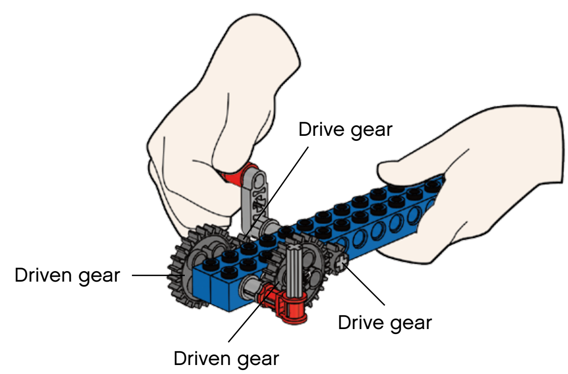
G4

This model shows an idler gearing. The small gear is an idler gear. The idler gear does not affect the speed or output force of either the drive or the driven gears. The drive and the driven gears turn in the same direction and at the same speed.



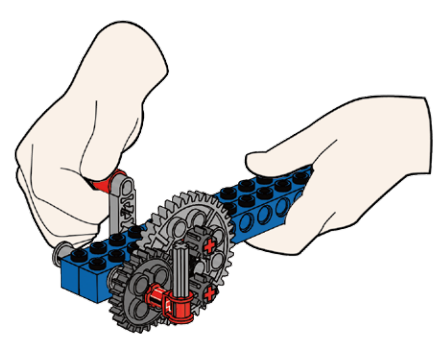
G5

This model shows an example of compound gearing. Because of the way this compound gearing is arranged, the turning speed is significantly reduced and the output force greatly increased. The smaller drive gear slowly turns the larger driven gear. The smaller gear on the same axle as the driven gear is now set in motion and slowly turns the second large driven gear, making it turn even more slowly.



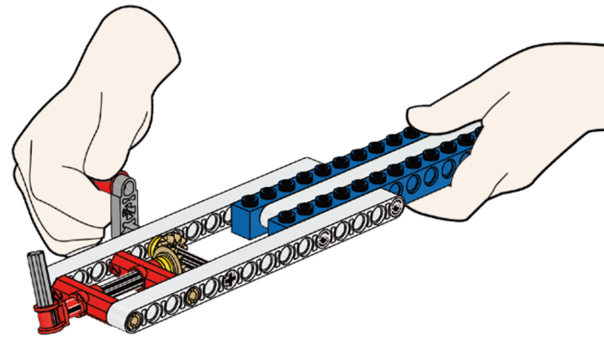
G6

This model shows gears set up for periodic movement: the driven gear turns for a short while and then stops for a moment. Speed is significantly reduced as movement only occurs when the driven gear is meshed with one of the two drive gears.



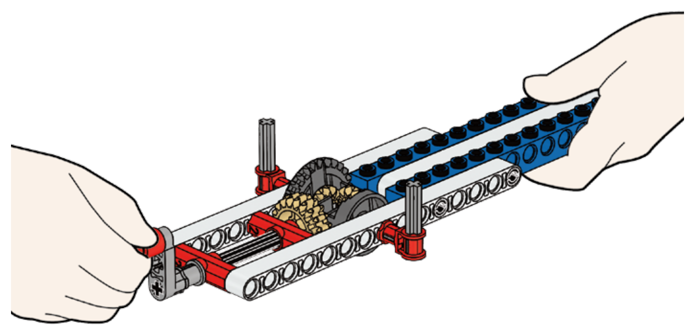
G7

This model shows an angle gearing. The two meshed bevel gears transfer the speed and force unchanged, but at an angle of 90º.



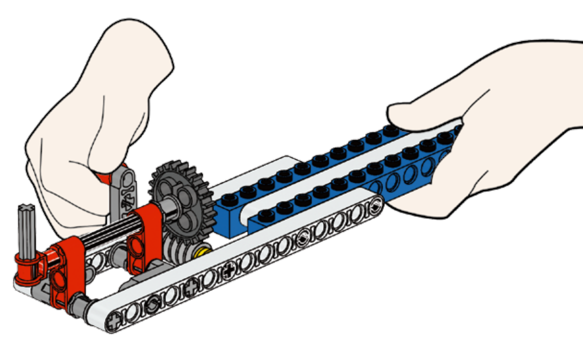
G8

This model shows a differential gearing. The input force is transferred to two output forces at an angle of 90º. When one output pointer is stopped, the other will double its original speed. When both output pointers are stopped the handle cannot be turned.



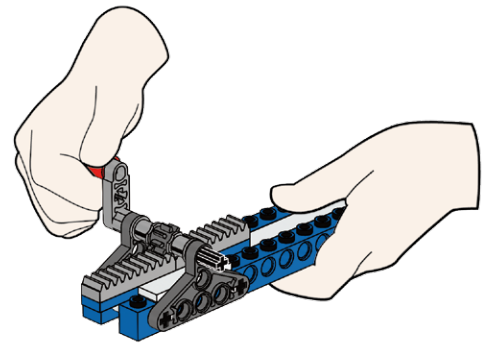
G9

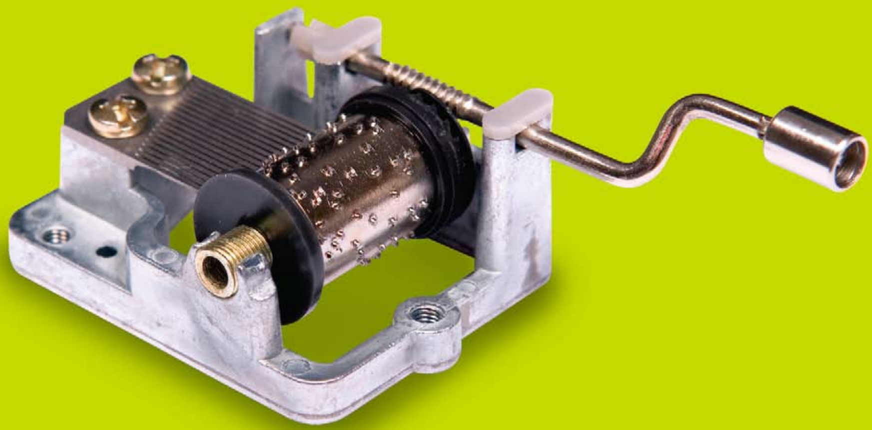
This model shows a worm gear. It reduces speed significantly as it takes a complete turn of the worm gear to move the gear above by a single tooth. It changes direction by 90º. The output force is increased significantly.
Worm gears can only be used as a drive gear.



G10

This model shows a rack and pinion gearing. Unlike the previous gears a rack and pinion gearing can only be used for linear motion, not rotary. When the handle is turned the gear rack moves forward or backwards depending on the rotational direction of the small gear (called a pinion).

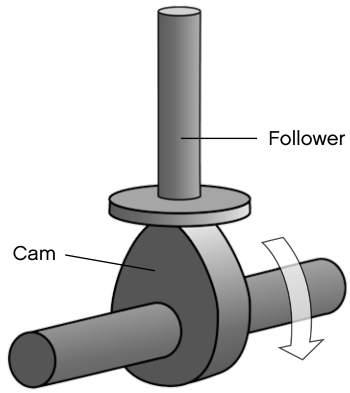




Cam

Mechanisms: Cam

A cam is a shaped frame turning about an axis, like a rotating wheel.



The profile of a cam allows it to control the timing and degree of movement of a follower. A cam can also be regarded as a continuous, variable inclined plane. Cams can be circular, pear shaped, or irregular.

Cams and cam followers are very prone to wear due to friction. Cam followers often have tiny rollers attached to them to reduce this friction.

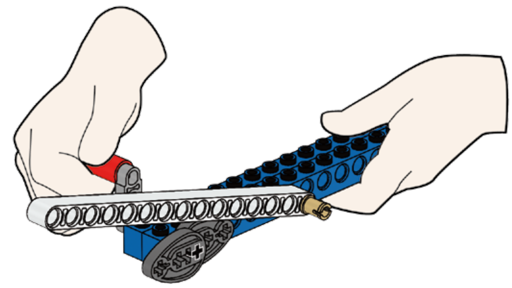
Common applications with cam mechanisms include an electric toothbrush, an engine camshaft, and clamps.

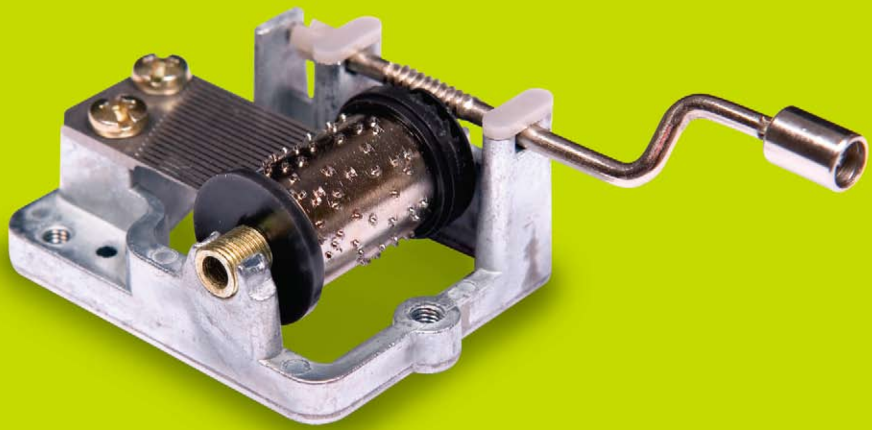
Did you know?
Spring-loaded cams are used by rock climbers to tightly grip rock crevices so that they can then attach climbing ropes.

H1

Build H1 book III, page 26 to 27

Turn the handle and describe the movement of the follower.





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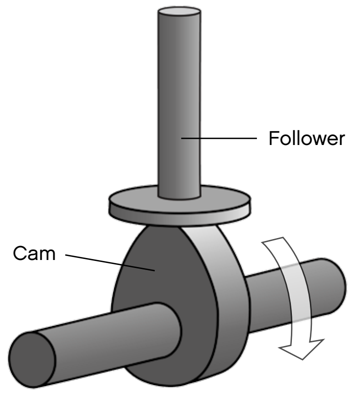

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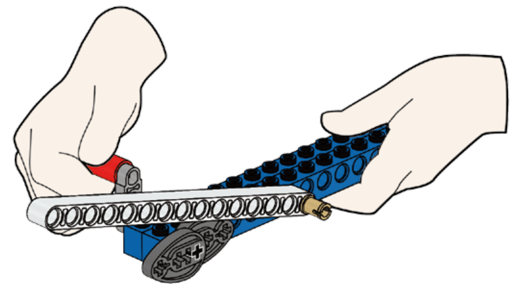
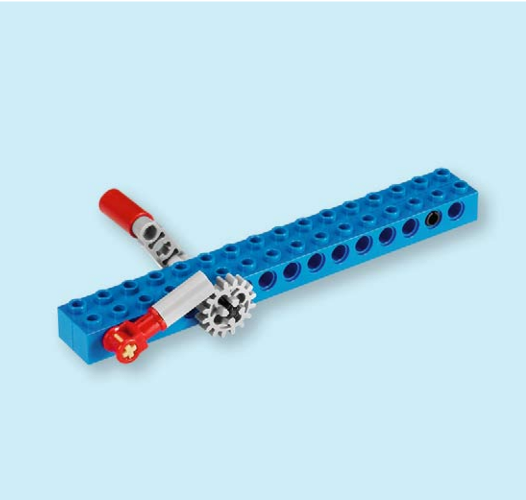
H1

This model shows a double cam mechanism. As the two cams rotate, their shape and size dictate a sequence of upward and downward movements of the follower.

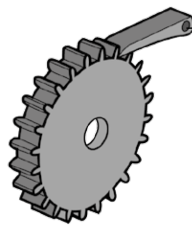




Pawl and Ratchet

Mechanisms: Pawl and Ratchet

A ratchet mechanism is based on a gear wheel and a pawl that follows as the wheel turns.



When the gear is moving in one direction, the pawl slides up and over the gear teeth, sending the pawl into the notch before the next tooth. The pawl is then jammed against the depression between the gear teeth, preventing any backwards motion.

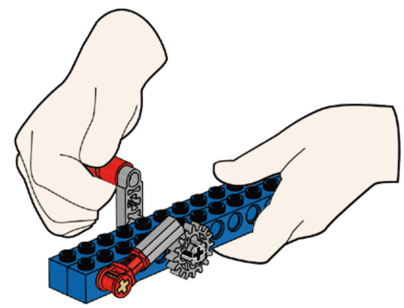
Ratchet mechanisms are very useful devices for allowing linear or rotary motion in only one direction.

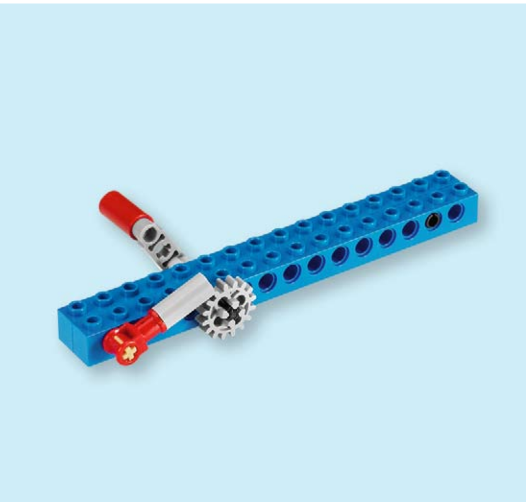
Common examples of ratchets are clocks, jacks, and hoists.

Did you know?
There are ratchets in some screw drivers that allow the user to turn with an effort in one direction and then turn back without turning the screw.

I1

Build I1 book III, page 28 to 29
Turn the handle in both directions and describe what happens.





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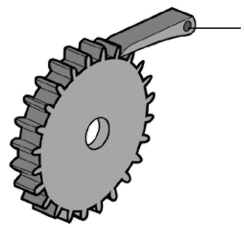

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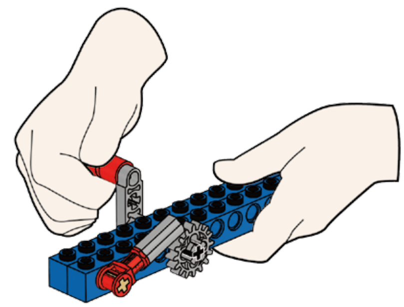
Common examples of ratchets are clocks, jacks, and hoists.

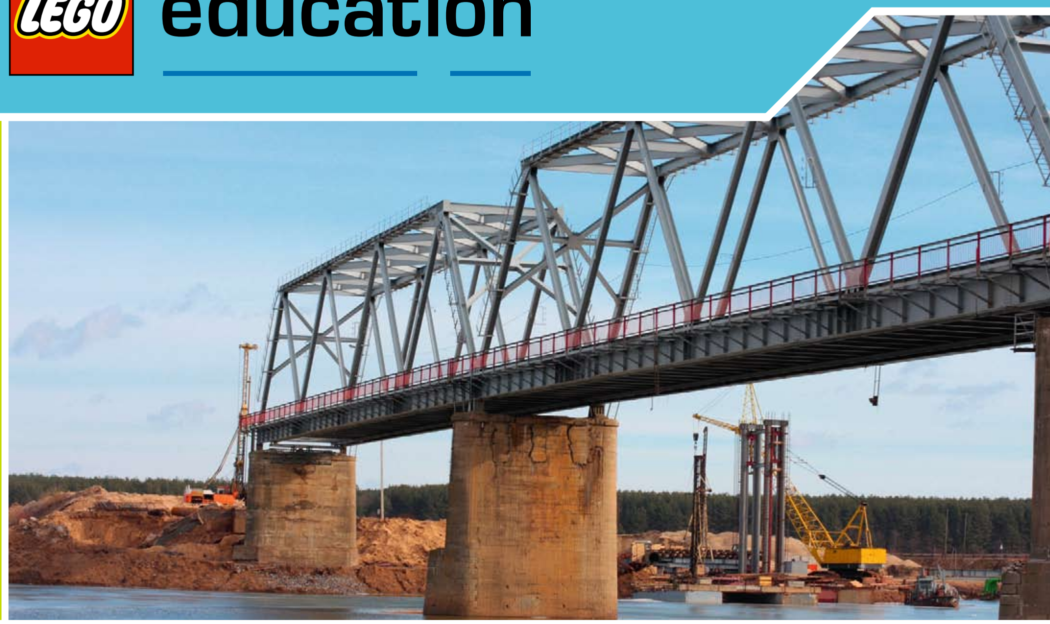
Did you know?
There are ratchets in some screw drivers that allow the user to turn with an effort in one direction and then turn back without turning the screw.

I1

This model shows a pawl and ratchet gearing. When the handle is turned in one direction, the pawl slides up and over the gear teeth, sending the pawl into the depression before the next tooth. When the handle is turned in the opposite direction, the pawl stops the movement.



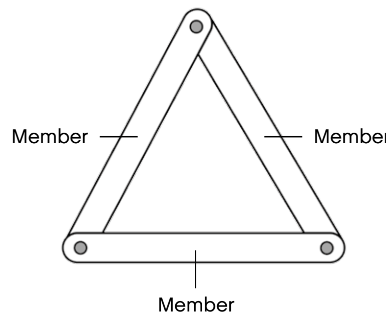
education



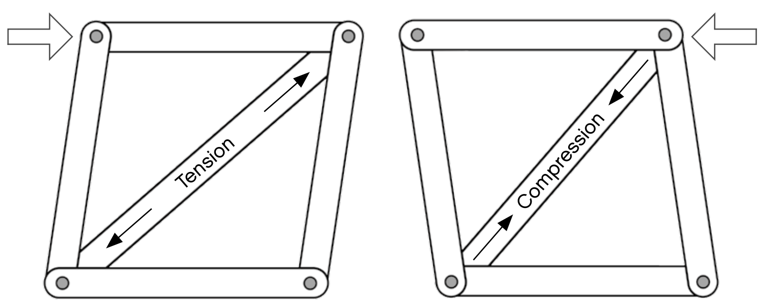
Structures

Structures

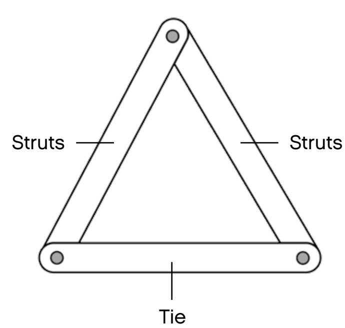
A structure is a construction in which individual parts are arranged to form a whole. All structures are under the influence of external and internal forces. Examples of external forces acting on a structure include the wind or the weight of trucks and buses passing over a bridge. An internal force could be the weight of a roof or the shaking of a large diesel engine on its mountings. Choice of materials will affect the safety level of a structure.



A frame structure is made from pieces called members. This frame is rigid because it is triangulated.



The forces that act on members are called tensile forces or compression forces. Tensile forces will stretch the structure and compression forces will squeeze the structure.



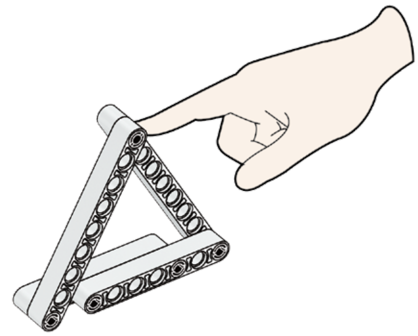
Members that are in tension are called ties; members that are under compression are called struts.

Common examples of structural principles can be found in scaffoldings, buildings and bridges.

Did you know?
In bridges, cranes, towers and even space stations, triangulation is often used to make structures rigid.

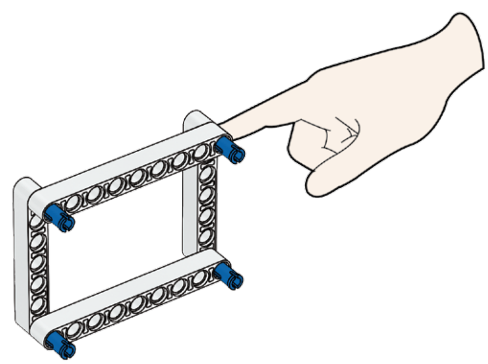
J1

Build J1 book III, page 30
Push to create compression forces and pull to create tension forces on the members of the triangular frame.
Describe what happens.



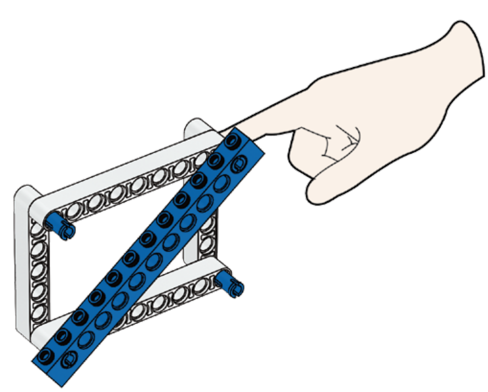
J2

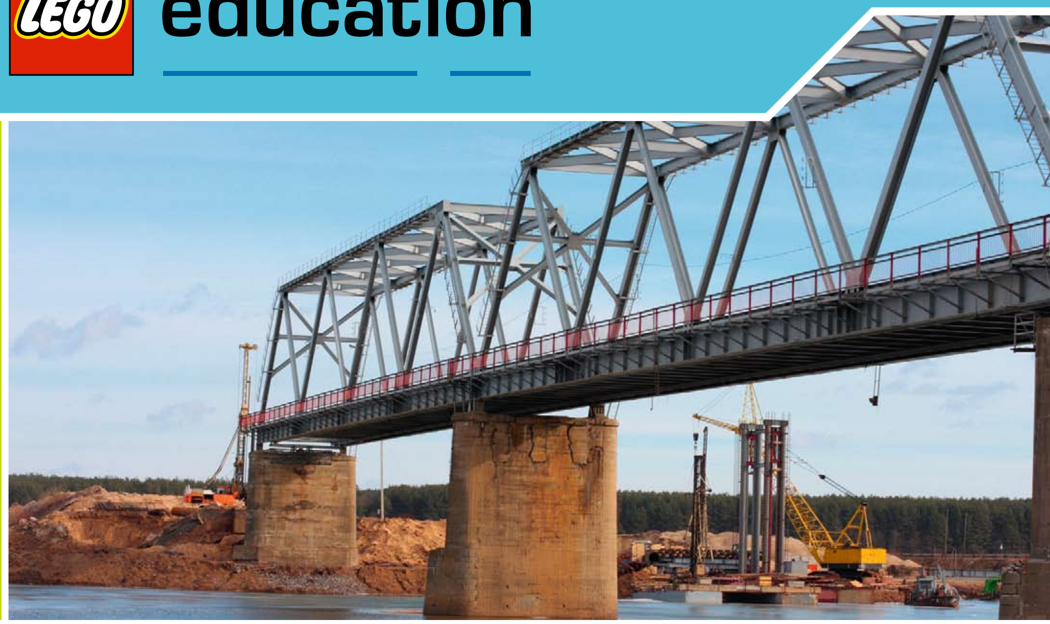
Build J2 book III, page 31
Push and pull to create tensile or compression forces on the members of the rectangular frame.
Describe what happens.



J3

Build J3 book III, page 32
Add the cross member and push and pull the rectangular frame to create tensile forces or compression forces.
Describe what happens.





Structures

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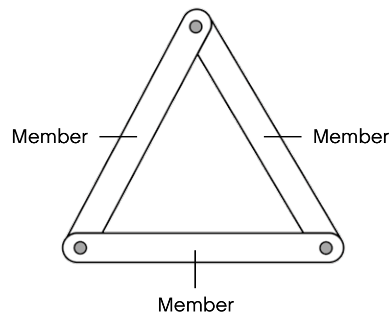
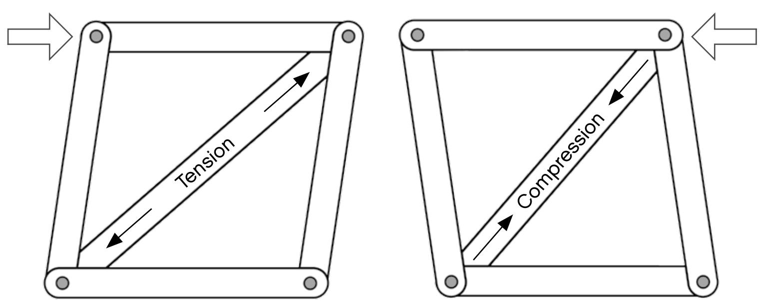


A frame structure is made from pieces called members. This frame is rigid because it is triangulated.



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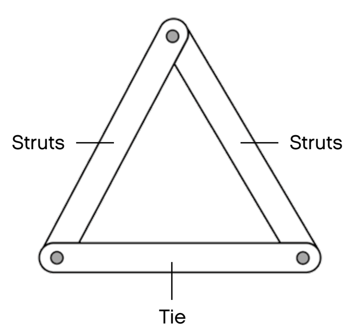

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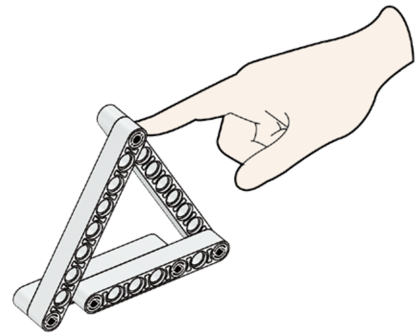
Common examples of structural principles can be found in scaffoldings, buildings and bridges.

Did you know?
In bridges, cranes, towers and even space stations, triangulation is often used to make structures rigid.

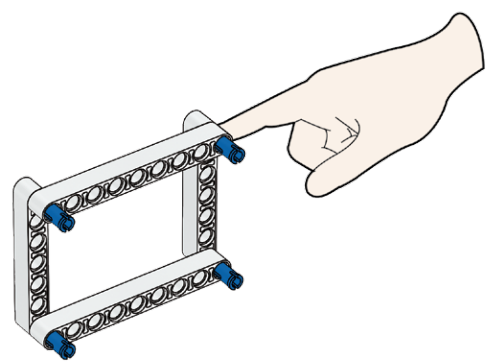
J1

This model shows a triangular structure. When the triangular frame is pushed or pulled the shape doesn't change.
The triangular frame is rigid.



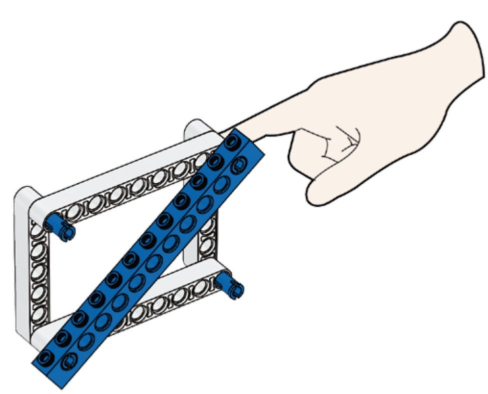
J2

This model shows a rectangular structure. The rectangular frame is easily changed when pushed and pulled.
A rectangular frame is not rigid.



J3

This model shows a rectangular structure supported by a cross member. The rectangular frame is prevented from changing when pushed and pulled by the cross member.
The cross members makes the rectangular frame rigid.



Sweeper

Technology
- Using mechanisms – bevel gears, gearing up, pulleys
- Testing before making improvements
- Safety systems

Science
- Measuring distance
- Friction
- Scientific investigations

Vocabulary
- Efficiency
- Gearing up
- Slip
- Pulley
- Belt
- Friction
- Bevel gear

Other materials required
- A large cardboard box or a low card wall to stop flying trash, approx. 60 x 40 cm (≈ 24 x 16 in) is ideal
- For trash: use crumpled scraps of paper, LEGO® connector pegs, bushings, crushed real leaves, or the like

Tip:
Don't use seeds or beads as they could hit someone in the eye.

Connect

The path is covered in trash and leaves. It looks terrible and could be dangerous if someone slips on it! Now Jack and Jill have the job of cleaning it up, but they are not keen on their brooms and would much rather play on their cart.

Zog the Dog tries to help out but he's not very good at it.

Suddenly they get an idea about combining the broom with the cart, but they are not sure exactly how to make it work.

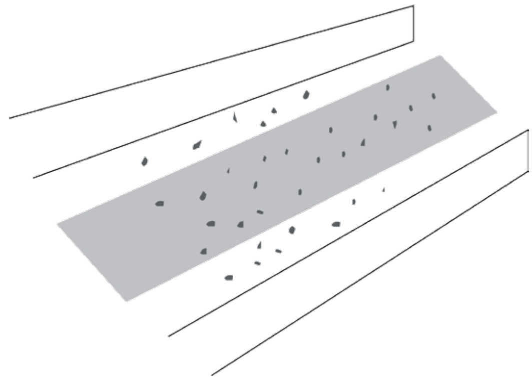
How can you combine pushing a cart with cleaning a path?
Let's find out!

Construct

Make the test park
Use a smooth tabletop or floor, and place your crumb-proof wall or box on it.

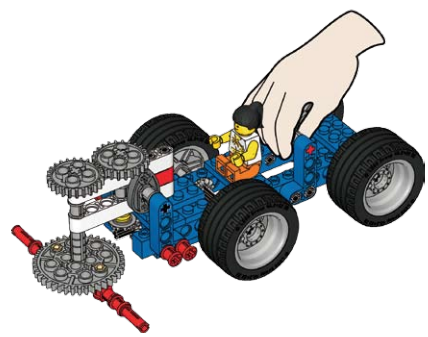
Evenly spread out strips of crumpled paper scraps across a 10 cm (≈ 4 in) wide and 60 cm (≈ 24 in) long section of your park. This is the path covered in litter.

Leave plenty of room on either side of the path for the scraps to fly!



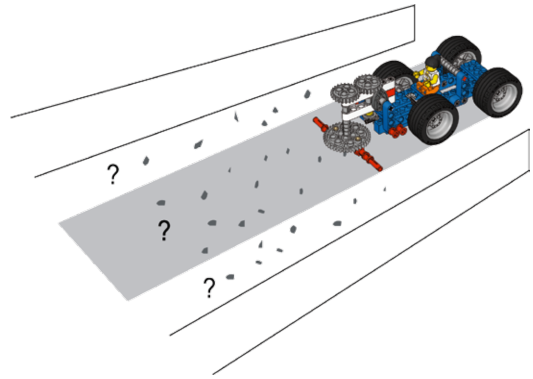
Build the Sweeper
(All of book 1A and book 1B to page 8, step 11).

Test that it runs smoothly
Push it gently across the table. The spinner should spin freely without hitting the frame of the cart and the sweeper 'blades' should open out and spin without touching the table.



Contemplate

How well does it sweep?
Push it along the dirty path. How much of the scraps did you sweep aside? A quarter? Half?

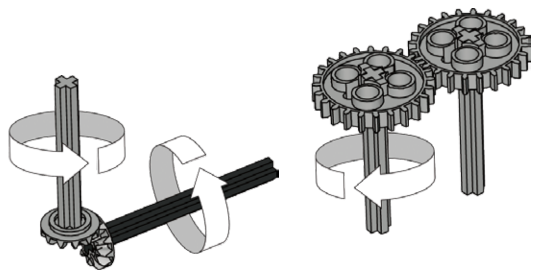


What problems are there with this design? Estimate the amount swept aside compared to what is left on the strip.

It is not a fast sweeper and it doesn't actually pick up the scraps!

Did you know?
All the gears with regular teeth, like the big gear, are called spur gears.

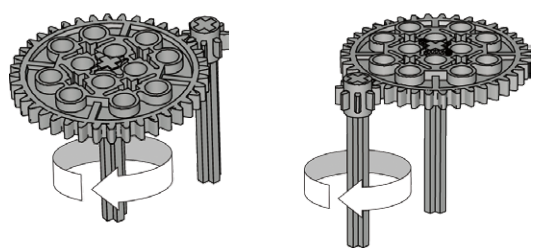
What is the gearing of the sweeper?
Push the sweeper along so the cart's wheels turn once. How many times does the sweeper head turn? Can you explain?



The sweeper head turns once. The gearing is 1:1. All the bevel and spur gears that mesh with each other are the same size. So there is no change in speed.

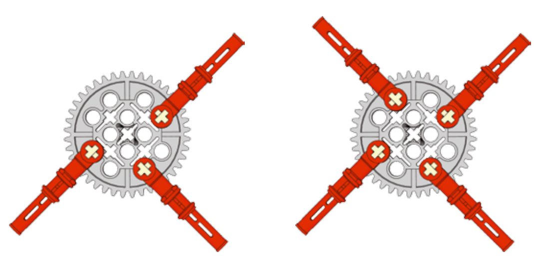
Tip:
What do the bevel gears do? They turn the direction of movement through 90°. They send moving energy around corners!

How can we make it sweep faster?
Try different combinations of drive gears (step 12, step 13).



Step 12 makes the sweeper head far too slow, step 13 makes it 5 times as fast.
Note the 40-tooth gear driving the 8-tooth gear!

Jack and Jill would like to finish the job as quickly as possible so no one will fall over in the leaves and hurt themselves. To help them, try adding more blades to the sweeper head (step 14).



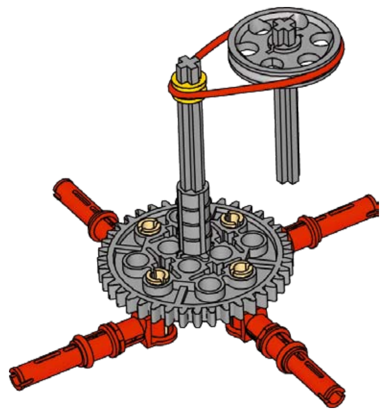
Three blades make it unbalanced and even worse than 2 blades. Four blades is better, and in balance.

Danger!
Push the sweeper and hold the sweeper head. What happens and what problems could this lead to?

The wheels may lock and the gears jump. Any items getting stuck in the sweeper may overload the machine or break the gears.

Continue

A Safer Sweeper
Rebuild the model to be driven by pulley belts. Try out different pulley systems. Predict and test how fast they will spin and how well they will sweep.



The sweeper head usually rotates more quickly. The bigger the driver pulley, the faster the rotation. It is harder to push though as there is more friction on the axles.

Push the sweeper and hold the sweeper head again. What happens? What are the pros and cons?

The driving band slips.

Good Points:
The sweeper will stop if something jams in it.
It could be safer for the operator too.

Bad Points:
It takes more energy to push.

A Dirt-Collector
Can you work out a way to not only remove the trash from the path, but also collect it?

Sweeper

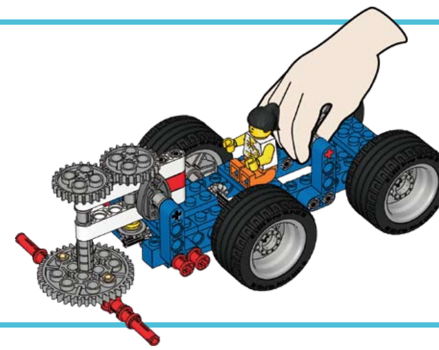
Name(s):

How can you combine pushing a cart with cleaning a path? Let's find out!

Build the Sweeper

(All of book 1A and book 1B to step 11.)

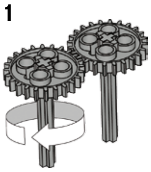
- Try it
- If it does not spin smoothly loosen the axle bushings and make sure the bricks are firmly linked to one another



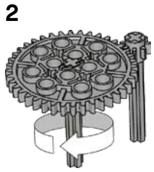
What makes a good Sweeper?

- Test your spin speeds with the gears shown below. Try them with only two sweeper blades **(a)**.

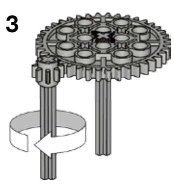
1



2

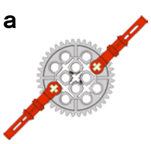


3

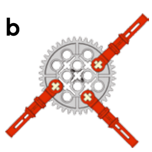


- Now try these sweeper blades with your FASTEST gears to see which one is best at sweeping crumbs

a



b



c

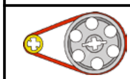
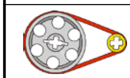
- Test different sweepers and compare them with your standard model

Tip: Write the words on the right into the boxes above. You can use them more than once. Make up your own descriptions too.

I tried this	My prediction	What happened?
1a		
2a		
3a		

The same
Faster
Slower
Worse
Better

A Safer Sweeper

	Prediction	What happened?
		
		

Also try:

- Holding the sweeper blades while you push the sweeper
- Cleaning up crumbs from a carpet

My own discoveries:

My Amazing Table Sweeper

Draw and label your Sweeper design.
Explain how the three best parts work.

Fishing Rod

Technology
- Using mechanisms – pulleys and levers
- Investigating a pawl and ratchet
- Designing and making a game

Science
- Forces
- Machines that make work easier
- Properties of materials
- Scientific investigation

Vocabulary
- Pulley block
- Ratchet
- Pawl
- Reel
- Effort
- Load

Other materials required
- Cardboard – big poster size (A2)
- Scissors
- Assorted color markers

Connect

Jack and Jill are at a friend's birthday party with some other children. They are in the garden and they have been selected to catch fish in the new Fishing Pond.

They have great fun, when suddenly Jack catches the largest and heaviest fish in the pond. Even using all his strength, he can't reel in the heavy fish.

Jill gets an idea as to how to reel in the fish. What do you think she plans on doing?

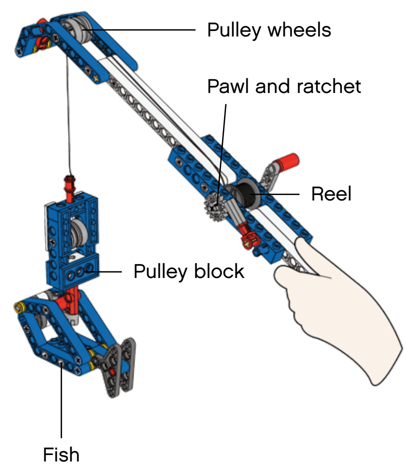
How can we make an exciting fishing device for Jack and Jill, and land the large fish? Let's find out!

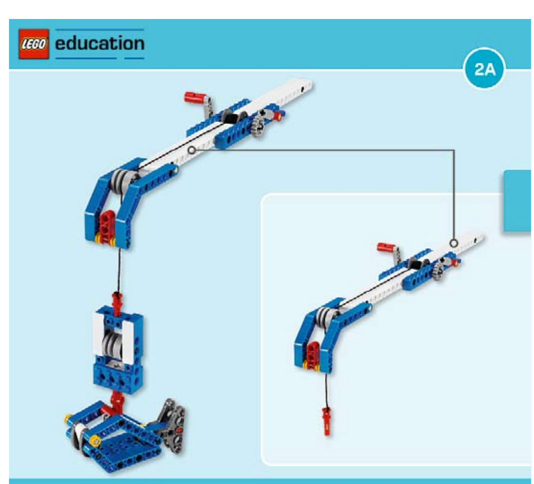
Construct

Build the Fishing Rod (including pulley block) and fish
(all of book 2A and book 2B to page 10, step 19).

Fine-tune your Fishing Rod
Loosen any overly tight bushings so that the reel and pulleys roll freely. If not, the tests will not work properly.

Test to see if you can catch the fish
You may need more than one attempt. Try catching a fish and releasing it from the hook several times.

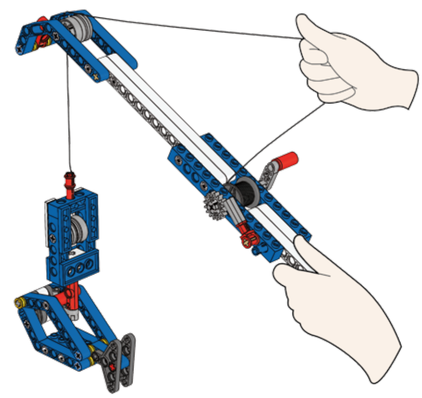




Contemplate

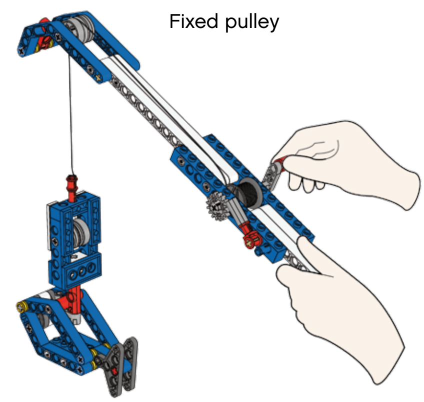
Why use a reel and ratchet?
Try first lifting the large fish by simply pulling on the line. Then, lift using the reel. What do you notice?
Try the pawl and ratchet safety system (book 2A, page 10, step 19).

What are the advantages?
The reel makes it easier to lift the fish.
But it is slower than pulling the line by hand.
The ratchet locks the reel if you stop winding.
This is a safety system.



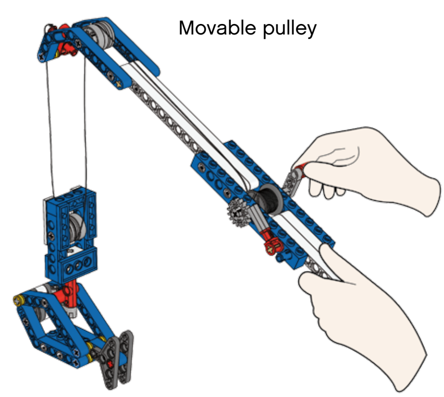
What difference does an extra pulley make?
Set up the Fishing Rod as illustrated here. Predict and test which effects this might have when landing fish?

It actually feels heavy. This is because the second pulley is not being used – it is a fixed pulley. Pulleys are dead weight unless they are properly connected!



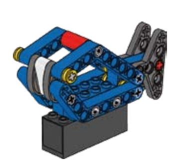
String up the pulley block as shown on page 11, step 20. Predict and test what effects this setup might have when landing the fish?

Even the heaviest fish is easier to lift. Using two pulleys – one fixed and one movable – means only half the effort is needed to lift the fish. But it is slower to reel in and you need to wind in twice as much line to reel in the fish.



Did you know?
Big cranes use this system to lift heavy loads with small motors. Some pulley systems, also called a block and tackle, use up to six or more pulley wheels!

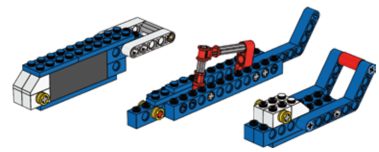
Add a load (the weight element) to the fish and test again with your Fishing Rod. Find out which is the easier way to land the heavy fish.



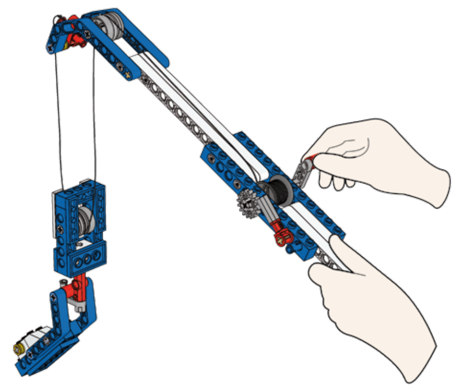
Did you know?
The weight element contains steel plates and weighs exactly 53 g!

Continue

Design and make your own Crazy Fishing Game
In the shortest possible time catch as many 'fish' as you can.
Build a variety of 'crazy fish' as shown. Invent more of your own. Maybe you can make them look more like real fish?



Hook them and see which are easy and which are more difficult to catch.



Agree on rules and a scoring system for your fish. Which designs would trigger a higher score if a fish is landed?

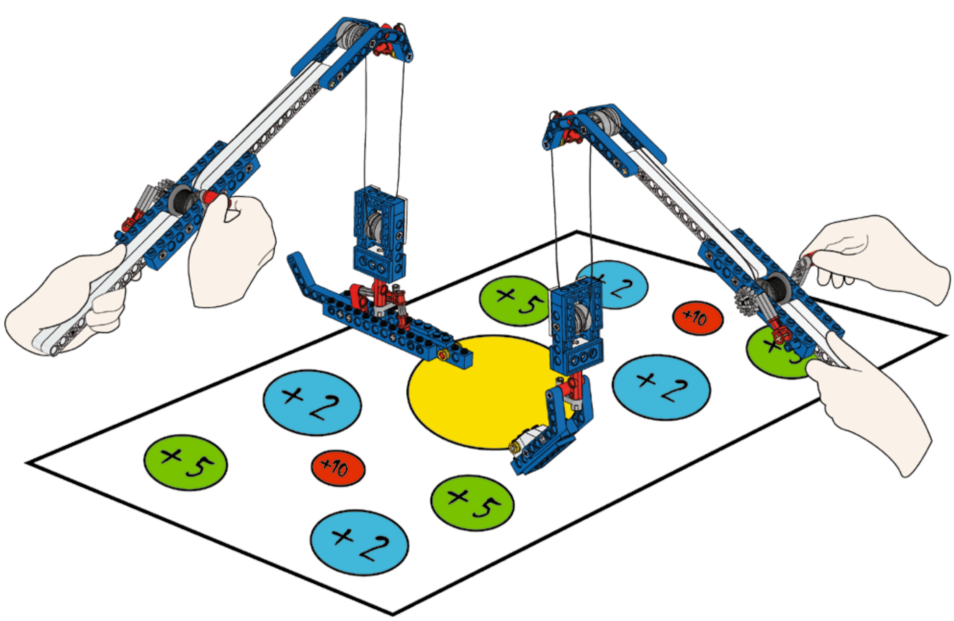
Play a timed game. What score did you get in 60 seconds?

Try again. How much did your score improve with each new attempt?

Extra challenge: Sorting Fish
Design a game board with different sized targets or 'baskets' in which to place the fish.

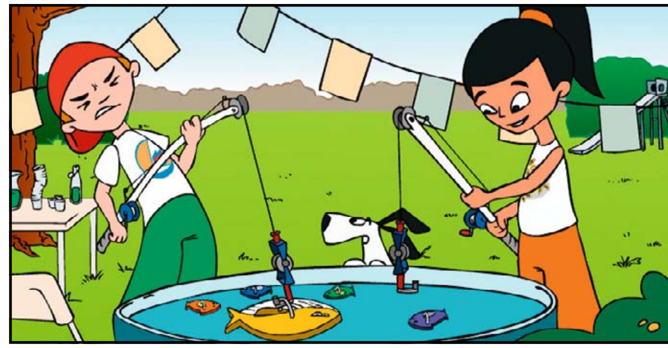
Work out additional scores for successfully landing a fish in a basket.

Ask another team to join in the great 'Fishing Game'.



Fishing Rod

Name(s):

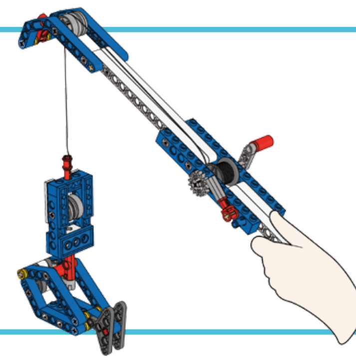


How can we make an exciting fishing device for Jack and Jill and land a big fish?
Let's find out!

Build the Fishing Rod (including pulley block) and fish

(all of book 2A and book 2B to page 10, step 19).

• Make sure the reel and pulleys spin as freely as possible.

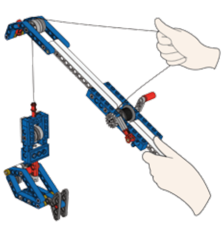


Which features of your rod make it easier to land a big fish?

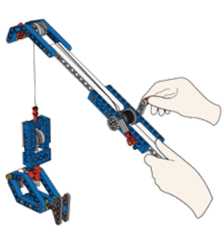
Predict and test:
• How much **effort** you need to lift the fish each time?
• How much **time** you need to lift each fish?
• Which is the **fastest** reel?
• Which is the **slowest** reel?
• Try using the ratchet.

Small effort
Very slow
Medium effort
Fast
Slow
Big effort

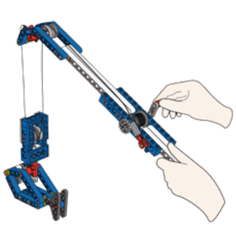
Tip: Write these words in the boxes.
You can use them more than once.



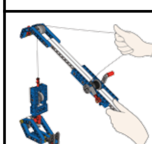
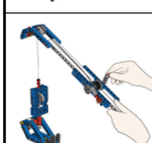
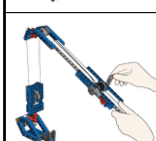
– by hand and with **one** fixed pulley



– with reel and **one** fixed pulley



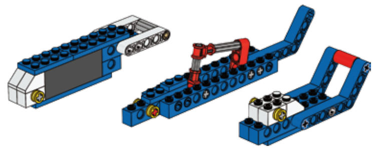
– with reel and **two** pulleys;
one fixed and one movable pulley

	My prediction	What happened?	Actual speed
			
			
			

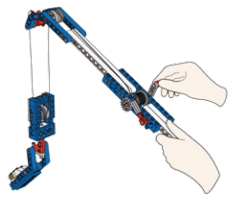
Block and Tackle
A block and tackle is a system of pulleys that is used to lift very heavy objects with a minimum of effort.

Design and make your own Crazy Fishing Game

Build a variety of ‘crazy fish’ as shown. Invent more fish of your own.



Hook them and see which are easy and which are more difficult to catch. Catch as many ‘fish’ as possible in the shortest time.



Agree on rules and a ‘scoring system’ for your catch. Which designs would trigger a higher score if a fish is landed?

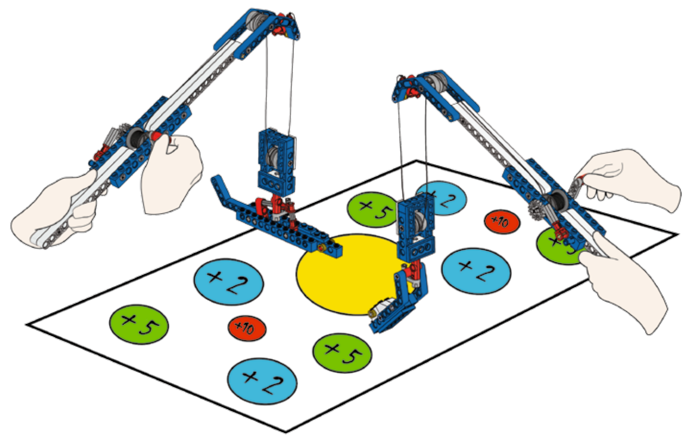
Play a game ‘against the clock’. What score did you get in 60 seconds in attempts 1, 2, and 3?

1	2	3

Extra challenge: Sorting Fish

Design a game board with different sized targets or “baskets” in which to place the fish.
Work out additional scores for successfully landing a fish in a basket.

Ask another team to join in the great ‘Fishing Game’.



My Fishing Rod

Draw and label your very best rod design.
Explain how the hook, crank, and pulleys work.

Freewheeling

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
- Kinetic energy
- Potenial energy

Other materials required
- 4 meters (≈ 4 yards) of smooth floor
- Masking tape
- Meter stick (yard stick) or measuring tape
- Plank of wood or shelf at least 1 meter (≈ 1 yard) 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.

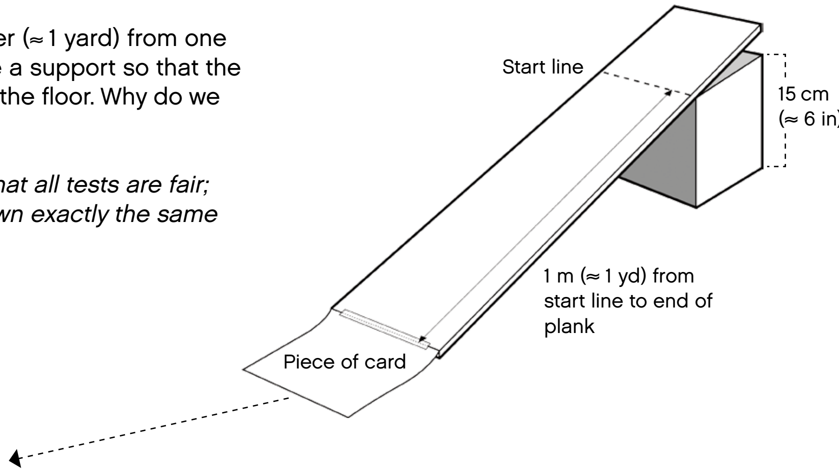
Jill says that if she puts some extra weight (Zog the Dog) on her cart, she will roll further because the cart is heavier. Jack thinks that because heavy loads are hard to move, he will go further. He prefers to go for bigger wheels, but Jill is not so sure this approach will help.

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

Construct

Make Launching Hill
Draw a start line, 1 meter (≈ 1 yard) 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 to ensure that all tests are fair; all carts should roll down exactly the same ramp.

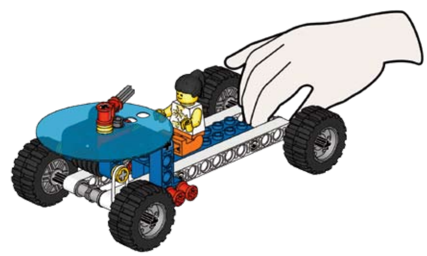


Approx. 4 m (4 yd)
of smooth floor

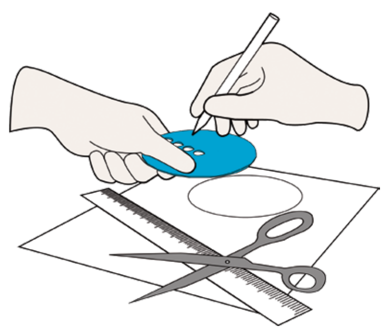
Tip:
If the thickness of the plank causes the carts to bump down from it onto the floor, use a piece of card to make a smooth transition from plank to floor.

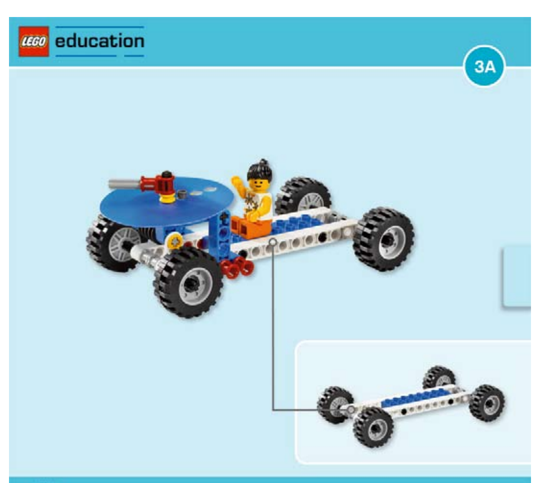
Build the Freewheeler
(All of book 3A and book 3B to page 6, step 12).

- 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
Or cut out paper copies of the dial discs if you want to keep the original discs untouched.

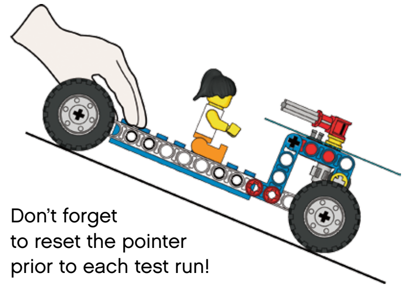




Contemplate

Measure how far the empty cart rolls. Measure with a meter stick (or a yard stick) and compare with the pointer and dial. Record the distance and use a LEGO® brick as a marker of where it stopped. Test at least three times to be sure you have made a scientifically correct answer.

An unloaded cart should roll about 160 cm (≈ 5.25 ft). This is more than once around the dial. The dial is accurate to within a few centimeters.

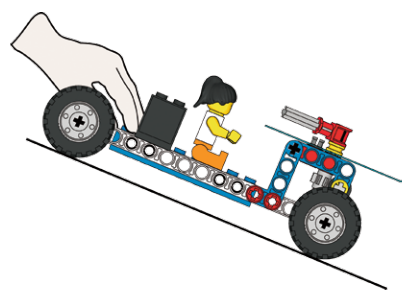


Don't forget to reset the pointer prior to each test run!

Tip:
Note that the dial measures almost exactly 1m (≈ 1yd) in one rotation. This means that the pointer is at zero when the cart hits the floor.

Trace the 1 m (≈ 1 yd) dial divisions on the plastic disc with an erasable whiteboard marker. Let the freewheeler go down the ramp again and see if it runs approximately 160 cm (≈ 5.25 ft) by looking at the dial 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 dial.

Add a weight brick to the cart (book 3B, 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.

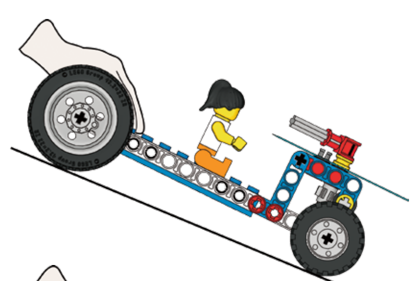
Did you know?
The empty cart weighs about 58 g (≈ 2 oz). And the weight brick weighs 53 g (≈ 1.9 oz)... almost the same!

What do you notice about the pointer?

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

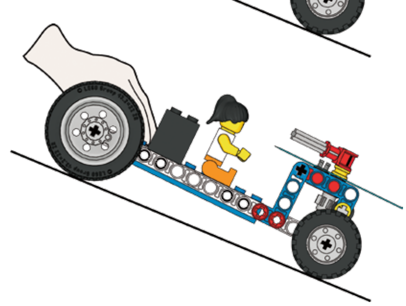
Test several times to make sure your findings are consistent.

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 (book 3B, page 7, step 14).



First test unloaded (book 3B page 7, step 14), then test loaded (book 3B, page 8, step 15).

Did you know?
The big wheels weigh 16 g (≈ 0.5 oz) each and the small ones only 6 g (≈ 0.2 oz) each.



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

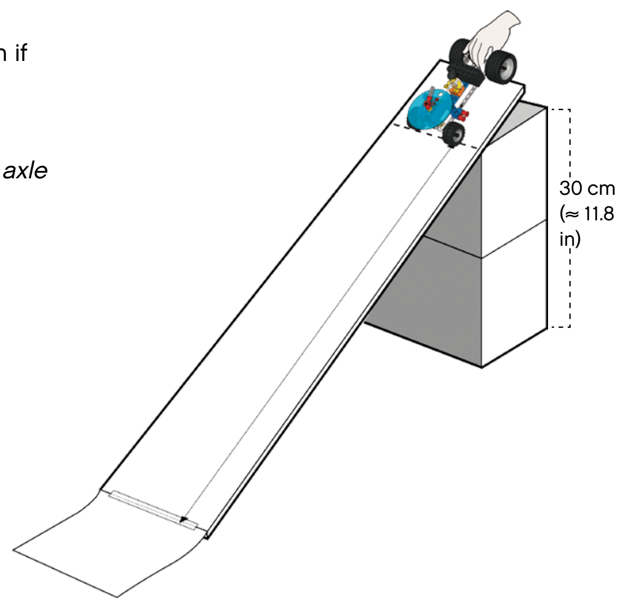
Continue

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.

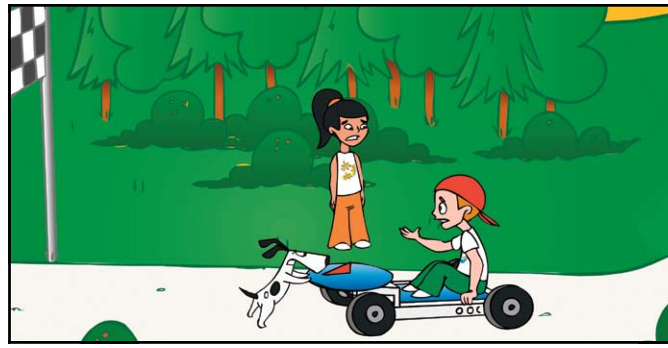
It rolls 3 meters (≈ 3 yards). The new gear wheel has 3 times as many teeth as the small one. The worm gear has to turn 3 times as often to get the 24-tooth gear wheel to turn once. Now you will need to calibrate the scale to measure distances accurately to 3 meters (≈ 3 yards).

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

You double the potential energy, double the moving energy, but do not double the axle friction.



Freewheeling



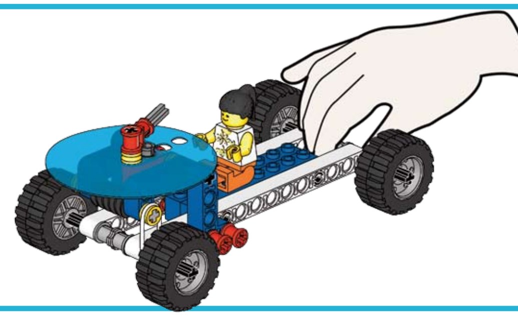
Name(s):

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

Build the Freewheeler

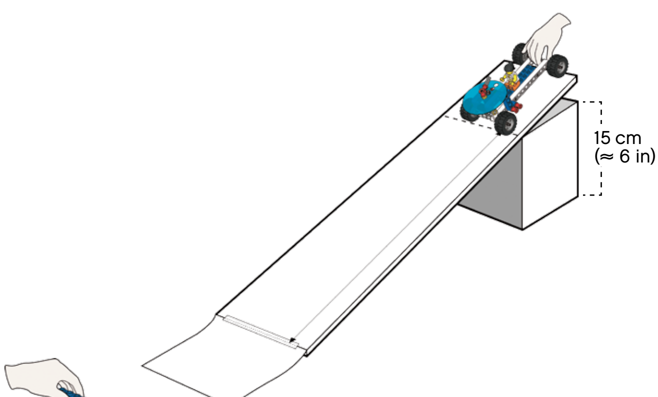
(All of book 3A and book 3B to page 6, step 12.)

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



Which will roll further ... heavy or light loads?

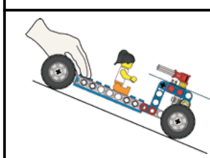
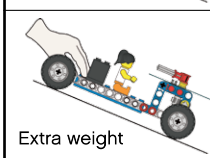
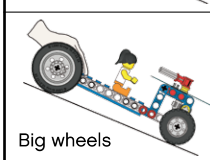
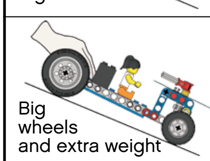
- Tip: Place a marker brick next to the track where you predict the cart will stop
- Reset the pointer on the dial after each test run



Are big wheels better than small?

- Try using big wheels on the back axle

Test accordingly, following the challenges below:

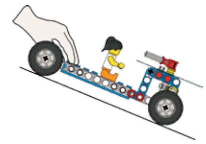
	My prediction	My measurements
		
 Extra weight		
 Big wheels		
 Big wheels and extra weight		
?		

Did you know?
The empty cart weighs about 58 g (≈ 2 oz). And the weight brick weighs 53 g (≈ 1.9 oz)... almost the same!
The big wheels weigh 16 g (≈ 0.5 oz) each and the small ones only 6 g (≈ 0.2 oz) each.

Larger scales ... and steeper hills

Build book 3B to page 12, step 12
Change the ramp position to be 30 cm (≈ 12in) high.
Test your different types of freewheelers.

What I found out when making the slope steeper:

	My prediction	My measurements
		

My Amazing Downhill Racer!

Draw your favourite freewheeler design.
Explain how the three best parts work.

The Hammer

Technology
- Using mechanisms – levers, cams, and inclined plane
- Properties of materials
- Product safety testing
- Combining materials
- Mechanical programming of actions

Science
- Recording data
- Friction
- Force
- Momentum
- Scientific investigation

Vocabulary
- Cams
- Sequencing
- Friction
- Product safety

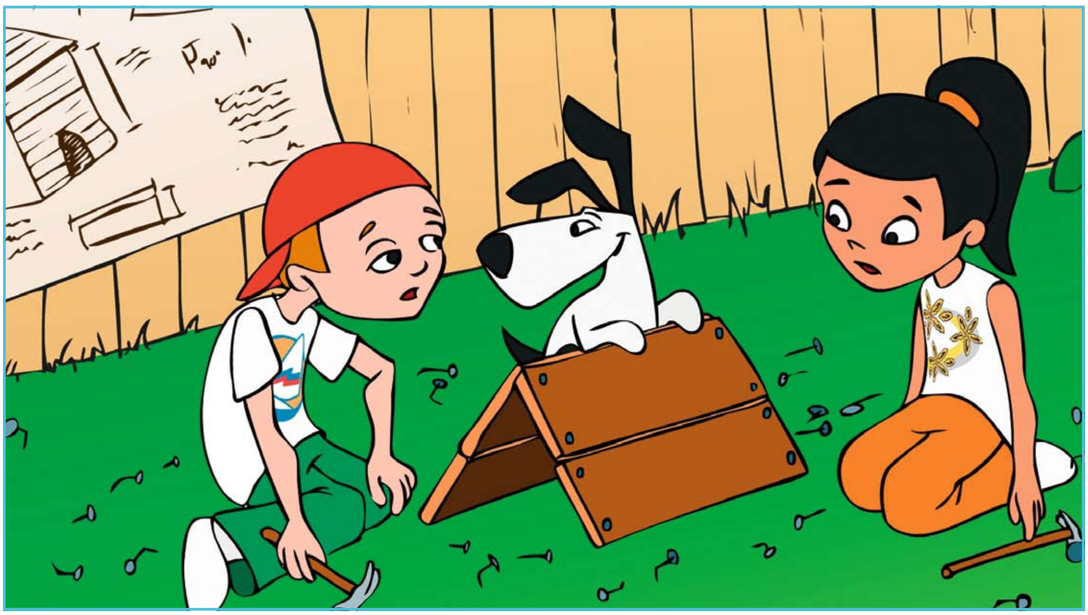
Other materials required
- Decorative materials: wool, foil, card
- Scissors
- Sticky tape

Connect

Jack and Jill are having fun hammering! They are trying to build a little shed for Zog the Dog, but the wood they are using is very hard and they need to use a lot of nails to make it hold.

After a while they are exhausted and try to think of simpler ways to hammer the nails into the wood. Two brains work better than one, they think, so together they try to solve the problem. Can you help them test a solution that will work and make the hammering much easier for them?

How can you make a hammer machine that will efficiently hammer nails into different surfaces? Let's find out!

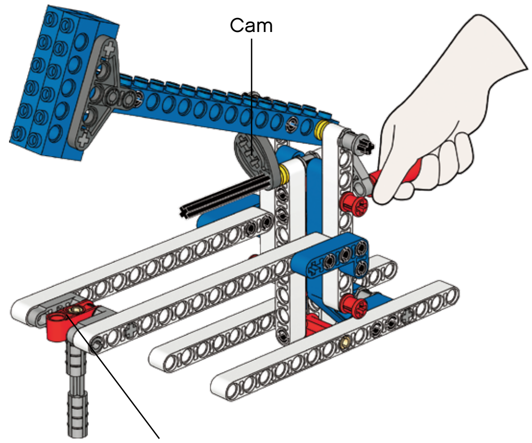


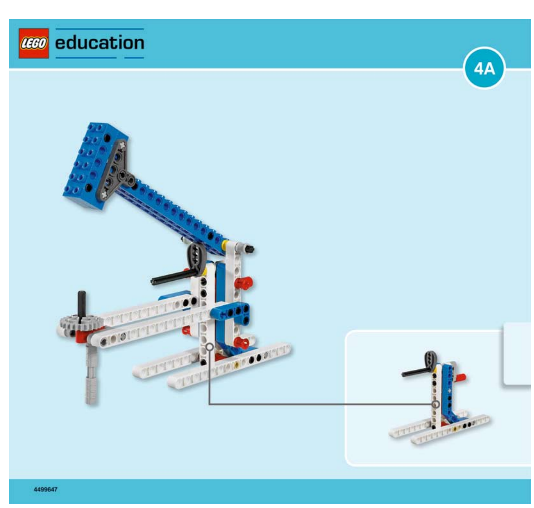
Construct

Build the Hammer
(All of book 4A and book 4B page 11, step 14).

Testing
Turn the handle of the hammer by hand.
Does it rise and fall smoothly?

If it feels stiff to turn, check that the axle bushings are not rubbing on the bricks and creating too much friction.

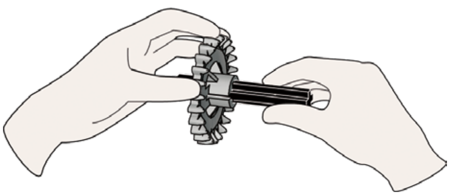


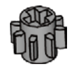


Did you know?
The LEGO® research labs make sure every element has exactly the right amount of grip for the job it does and for safe handling by children. We call it 'clutch power' and it is measured very carefully!

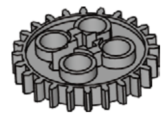
Contemplate

Can you measure grip forces by hand?
Push the axle into each gear in turn – and pull it all the way through. Can you arrange them in order from most grip (most friction) to least grip?

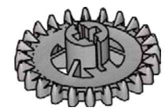




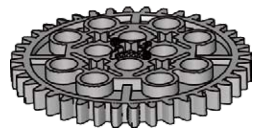
8-tooth
spur gear



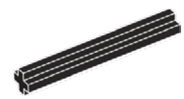
24-tooth
spur gear



24-tooth
crown gear



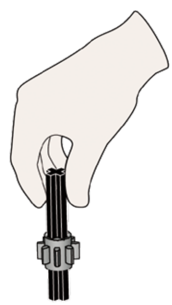
40-tooth
spur gear

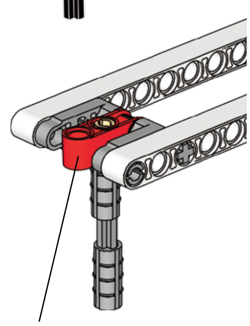


4-module axle
Black

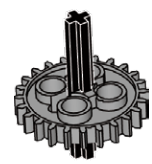
How can we measure the clutch power more accurately?
- Use the same size axle to test each gear
- Turn the handle to hammer the axle down
- Count how many hits until the axle touches the tabletop for each gear

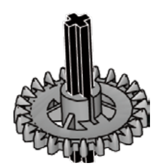
In our tests, the 8-tooth gear has the least amount of friction. It is so small it is hard for fingers to grip. The crown gear is next. Even though it is big enough to grip, it also has pointy teeth. The 24- and 40-tooth spur gears have most friction as they have blunt teeth, are easy to grip, and transmit the most power in a model.

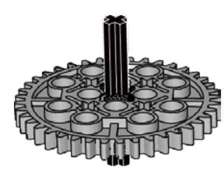




About 5 mm (≈ 0.2 in) to go into the hole of the anvil







Is the hammer a better test of axle friction than testing by feel?
If you hammer each gear several times, you will find very similar results each time. This hammer is a real scientific instrument and much better than guessing. The LEGO® labs have huge machines that do the same job, but much more accurately.

What else can the cam do?
On page 14, step 18, the modification makes it so that the hammer hits twice for each turn of the handle. Also change the axle position through the cam to make different actions and timings. Try making a slow rise and a fast drop, or a fast rise and a slow drop.

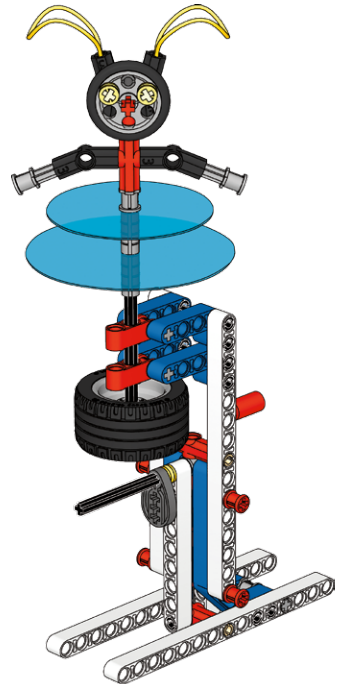
Optional: Using a heavier hammer
It will drive the axles through more quickly. You need to put in more energy to lift the hammer, but it drops with more force. It has more momentum. The smooth cam edge is an inclined plane, which make it easier to lift heavier weights.

Continue

Bouncing Ballerina!

- Build the ballerina in book 4B page 23, step 21
- Predict, then test what happens when you turn the handle

She rises, falls and turns at the same time.

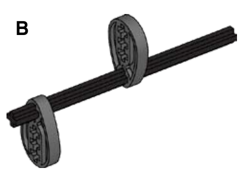


Did you know?
Cams work inside car engines, clocks, toys, sewing machines, and locks – in fact anywhere complex timed actions are required. Bring in clocks, toys, locks, and other things that contain cams. Disassemble them and see how cams move.

- Can you predict the 'dancing' action made by the cam shaft arrangements shown
- Now try them and see

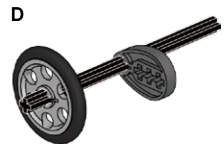
A

B



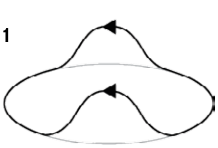
C

D

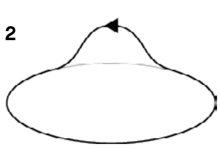


Note:
The wheel is in fact a round cam. It spins the dancer but does not lift her.

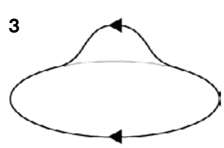
1



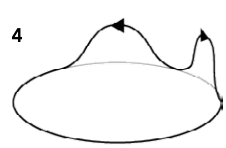
2



3



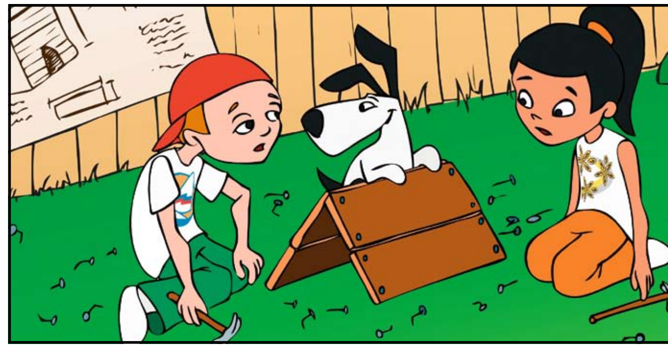
4



Answer: A2, B1, C4, D3.

Deco-rotate-her!
Add your own fun decorations. Make a card screen to hide the cams. Can anyone else work out your cam dance program just by watching her dance? Make her arms fly out as she pirouettes.

The Hammer



Name(s): ______________________________

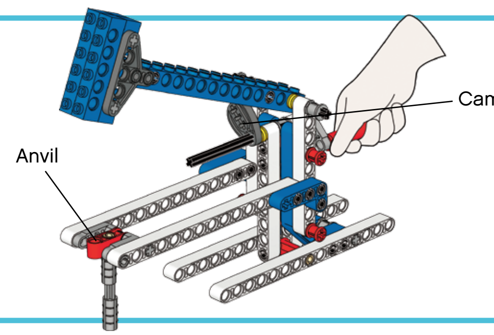
____

How can you make a hammer machine that makes it easy to hammer different nails into different surfaces? Let's find out!

Build the Hammer

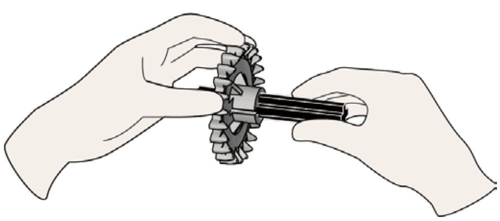
(All of book 4A and book 4B page 11, step 14.)

Make sure that the hammer lifts and drops smoothly.
If it is too stiff, loosen the bushings and make sure all other elements fit tightly together.

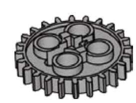
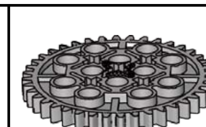


Which gears have the most friction when tested by hand?


4-module axle

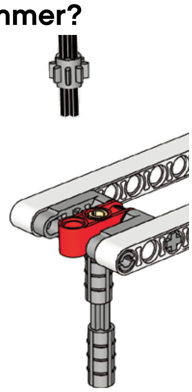


How much force is needed to push the axle through each gear?

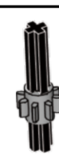
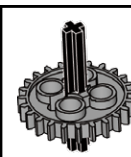
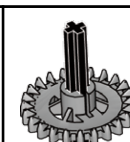
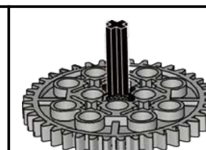
 8-tooth spur gear	 24 tooth	 24-tooth crown gear	 40-tooth spur gear

4 = most force, 1 = least force

Which gears have most the friction when tested by the hammer?



How many hits with the hammer are needed to push the axle through each gear?

 8 tooth	 24 tooth	 24-tooth crown gear	 40 tooth

Which is the better test system, and why? ______________________________

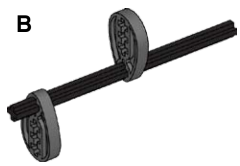
____

Ballerina

- Build the Ballerina, from book 4B to page 23, step 21
- Try out these cam shaft designs (dance program)
- Connect each cam shaft with one of the 4 ‘dance diagrams’

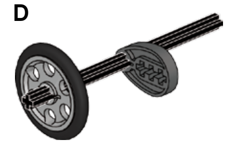
A

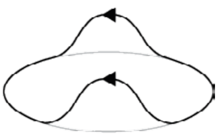
B



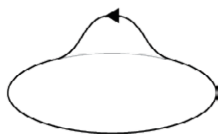
C

D

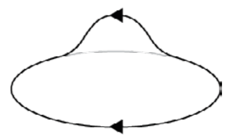




Dance diagram 1



Dance diagram 2



Dance diagram 3

Dance diagram 4

Also try:

- Amazing decorations
- Hiding your cams – can anyone guess your dance program
- Making the ballerina’s arms wave
- Making your own cam profiles

My Moving Sculpture

Draw and label your favourite moving sculpture or animated toy that uses cams. Explain how the best three parts work.

Trundle Wheel

Technology
- Using mechanisms – gear ratios, gearing down
- Assembling components
- Combining materials

Science
- Measuring distance
- Calibrating scales
- Scientific investigations

Vocabulary
- Calibrating
- Scales
- Gearing down
- Errors
- Accuracy

Other materials required
- Ruler
- Three straight-edged objects less than 1 m (≈ 1 yd) long
- Space on a smooth floor to safely carry out a long jump
- Whiteboard markers

Connect

Jack and Jill are in the park preparing for the school sports day. Their favorite sport is the long jump. Jack has just made a huge jump. He is all excited and wants to know how long his jump is.

Jill has not got a ruler long enough to measure the distance so she is doing it in footsteps. Zog the Dog feels that he is much better at jumping so he is trying too.

Jill says that Jack's jump was 58 cm (≈ 22.8 in).

Jill takes her turn on the long jump. She says her jump was 4 meters (≈ 4 yards), so Jack thinks she is just guessing ... and not very well, either!

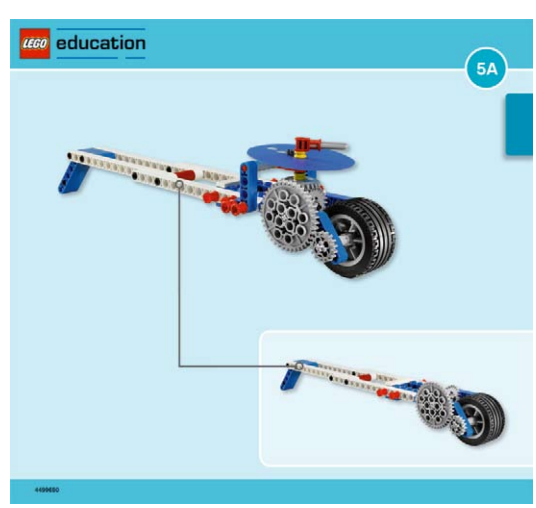
They need some sort of device that can measure a long jump properly.

What sort of measuring machine can you invent that could measure a long jump? Let's find out!

Construct

Build the trundle wheel
(All of book 5A and book 5B to page 6, step 11.)

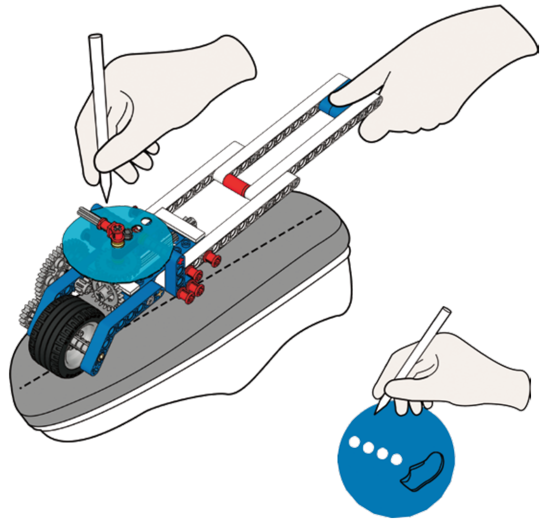
- If using whiteboard markers, you can write directly on the blank plastic dial disc. Otherwise trace around the disc to create your own copy
- Make sure that the pointer moves smoothly as you push the trundle wheel. If it is stiff, loosen overly tight axle bushings and make sure all other elements are firmly pressed together
- What is this measuring device good at measuring? Ask the students for ideas and draw up a list
- Measure all sort of lengths, such as your arm, hand, and leg to get a feel for measuring



Contemplate

Stepping out: Making a Foot Wheeler
How many "feet" fit on the scale?
Measure your shoe – several times! Mark zero and then add a new mark to the dial each time you reach the end of your shoe until you've been around the scale (you probably won't get a whole number of shoes).

This is calibrating the scale in units of "shoe".

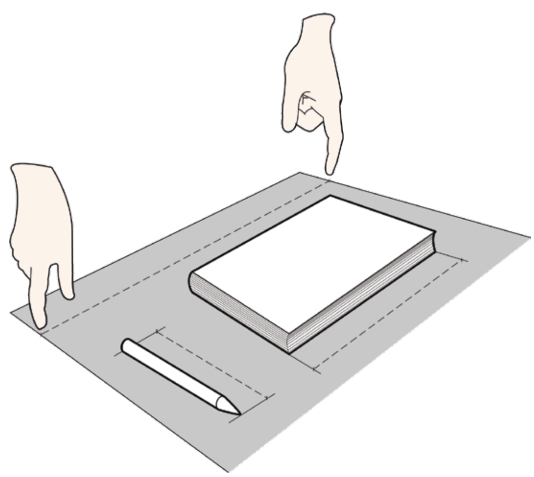


Predict
How many shoes wide is your desk! First use your foot wheeler to measure it! Then take off your shoe and measure it with your shoe. How accurate was your foot wheeler?

What are the problems of measuring in shoe lengths?

People's feet are not always the same size! This is why we usually select a standard unit of measurements, such as the metric system or US customary system.

Meter Magic Trundle: is it better than a ruler?
Collect three items that you believe are less than
1 meter (≈ 1 yard) long.
- Predict how long each is
- Measure with the trundle wheel
- Measure with a ruler
- What did you discover?



Rulers are the most accurate, usually followed closely by the trundle wheel, and then predictions. What trundle wheels are really good at is quickly measuring things that are longer than a normal ruler.

But what happens for distances over 1 m (≈ 1 yd)? What happens with your perfect long jump?

If you measure 1.5 m (≈ 1.5 yd), the pointer shows 50 cm (≈ 19.6 in)! The pointer has been around once and is starting again. This may be a problem: you need to remember how many times the pointer passes the zero marker.

Note:
Learn how to reset the pointer after each measurement

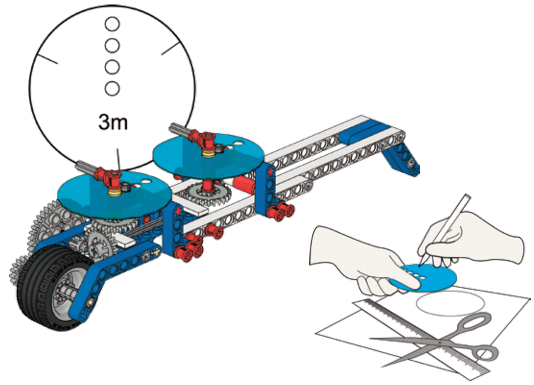
Note:
The accuracy of our scale depends on how much pressure the children place on the tire. Light pressure is ideal. Try it and see.

Continue

How can we use the trundle wheel to measure long jumps of more than 1 m (≈ 1 yd)?
What might happen if we add another dial with a pointer that moves much slower than the first dial?

It should measure more than 1 meter (≈ 1 yard).

Build the model to page 12, step 11.
Trace and cut out the 3 m (≈ 3 yds) dial in paper if you want to keep your dials. Wheel it further than 1 m (≈ 1 yd). Practice reading both scales for extra accuracy.



Gear facts
The two pointers are connected via an 8-tooth and a 24-tooth gear. This gears down the speed of the second pointer three times, allowing one dial to now cover 3 m (≈ 3 yds).

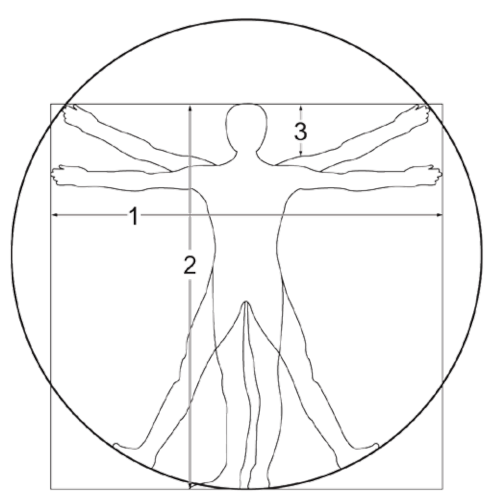
Now it's time to start jumping!

- Students should practice their long jump skills, though obviously conditions in the classroom have to be taken into consideration and safety comes first. One possibility is to go outside and practice jumps on a lawn, another is to use a standing long jump
- Predict how far you'll jump. Then use the trundle wheel to measure the result. You could also try measuring with a ruler. What did you discover?

It is much easier to use the trundle wheel. It measures up to 3 m (≈ 3 yds) in one go. But you must read two dials for the most accuracy. By comparison, you need to move the ruler a lot and add up the amounts in your head. And every time you move the ruler there's a chance that an error might occur.

Leonardo's magic body facts
What does Leonardo da Vinci's famous symbol mean?
Try measuring all the distances shown.
See if you can spot any 'patterns'.
If another person tells you her height, can you tell how long her arm span will be – or how long her head will be?

Often arm span (1) and height (2) are the same. The head (3) is often 1/6th of a person's full height. These are handy rules to know when drawing people. What about legs and arms?



Idea:
The wonderful thing about a trundle as opposed to a ruler is also that it is great at measuring around curves. Estimate your head and waist size – then measure and be amazed.

Note:
You may need to measure with the person standing against a wall and running the trundle wheel up the wall beside them.

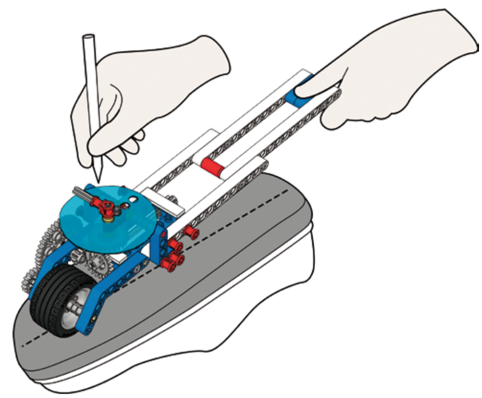
Trundle Wheel

Name(s):

What sort of machine can you invent that could measure a long jump?
Let's find out!

Build the Trundle Wheel

(All of book 5A and book 5B to page 6, step 11.)



How many shoes wide is your desk?

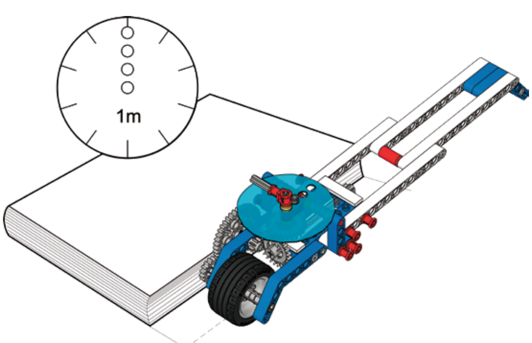
My answer:

How many shoe lengths will fit on your dial?

My answer:

Measuring objects

- Collect three more objects shorter than 1 m (≈ *1 yd)*
- Estimate the length of each
- Measure with the trundle wheel
- Measure with a ruler



	My estimate	My trundle reading	My ruler reading
Pen	cm (≈ in)	cm (≈ in)	cm (≈ in)
Pencilcase	cm (≈ in)	cm (≈ in)	cm (≈ in)
	cm (≈ in)	cm (≈ in)	cm (≈ in)
	cm (≈ in)	cm (≈ in)	cm (≈ in)
	cm (≈ in)	cm (≈ in)	cm (≈ in)

Doing the long jump!

- Build your model to page 12, step 11
- Add the 3 m (≈ 3 yds) dial to the trundle wheel
- Predict and then measure your long jump
- Do this three times

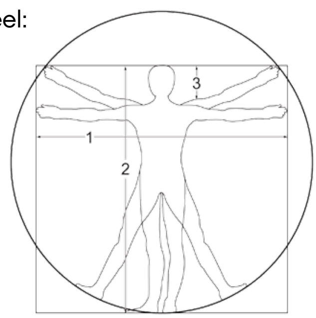
	My prediction	My measurements
Jump 1	cm (≈ in)	cm (≈ in)
Jump 2	cm (≈ in)	cm (≈ in)
Jump 3	cm (≈ in)	cm (≈ in)

In what ways is a trundle wheel better than a ruler?

My answer:

Leonardo's Magic Body Facts

Leonardo's Wheel:



	My estimate	My trundle reading
Arm span (1)	cm (≈ in)	cm (≈ in)
Height (2)	cm (≈ in)	cm (≈ in)
Head (3)	cm (≈ in)	cm (≈ in)

My Amazing Trundle Machine!

Draw and label your creative design for measuring distances.
Explain how the three best parts of your amazing machine work.

Letter Balance

Technology
- Using mechanisms – levers and gears
- Combining materials and components
- Testing before making improvements

Science
- Measuring weight
- Calibrating scales
- Scientific investigation

Vocabulary
- Efficiency
- Balance
- Accuracy
- Calibrate
- Scale
- Resetting
- Net weight

Other materials required
- Whiteboard markers for tracing the scale
- Scissors, markers or pencils, old envelopes, paper and sticky tape to make some letters and stamps
- A collection of small objects less than 150 g to weigh
- A small bag of identical coins
- Light plastic cup
- Measuring jug
- Water

Connect

Jack and Jill have set up a post office and delivery service at their school. They have a plan to write letters and send them to all their friends at school.

To make everything as real as possible, Jill has designed some very spectacular stamps and she is having fun weighing all the letters and finding out what stamps to put on.

Jack is also thinking of using the new post office to send a big parcel to Granny – it is her birthday soon. He wraps it up and wants to find out about stamps for the parcel but ... it looks like the letter weight can't deal with such a heavy object.

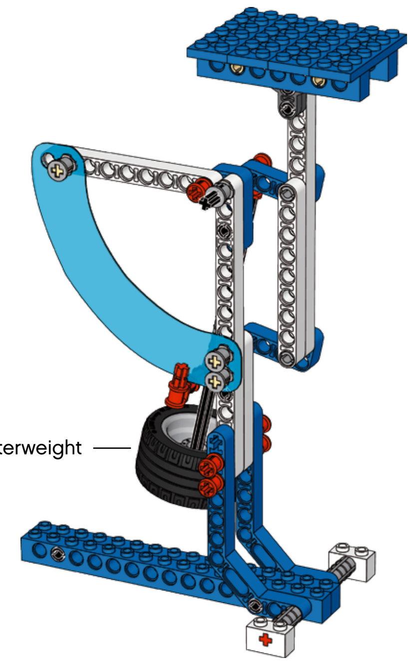
How will Jack and Jill solve this problem so they can be sure what stamps to put on for Granny's birthday present to be sent off?

How can Jill work out a fair system that differentiates between the weight of the different letters and parcels her classmates are bringing to her?
Let's find out!

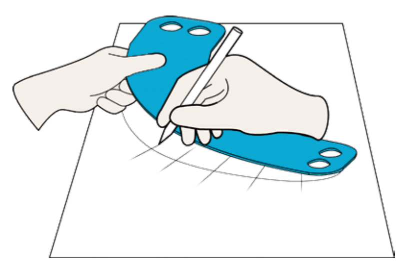
Construct

Build the Letter Balance
(all of book 6A and book 6B to page 11, step 20).

Fine-tuning the balance
The arm should swing freely and should return to the same spot each time. If it 'sticks' make sure the axle bushings are not too tight. Slide the counterweight up or down the axle so the pointer stops at zero on the scale.



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



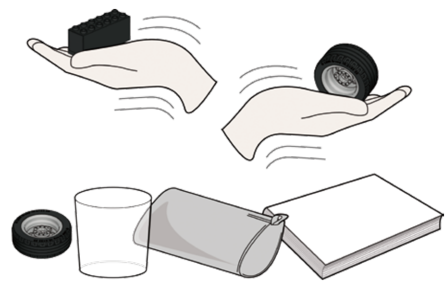
Tip:
To be accurate, Letter Balances require careful adjustment.
Make sure your LEGO® Letter Balance is always correctly adjusted.

Did you know?
Although it is a rather complicated one, the Letter Balance is in fact a first-class lever.

The letter becomes the effort trying to lift the load of the counterweight. Can you locate the main fulcrum or pivot point?

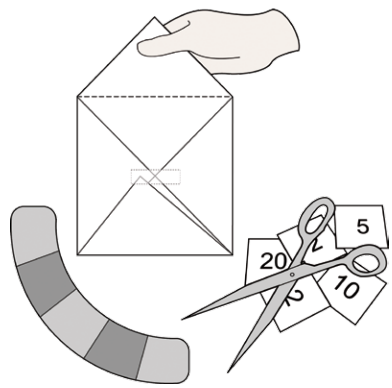
Contemplate

Hand versus Machine
Line up a collection of 5 objects in the order you think is from lightest to heaviest. Include the big wheel with tyre (16 g) and the weight brick (53 g). Record your estimated weights. Then weigh them. How close were your estimates? Did you get them in the right order?



Tip:
Usually we are better at estimating heavier weights.
The machine is nearly always more accurate than us.

School post office
A daily or weekly postal service in school run by children is a wonderful activity, so give it a try! Make your own envelopes, letters and packages. Design your own stamps and start weighing.

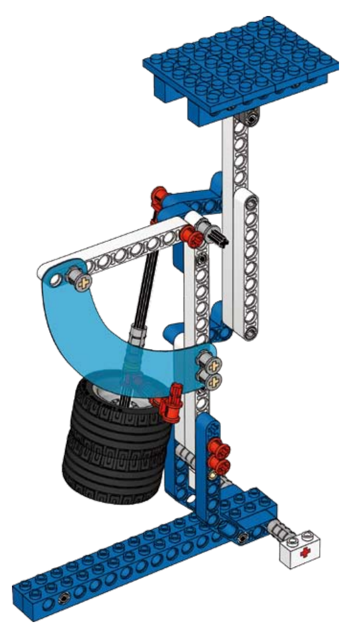


Tip:
Slide the counterweight high up the axle.
You may need to move the pointer too. This will make lighter objects such as letters move the arm to a greater extent across the scale. BUT you will need to calibrate a new blank scale in euro cents ... pence ... or 'stamps'.

Heavyweights
How can we weigh packages over 150 g?
Ask the class for ideas, and make a list.

Build model to page 11, step 21 by adding a second wheel to the counterweight axle. Now you will need to calibrate another new blank scale or redo the blue plastic scale.

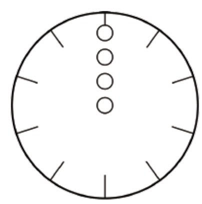
Find heavier things to weigh.
Can you find 2 different things/items that weigh approximately the same?



Continue

Money Bags
Let's find out: Is there a quick way to count lots of the same coins?
Build the final model with the rotating pointer page 16, step 12.

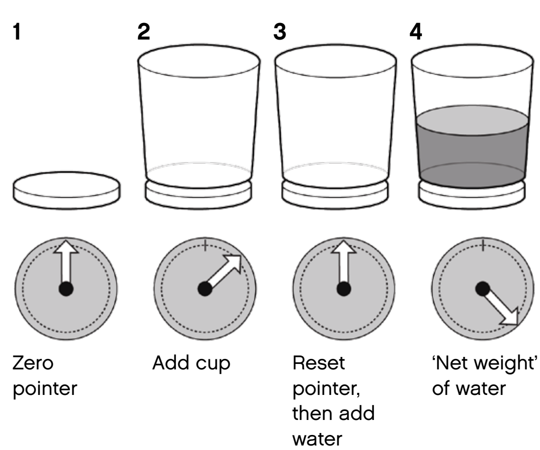
Start with a blank scale. Weigh 5, 10, and then 20 of the coins marking their positions on the scale. Work out the rest of the scale in pounds or euro, etc.
Now test it with a 'bag of money' or just a small pile!



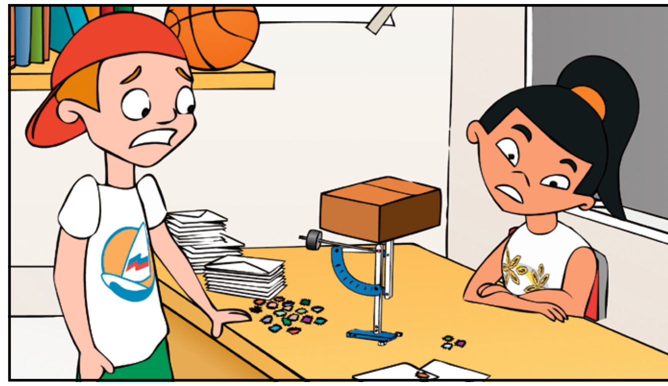
Smart Balance
Let's find out: What if we want to weigh how much fluid there is in a cup or the weight of chocolates in a box ... or coins in a piggy bank – but not their containers?
Ask for suggestions to see if the children can develop the idea of moving the pointer back to zero.

We have to subtract the weight of the container first

1. Trace or cut out a copy of the calibrated circular scale and attach it to the model scale and reset the pointer.
2. Place a plastic cup on the balance tray.
3. Move the pointer back to zero. Measure 100 ml of water in a measuring jug.
4. Add it to the cup ... it should weigh 100 g! Resetting the pointer means that the weight of the container is subtracted. This way we measure the net weight (the weight of the contents only).



Letter Balance



Name(s): ______________________

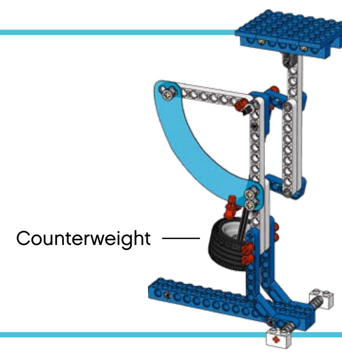
____

How can Jill work out a fair system that differentiates between the weight of the different letters her classmates are bringing to her? Let's find out!

Build the Letter Balance

(all of book 6A and book 6B to page 11, step 20).

- The arm should swing freely. If not, loosen axle bushings and make sure other parts are pressed firmly together
- Slide the counterweight along its axle to reset the pointer



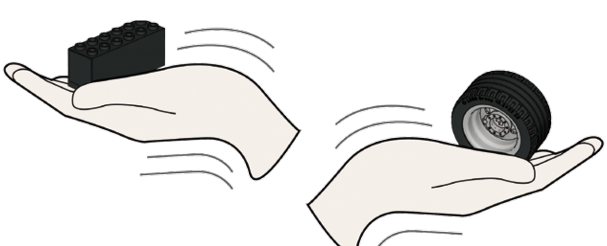
Hand versus Machine: Which is best?

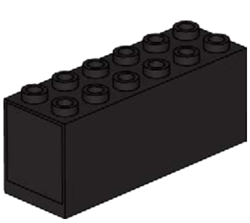
- Line up 5 objects from lightest to heaviest
- Write them down in the table
- Estimate their weights first
- Then weigh them all

	My objects	My estimate	My measurement
1		g	g
2		g	g
3		g	g
4		g	g
5		g	g

Idea:

When you are estimating, try holding one of these known weights in your other hand!





53 g

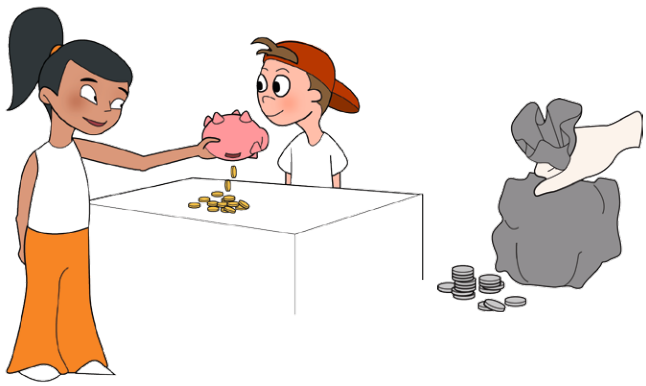
16 g

Tip:
Usually we are better at estimating heavier weights.
The machine is nearly always more accurate than us.

Tip:
Slide the counterweight high up the axle. You may need to move the pointer, too. This will make lighter objects such as letters move the arm to a greater extent across the scale, but you will need to calibrate a new blank scale in cents or 'stamps'.

Money Bags

Build book 6B to page 16, step 12 with a blank scale.
- Weigh 5, 10 and 20 of the same sort of coins
- Mark your scale in 'money'
- Guess and then weigh with the scale how much money is in a secret 'money bag'
- Count out the coins – how close were you?



My guess	My measure	My count

My Awesome Weighing Machine

Draw and label your design for a weighing machine.
Explain how the best 3 bits work.

Click-Clock

Technology
- Combining materials and components
- Using mechanisms – gears
- Testing before making improvements

Science
- Measuring time
- Calibrating scales
- Investigating momentum
- Energy
- Scientific investigation

Vocabulary
- Pendulum
- Accuracy
- Calibrate
- Scale
- Energy

Other materials required
- Stopwatch or timer

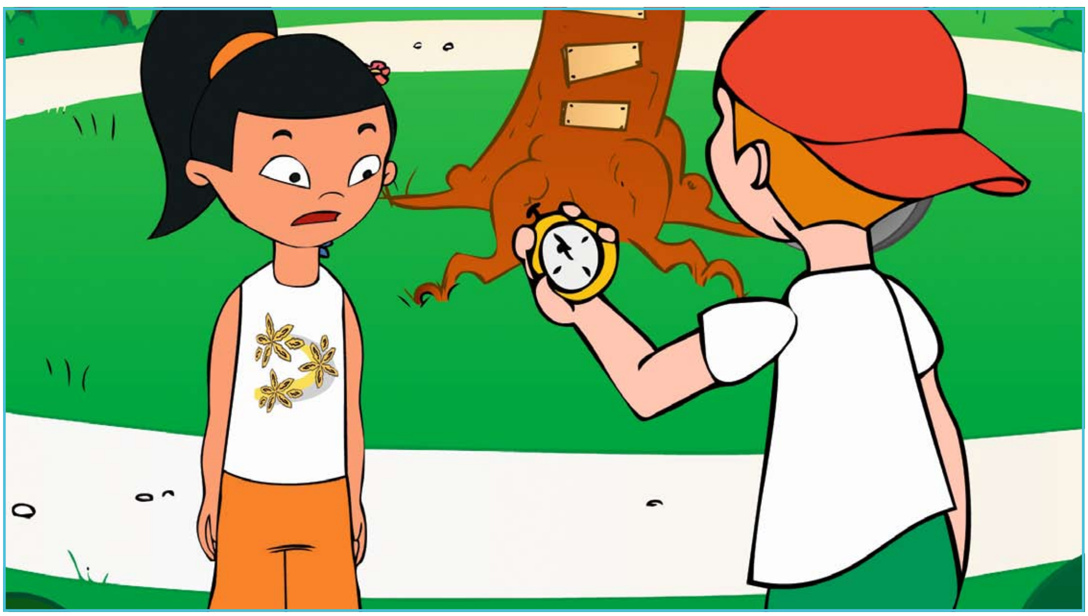
Connect

Jack and Jill have been watching the Olympics on the TV and have become quite keen on finding out what it takes to beat Olympic records. They go out in the garden and decide to race 3 times around the old oak tree on the lawn.

Jill is the first to go and Jack says: “Ready, Set, Go!” He presses the stopwatch in his hand at the exact time of saying “Go”! Unfortunately, in his excitement, Jack presses too hard and the stopwatch breaks.

How are they now going to time the race around the oak tree?

How can we make a timer that can help us time races?
Let’s find out!

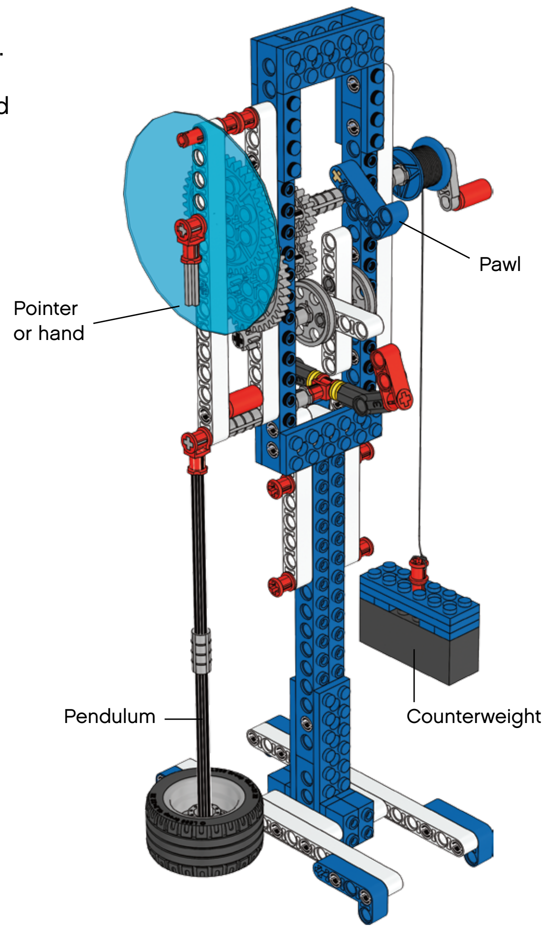


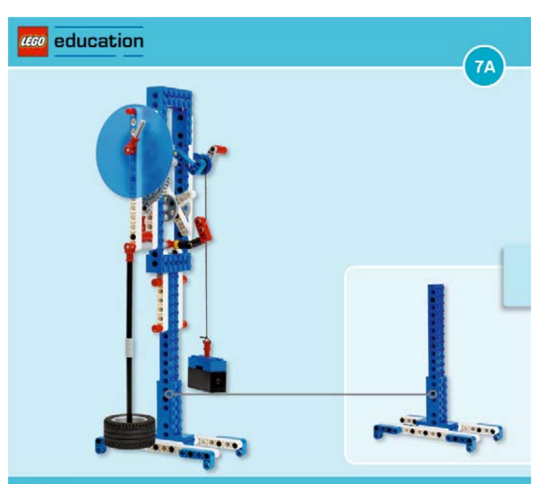
Construct

Build the Click-Clock
(All of book 7A and book 7B to page 17, step 26).

Release the pawl stopping the top axle, extend the gear wheels and use the handle to wind up the counterweight. Reposition the gear wheels, reset the pawl and start the pendulum swinging.

What happens?
The Click-Clock starts to tick.



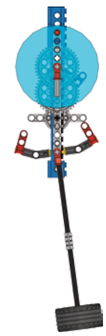


Contemplate

Making time go slower or faster!
First predict, then test.

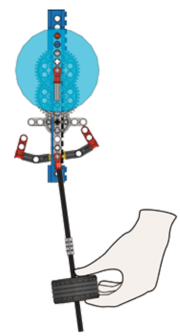
A. Make sure the big wheel is at it's lowest position. How many seconds does it take for the pointer to go around the dial once?

It takes approximately 70 seconds.



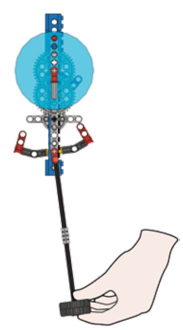
B. Slide the big wheel high up on the axle, set the pendulum swinging, and try timing it again.

The clock ticks even faster. The pointer rotates in approximately 55 seconds.

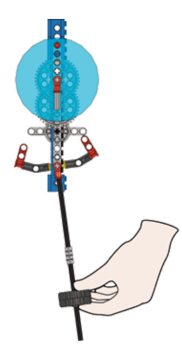


C. Change the pendulum to a small wheel as shown on page 18, step 27. How many seconds does it now take for the pointer to go around the dial once?

It takes approximately 56 seconds.
It is faster than the same position with a big wheel because a small wheel weighs less and needs less energy to make the pendulum move back and forth.



Calibrating to 1 minute
It is possible to calibrate to almost 1 minute. Move the small wheel up and down the pendulum until you find a position where the pointer goes around the dial in approximately 60 seconds.



Tip:
You can get close to 1 minute by positioning the wheel approximately 3 cm (approximately 1.18 in.) up the pendulum.

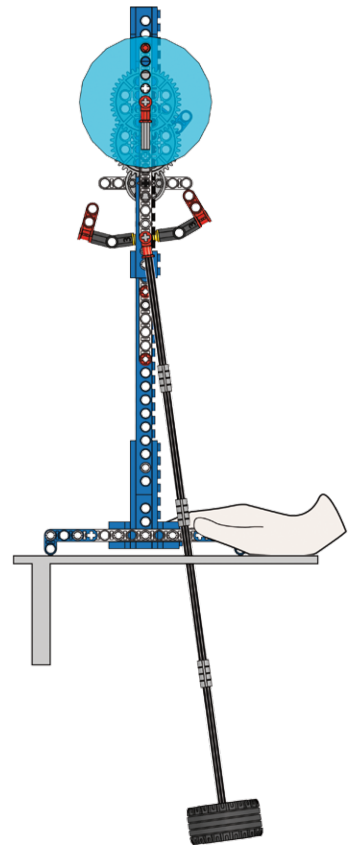
Continue

Long Pendulum
Build book 7B to page 20, step 3.

How about finding out what happens when the pendulum is made much longer?

Place the Click-Clock at the edge of a table.
Hold the base to keep it steady.
What happens?

The Click-Clock runs much slower.
The pendulum swings more slowly which means that you can now time much more than a minute because a longer and heavier pendulum needs more energy and takes more time to swing back and forth.



Click-Clock

Name(s): ______________________________

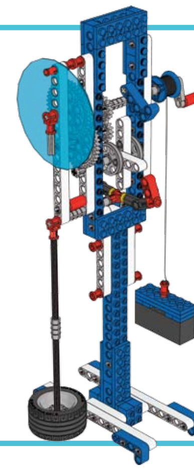
____

How can we make a timer that can help us time races?
Let's find out!

Build the Click-Clock

(all of book 7A and book 7B to page 17, step 26).

Wind it up and start it ticking by swinging the pendulum.



Making time go slower or faster!

Predict first, then test following the challenges in the table.

How many seconds does it take for the pointer to go around the dial once in models A, B and C?

	My prediction	My measurements
A 	seconds	seconds
B 	seconds	seconds
C 	seconds	seconds

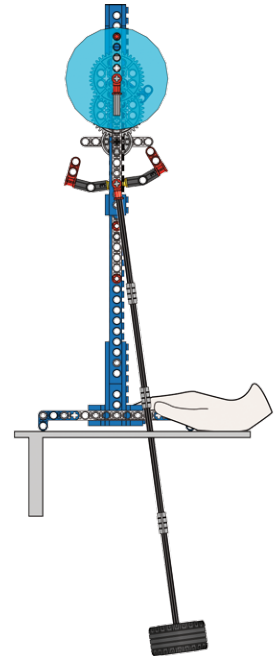
Tip:
You can get close to one minute by positioning the wheel approximately 3 cm up the pendulum.

Long Pendulum

Build book 7B to page 20, step 3.

Place the Click-Clock at the edge of a table.
Hold the base to keep it steady.
What happens?

My answer:



My Shock-O'clock:

Draw your best design for a timer and possibly an idea about how to trigger a funny sound after one minute.
Explain how the 3 best bits of your Shock O'clock work.

Windmill

Technology
- Using mechanisms – gearing up and down
- Designing and making
- Combining materials
- Ratchets
- Safety and control systems

Science
- Forces and motion
- Renewable energy
- Measuring weight
- Measuring time
- Force
- Area
- Fair testing
- Energy capture, storage and use
- Scientific investigations

Vocabulary
- Renewable energy
- Force
- Area
- Weight
- Angle
- Shape
- Gearing down
- Efficiency

Other materials required
- Wind or desk fan
- Brass weights or play dough
- Stopwatch or other form of timer with a second hand
- Optional: card and scissors to make own sails for the windmill

Connect

Jack and Jill have found a huge but heavy treasure chest buried near an old mine. It is really heavy and though they try as hard as they can, they can't pull it out of the hole.

The old windmill nearby once used to lift water out of the mine and they are wondering if it can be of any help to them.

Zog the Dog has done a very good job helping them to dig out the treasure chest so he is pretty tired too. He walks away from Jack and Jill to rest a bit and suddenly finds a long piece of rope. He runs back to the two kids to suggest that they take him for a walk on his new "leash".

Jack has once seen a film where a mill was used to lift up something and seeing the rope he immediately tells Jill about his idea. Now they know they can figure out how to get the treasure out of the hole!

How can you use a windmill and a rope to lift a heavy load?
Let's find out!

Construct

Warning!
Fans are potentially dangerous. Make sure that children handle them with great care!

Build the windmill
(All of book 8A and book 8B to page 12, step 17.)

- Spin the mill by hand. Is it running smoothly?

- If it feels stiff to turn, loosen the axle bushings and make sure all other elements fit tightly together

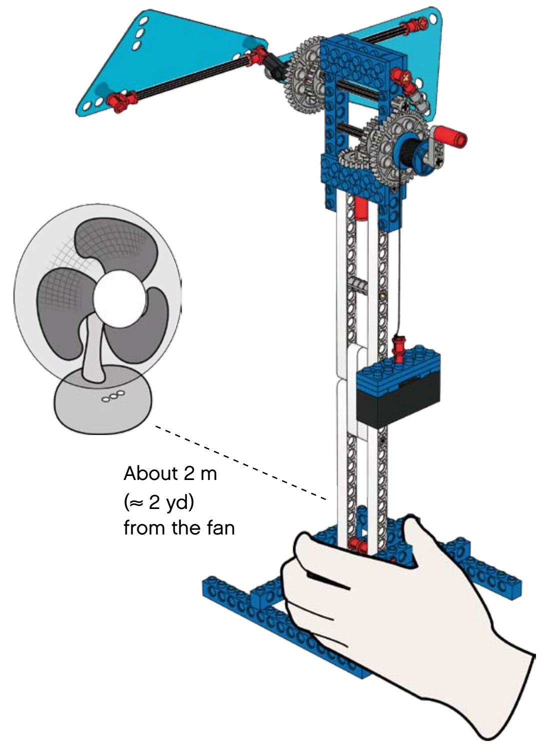
Setting up the windmill
- Position the fan on the floor near a power outlet

- Place the model about 2 m (≈ 2 yd) away

- Choose a power setting, and move the model back and forth to find a distance where the wind speed is just enough to lift the weight brick, slowly

- KEEP THIS POWER SETTING FOR ALL TESTS (until you want to test the effects of different wind speeds, of course)

- Make a long line (e.g. with tape) in front of the windmill. This is the test zone (where it is safe), and behind the line several groups can test several mills at the same time.
  Check that all the windmills are getting the same amount of wind

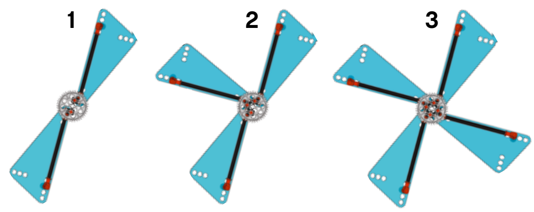


Contemplate

What is the best number of sails to use?
Predict and test which combination will lift up the treasure chest (weight brick) most quickly. Can you explain why?

Example 3 is best. It has the most area in which to catch the wind energy.

Surprise!
Example 2 with the sails off-center is usually the worst. It is too unbalanced to work efficiently even though it has more area than Example 1 with just two sails.

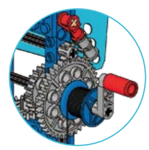


Idea:
Does shape matter?
If you have time, try making sails of different shaped pieces of card, but with the same area as that used in your models.

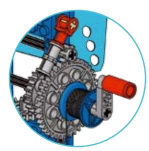
Note:
Each sail has an area of approx. 40 cm (≈ 15.7 in)^2.

What does the ratchet do when:

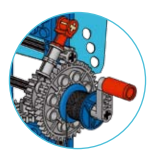
- The load is being lifted up and the wind stops?
  The mill stops but the ratchet stops the heavy load from falling — a good safety feature.



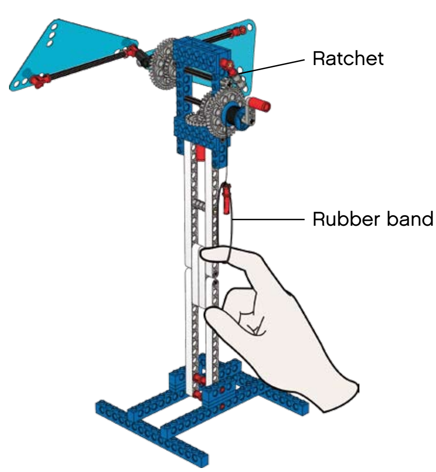
- The wind is blowing and you flip the ratchet to this position?
  The mill stalls. The forces are opposite.



- The load is up, the wind stops, and you flip the ratchet to this position?
  It will become a fan powered by the energy stored in the falling load. You get the wind back again!



Rubber Band Force Meter
Tie a rubber band to the lifting string or use a spring balance to measure the lifting force before the mill stalls. Measure how much it stretches. You'll be amazed by the power generated!

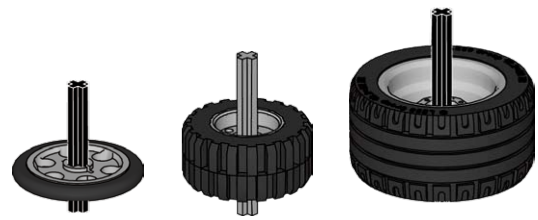


Continue

In a Spin!
How can we store and use energy later?

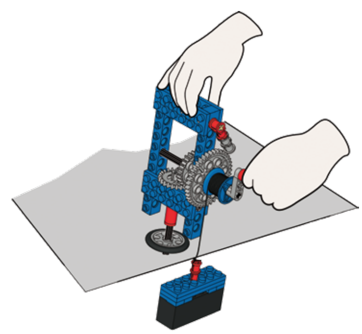
In this exercise we are actually cranking the weight up by hand. You can do it using wind power too, of course, if you then take off the sails before releasing the top.

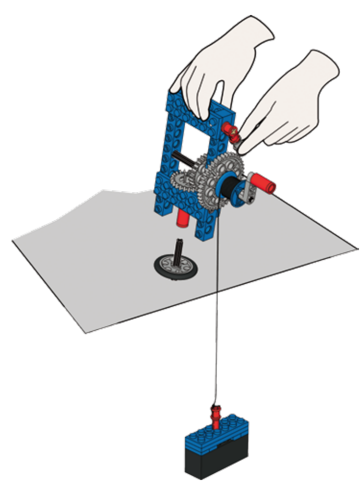
Disconnect the gearbox as in page 14, step 1 and make the three different spinning tops page 14, step 16.



Did you know?
The different spinning tops weigh approx.:
2 g (≈ 0.1 oz)
8 g (≈ 0.28 oz)
16 g (≈ 0.5 oz0

- Crank up the weight (adding energy) and flip the ratchet to hold the weight up (store the energy)
- Connect a spinning top
- Position the weight so it will fall over the edge of a table
- Flip the ratchet to release the energy in the weight brick so it spins the top
- Lift to release the spinning top
- This takes skill so be patient
- Which top will spin the longest and why? Predict and test more times with each spinner





More Spins
Invent your own spinners to see if you can get even more speed and longer spinning times.

Invent your own spinning games and introduce your very own scoring system.

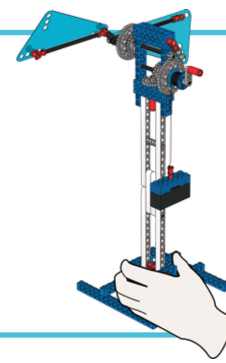
Windmill

Name(s): ____________________

____

How can you use a windmill and a rope to lift a heavy load?
Let's find out!

Build the Windmill



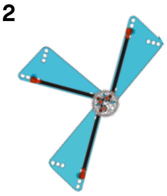
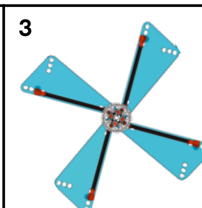
(All of book 8A and book 8B to page 12, step 17.)

- Make sure it turns smoothly
- If it feels stiff to turn, loosen the axle bushings and make sure all other elements fit tightly together

What difference does the number of sails make?

- Predict and test how fast each design will lift the treasure chest (weight brick). Use some sort of timing device
- Use the same wind speed each time

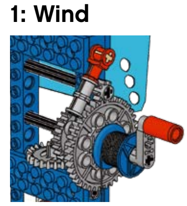
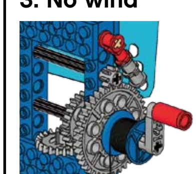
Slow	Fast	Medium

1	2	3
		
My prediction	**My prediction**	**My prediction**
Actual speed	**Actual speed**	**Actual speed**

What difference does the ratchet make?

Predict and test what will happen to the treasure chest with each position of the ratchet with or without wind.

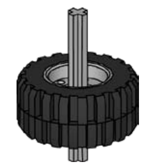
Lift	Stopped	Fall

1: Wind	2: No wind	3: No wind
		
My prediction	**My prediction**	**My prediction**
What happened?	**What happened?**	**What happened?**

In a Spin

Build the wind-up top model page 14, step 1 and the three different spinning tops on pages 14, 15 and 16.

- Use the energy from a falling weight brick to power these spinning tops
- How long will each top spin for?

		
My prediction	**My prediction**	**My prediction**
Actual spin time	**Actual spin time**	**Actual spin time**

Also try:

- Coloured spirals on card spinners
- Gears as spinners
- Inventing your own Spinning Game and making a scoring system

My Magnificent Mill

Draw and label your design for capturing and using wind energy. Explain how the three best parts work.

Land Yacht

Technology
- Using mechanisms – gearing down
- Assembling components
- Combining materials

Science
- Renewable energy
- Measuring area
- Measuring distance
- Measuring time
- Forces
- Friction
- Air resistance
- Pressure
- Scientific investigation

Vocabulary
- Area
- Wind resistance
- Renewable energy
- Gearing down
- Friction

Other materials required
- 4-meter (4 yards) strip of smooth floor
- Masking tape
- Meter stick (yard stick) or measuring tape
- Timer or stopwatch
- 3-speed desk fan
- Optional: card, scissors, pencils, and rulers to make your own sails

Connect

It is a windy weekend at the beach and Jack and Jill are out to have a bit of fun. They have this old cart they normally use, but today it's Jill's turn to push Jack and Zog the Dog, and the weather is really windy, which makes it very hard work for her.

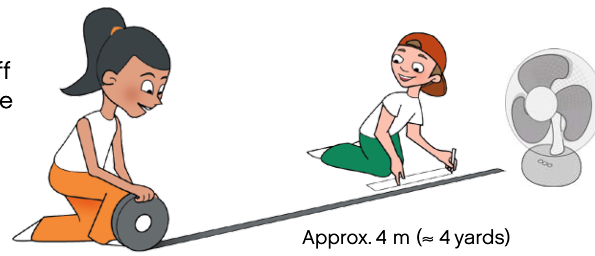
Jill gives up in the end and Jack can understand why. Zog the Dog does his best to help out and suddenly he sees an old towel half buried in the sand. Jill spots it at exactly the same time and they discuss between them how using the towel, the wind power, and a few other things, it may be possible to make a kind of land yacht that will safely take them all for a fun ride.

How can you make a safe cart that is powered by the wind … and carries at least one person? Let's find out!

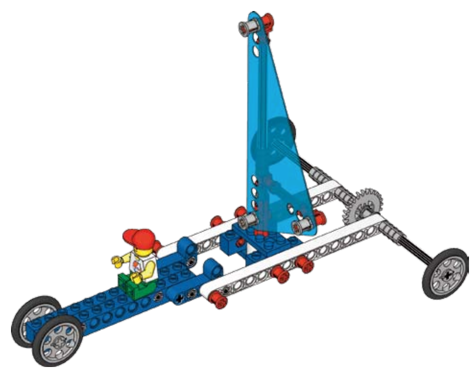
Construct

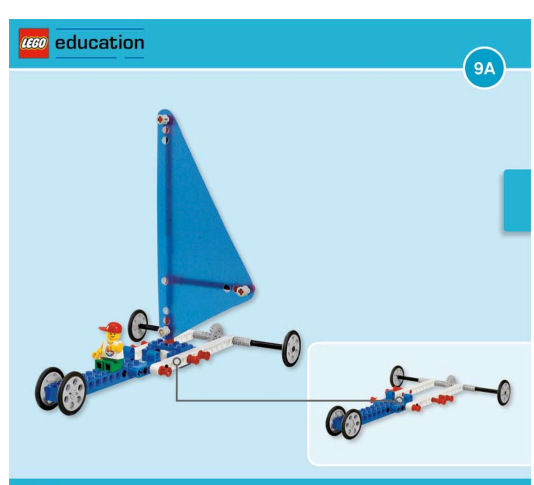
Warning!
Fans are potentially dangerous. Make sure that children handle them with great care!

Make your test track
Stick a 4-meter (≈ 4 yards) strip of masking tape across a stretch of floor and mark it off every 10 cm (≈ 4 in) from the fan. Now we are ready to build models!



Build the Land Yacht
(All of Book 9A and book 9B to page 5, step 12).
Build it with the small sail first.

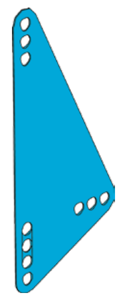




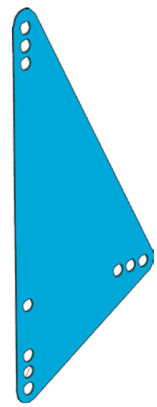
Contemplate

What difference does sail size make?
Predict and test: what difference could there be between the 40 cm^2 (≈ 15 in^2) (small), 80 cm^2 (≈ 31.5 in^2) (medium), and 160 cm^2 (≈ 63 in^2) (large) sails on the yacht. How far will each roll ... and (optional) how fast? Test at least three times with each sail attached to obtain a scientifically valid answer.

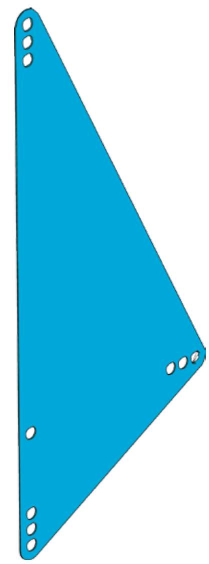
In our tests, the small sail rolled about 1.5 m, the medium about 2 m and the large about 2.5 m. Double the area gathers more wind energy but does not double the distance. Why? The further from the fan, the weaker the wind! Larger sails moved faster at first. But all the sail sizes stopped rolling after about 10 seconds. None of them sail faster than the wind!



40 cm^2
(≈ 15.7 in^2)
small
page 5, step 12



80 cm^2
(≈ 31.5 in^2)
medium
page 9, step 21



160 cm^2
(≈ 63 in^2)
large
page 14, step 30

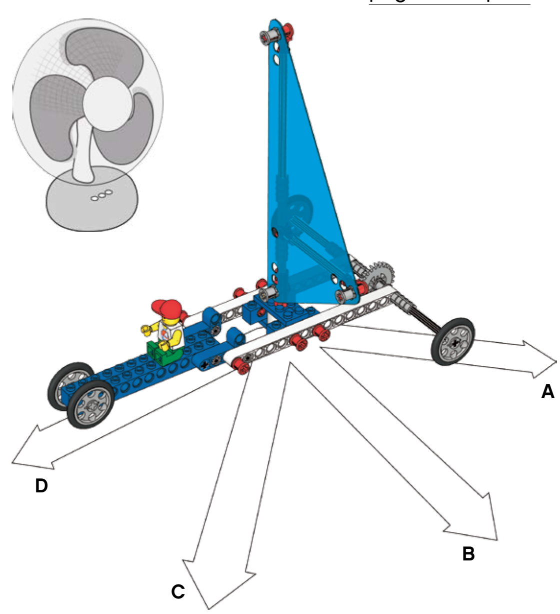
Tip:
Choose ONE speed setting to do all the tests. Any speed will do. We used high speed.

Note:
Your 'serious' scientists might also suggest testing the land yacht with just the bare mast, i.e. with no sail at all, so you might wish to try that as well.

What if the wind is blowing from an angle?
Launch your land yacht at different angles across the wind stream. Can you explain what happens?

At most angles except D the yacht still moves forward! One part of the wind's force is deflected off the sail, propelling it forward.

The other part of the force tries to blow it sideways. In fact a land yacht sailing across the wind at angles B and C can go very fast – but could also flip over.



Did you know?
The LEGO® figure weighs 3 g (≈ 0.1 oz).
The yacht weighs about 55 g (≈ 1.94 oz).
The weight brick is 53 g (≈ 1.9 oz).
Predict and test how the yacht would perform with a weight brick load.

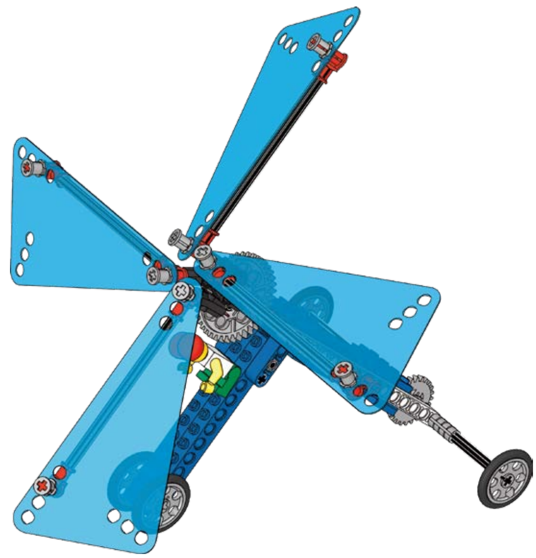
Does sail shape matter?
Try making card or paper sails with the same area but a different shape. Find out about Square Riggers, Kon Tiki, Chinese Junks, and Arab Dhows from books or by searching the internet.

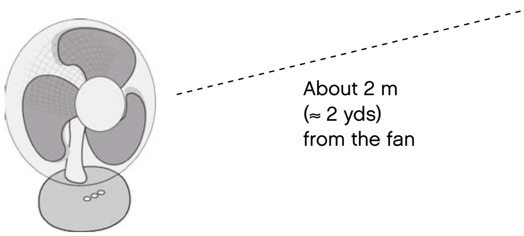
Continue

The Wind Sucker
Rebuild the model to page 24, step 15.
Hold the model 2 m (≈ 2 yds) away facing the fan (set on high speed). Predict what will happen when you let go. Then try it! Can you explain?

It builds up speed running towards the fan. The wheels may skid when it is close to the fan.

- *The energy from the wind is collected by the sails, geared down (3:1), which increases the force and turns the wheels, but in the opposite direction*
- *When it skids – the wind force one way is equal to the friction force of the tires pushing the other way*





About 2 m
(≈ 2 yds)
from the fan

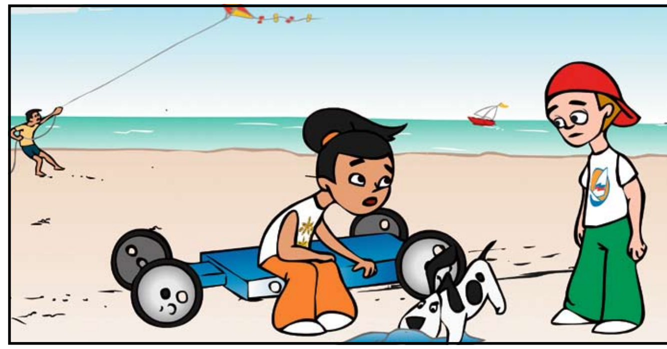
Making it more efficient?
Add a weight brick and see what happens.
Swap the thin wheels for big wheels.

If it is skidding, adding weight increases friction by pressing the tires harder onto the floor. Large wheels also have more area in contact with the floor, i.e. friction and grip increase and it moves forward. It will also move faster (larger wheels).

Idea:
Predict and test what happens if you face it away from the fan.

Land Yacht

Name(s):

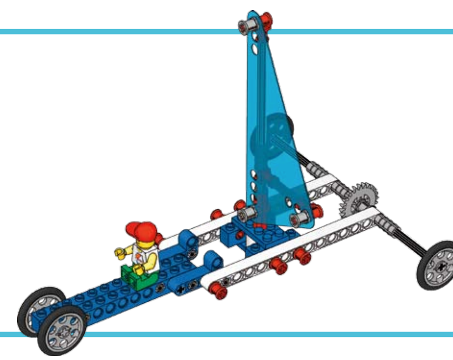


How can you make a safe cart that is powered by the wind and carries at least one person? Let's find out!

Build the Land Yacht

(All of book 9A and book 9B to page 5, step 12.)

- Use the small sail



What difference does the size of the sail make?

- Turn on the fan. Predict and test how FAR each model will roll with the same wind speed
- Test at least three times with each sail to achieve a scientifically valid answer

NOTE: FANS and FINGERS! TAKE CARE!

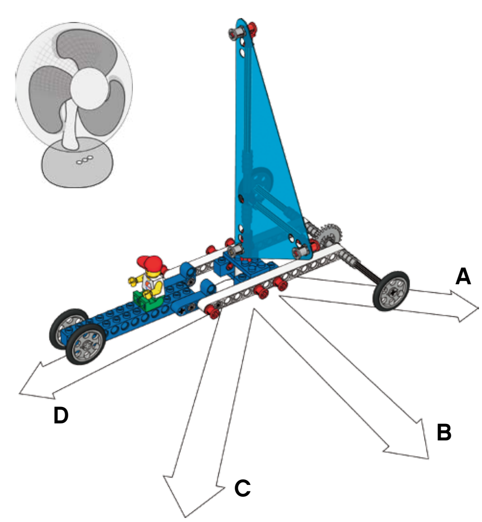
Tip:
Choose ONE speed setting to do all the tests. Any speed will do. We used high speed.

	My prediction	Actual distance
Small 40 cm² (≈ 15 in²) sail page 5, step 12		
Medium 80 cm² (≈ 31.5 in²) sail page 9, step 21		
Large 160 cm² (≈ 63 in²) sail page 14, step 30		

What difference does wind angle make?

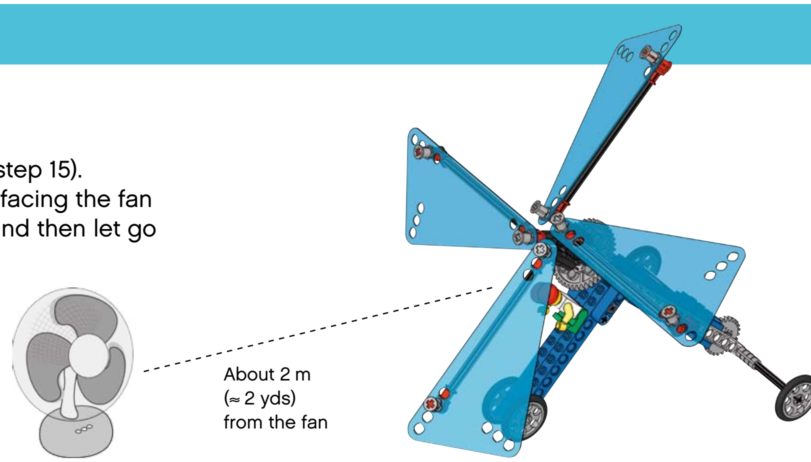
- Launch your yacht at different angles across the wind stream
- How fast does it travel each time?
- Write the words next to the arrows to match what you saw happening

Stopped Medium speed
Fast Slow

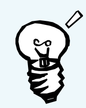


The Wind Sucker

(Build book 9B to page 24, step 15).
- Hold it 2 m (≈ 2 yds) away facing the fan
- Predict what will happen and then let go



My prediction	Actual distance



Also try:
- Fat back wheels
- A weight brick
- Two or three sails
- Facing backwards

Did you know?
The LEGO® figure weighs 3 g (≈ 0.1 oz). The yacht weighs about 55 g (≈ 1.94 oz).
The weight brick is 53 g (≈ 1.9 oz). Predict and test how the yacht would perform with a weight brick load.

My Land Sailor

Draw and label your design for a wind-powered vehicle.
Explain how the three best parts work.

Flywheeler

Technology
- Using mechanisms – gearing up
- Assembling components

Science
- Measuring distance
- Measuring time
- Forces
- Moving energy
- Friction and air
- Resistance
- Scientific investigation

Vocabulary
- Gearing up
- Flywheel
- Mass
- Position

Other materials required
- 3-meter (≈ 3 yard) strip of smooth floor
- Masking tape
- Meter stick (yard stick) or measuring tape
- Timer or stopwatch

Connect

Jack and Jill have had a little quarrel and have been sent outside to cool down. Jill gets Zog the Dog to pull her on the cart, but it is far too slow.

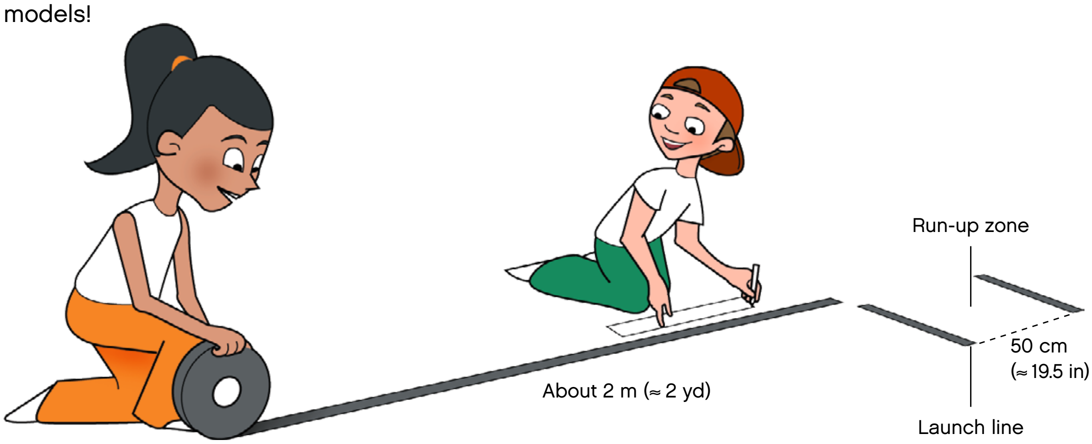
Jack plays with his spinning tops. They spin very fast, but really he would much rather be friends with Jill and play with her again. Jill feels exactly the same – it is much better when they are good friends, and quite frankly, they are bored playing games that are not fun.

They look at each other and suddenly Jill gets an idea. How about a combined game using both the cart AND the power of the spinner? Will that work, do you think?

Could the spinning of a spinning top help a push-along car move and will it travel further – and for a longer time?
Let's find out!

Construct

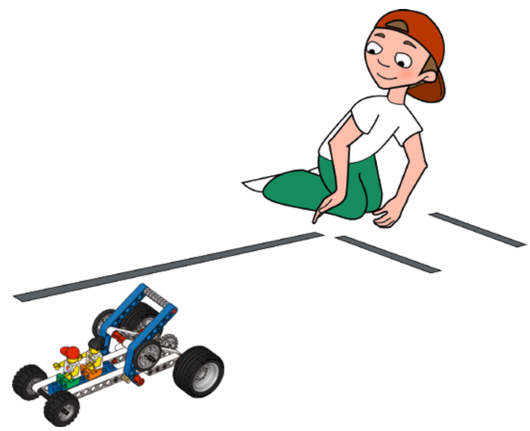
First make the test track
Mark out a 50 cm (≈ 19.5 in) section of run-up track. This is the run-up zone and in front of the launch line. Then stick a 2 m (≈ 2 yd) strip of masking tape along the floor and mark it off every 10 cm (≈ 4 in). Now we are ready to build models!



Build the Flywheeler
(All of book 10A and book 10B to page 10, step 20.)
- When pushed it should roll to a stop quite slowly
- If it slows too soon, loosen the axle bushings, make sure gears are meshing properly, and make sure all other elements are pressed firmly together

Contemplate

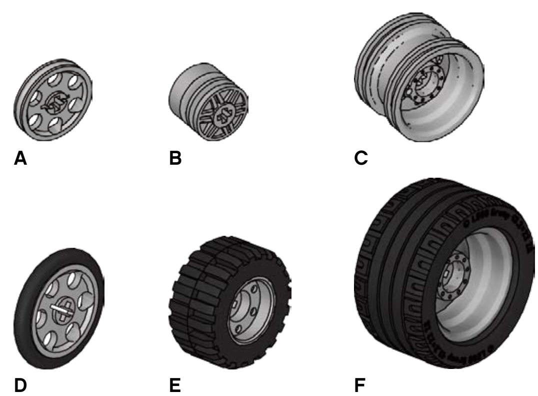
Fair testing
To fair test each model, use a 2-second run-up over 50 cm (≈ 19.5 in) and release at the launch line – at the same speed. It takes practice! This is why it is a good idea to test each model three times to be sure.



Did you know?
The best energy storing flywheels are put inside an airtight case and run in a vacuum to remove air resistance!

What makes a good flywheel?
The best flywheel will carry the model further, and roll for a longer time – with exactly the same run up! Try it without any flywheels at all! Try the big hub with and without its tire. Invent your own combinations too.

Heavier flywheels work better than lighter ones, but they need a lot of arm energy to get up to speed, i.e. the amount of moving or kinetic energy it stores depends on its weight and on the speed it is travelling.



Did you know?
We use 8-tooth and 24-tooth gears to gear up. There are two gearing-up stages, each 1:3, i.e. one turn of the wheel on the ground gives 9 turns of the flywheel.

How far and for how long will it roll?
Measure how far each flywheel rolls.
Even better, but optional, time how long it rolls!

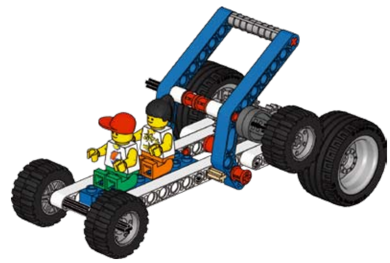
Build to page 12, step 22.
Test and measure.

Build to page 14, step 24.
Test and measure.

The flywheel cars travel very slowly. The bigger the flywheel – often the slower they travel – but the longer they run for and the further they go.

Continue

Shakey Brakey!
Build book 10B to page 17, step 3 with a flywheel mounted off center.
Predict what will happen – then test it.



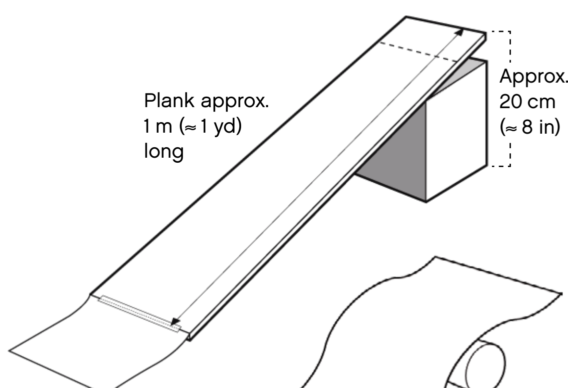
It stops the car very quickly! Flywheels must be DYNAMICALLY balanced when spinning, otherwise they produce large forces going in many directions, which increases FRICTION on the axles.

Did you know?
In real life, an off-balance super fast flywheel can explode!

Try rolling Shaky Brakey down the hill. What happens? Compare it to rolling with the balanced flywheel.

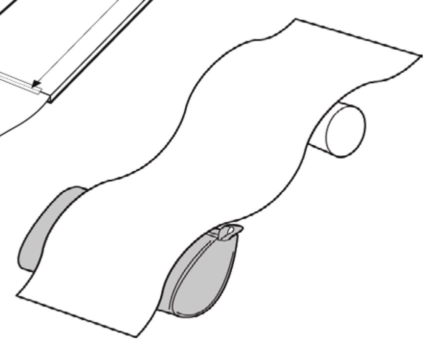
It rolls very slowly and does not get faster. Dynamic imbalance forces increase hugely with just a little increase in speed. At low speeds they are small, so the vehicle stays at a slow speed.

The Hill Climber
Make a ramp for the cars to run up. Predict and test how a flywheel and a non-flywheel car will perform with the same speed run up (this can be tricky!). You may want to work with some of the other teams in class on this activity.



The flywheel car travels further up the plank. It has a lot of stored energy.

Make a series of low hills for the cars to negotiate. Thin card taped over shoes or objects works well.



The flywheel car goes slowly both up and down the hills. It acts as kind of 'controller' to help cars get over hills at an even speed.

Taking on an Obstacle Course
Make a big pile of LEGO® bricks on the floor or on the table and find out which type of flywheel it will take to cross the LEGO "mountain".

The flywheel car with the big tires is best at forcing its way through the course and over the pile.

Flywheeler

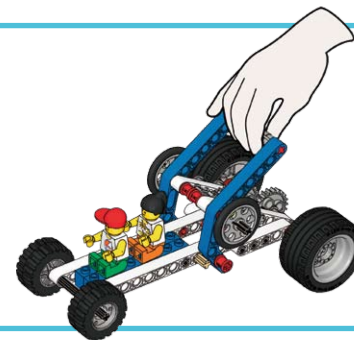
Name(s):

Could the spinning of a spinning top help a push-along car move, and will it travel further – and for a longer time? Let's find out!

Build the Flywheeler

(All of book 10A and book 10B to page 10, step 20.)

- Make sure it rolls smoothly
- If it stops too quickly, loosen bushings and make sure all other elements fit tightly



What makes a good flywheel?

Predict and test how far each model will roll:
- With at least three different flywheels or combinations
- With the same run-up
- Launched at the same speed

Optional: time how long each car rolls for

A

B

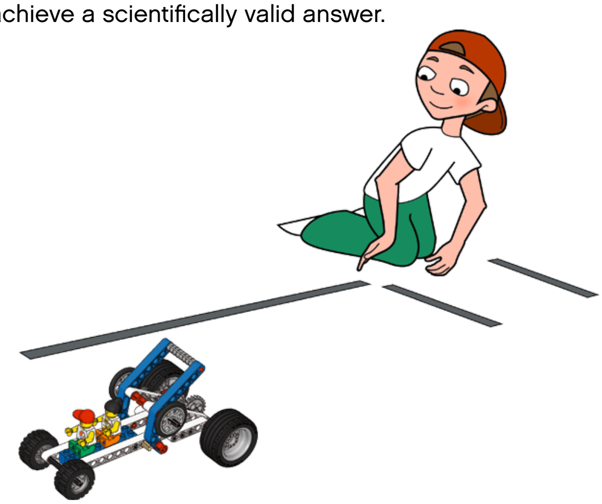
C

D

E

F

Test at least three times with each flywheel combination to achieve a scientifically valid answer.



My combination	My prediction	Actual distance	Time
A+B			

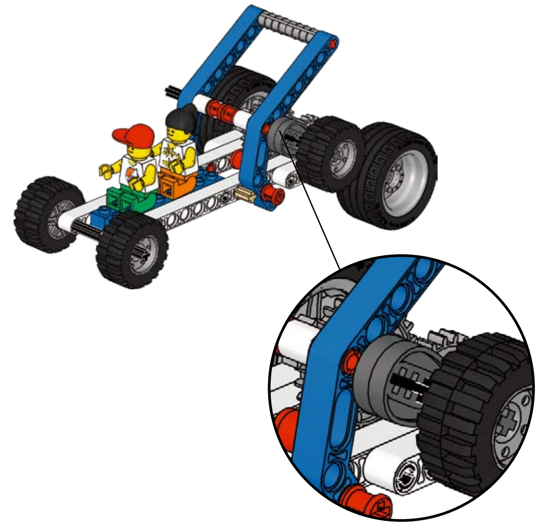
Did you know?
In real life, an off-balance super fast flywheel can explode!

Shakey Brakey

Build to book 10B page 17, step 3.
What happens if your flywheel is unbalanced?

My prediction:

And this happened after testing:



Also try:

- Climbing up hills
- On smooth floors and carpets
- Climbing over an all-terrain obstacle course, e.g. a pile of LEGO® bricks!

My Fab Flywheeler

Draw and label your flywheeler design.
Explain how the three best parts work.

Power Car

Technology
- Combining components
- Gears
- Wheels

Science
- Friction
- Measuring distance, time and force
- Scientific investigation

Vocabulary
- Counter balance
- Friction
- Gears
- Grip
- Torque

Other materials required
- Meterstick (yard stick) or measuring tape
- Plank – 240 cm (≈ 95 in) or longer
- Small books or other objects to make a load
- Stopwatch or timer

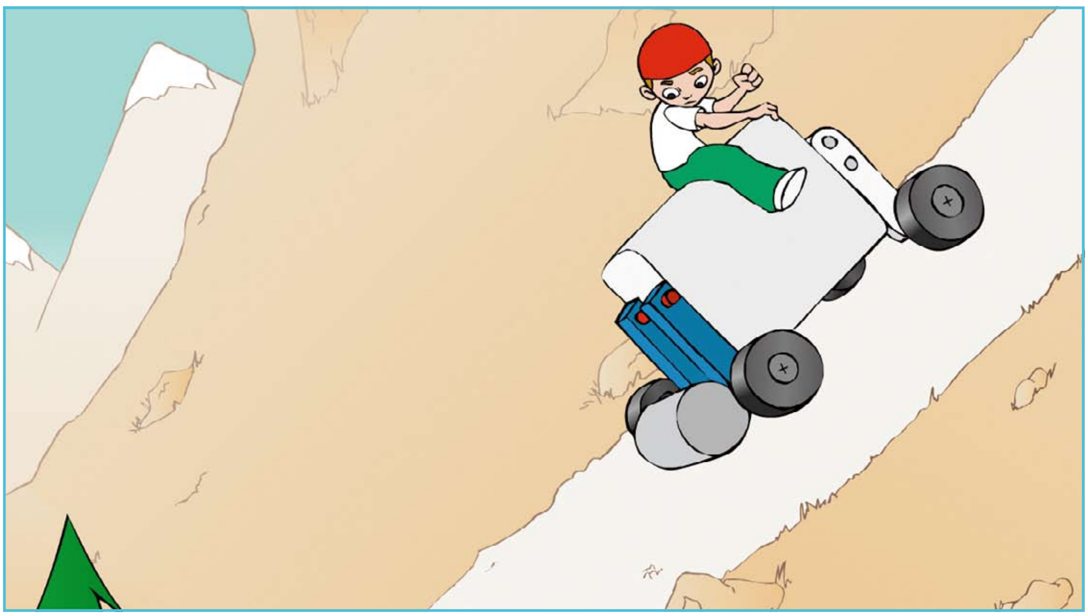
Connect

Jack and Jill are out in the hills behind their house testing their Power Car. It's great fun and a great way for Zog to keep fit too. The car works just fine on level ground but it just can't seem to climb those hills.

The wheels skid, the motor makes terrible noises, and the front end of the car lifts off the ground.

Jack thinks the car needs to be heavier. Jill thinks the gears are all wrong for going up hills.

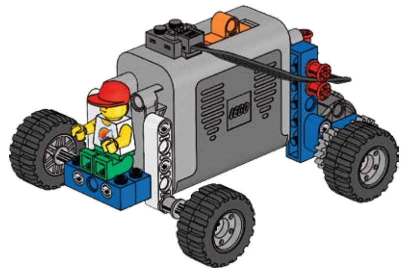
How can you make a Power Car that climbs hills?
Let's find out!



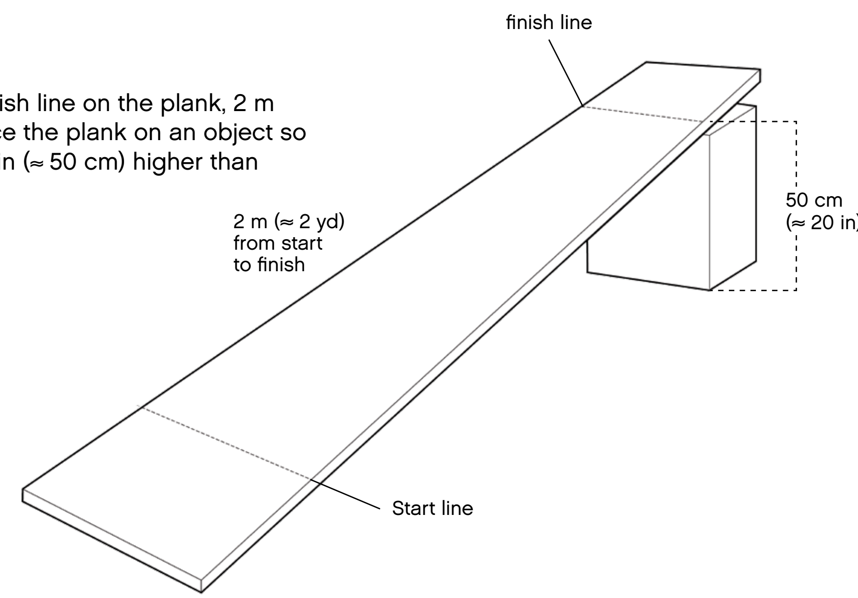
Construct

Build the Power Car
(all of book 11A and book 11B to page 9, step 10).

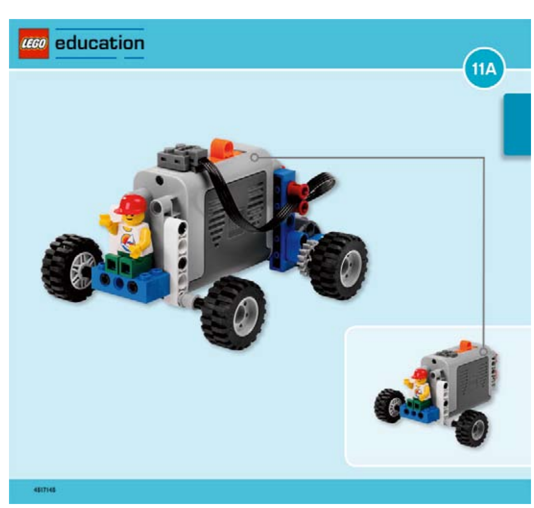
- Turn on the motor by pushing the battery box switch forward
- Make sure all the wheels turn freely and do not rub on the sides of the Power Car



Build your test hill
Mark a start and finish line on the plank, 2 m (≈ 2 yds) apart. Place the plank on an object so the finish line is 20 in (≈ 50 cm) higher than the floor.



Tip:
The Power Car can travel very fast, even up hills, so it might be a good idea to put the ramp against the wall in a corner to prevent it going over the edge.



Contemplate

Which is the fastest uphill Power Car?

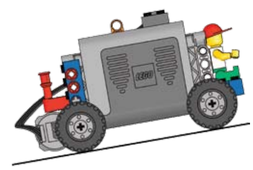
The Power Car needs to be as fast as possible when driving uphill.

First predict how fast Power Car A will travel 2m (≈ 2 yd) uphill. Then test your prediction. Next, follow the same procedure for Power Cars B, C and D.

Test several times to make sure your results are consistent. Test results may vary depending on surface of the hill.

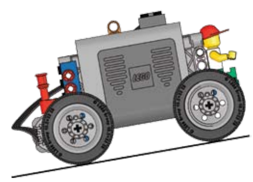
Power Car A (page 9, step 10) will need approximately 4 seconds to travel 2 m (2 yd) uphill.

A



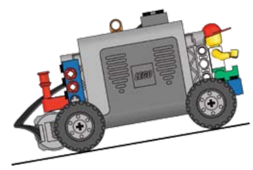
Power Car B (page 10, step 11) will need approximately 3 seconds to travel 2 m (≈ 2 yd) uphill.

B



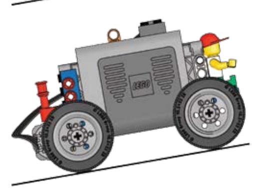
Power Car C (page 11, step 12) will need approximately 10 seconds to travel 2 m (≈ 2 yd) uphill.

C



Power Car D (page 12, step 13) will need approximately 7 seconds to travel 2 m (≈ 2 yd) uphill.

D



The fastest of the four is Power Car B, using big wheels and 1:1 gearing.

Optional: How steep a hill?
How steep a hill is your Power Car able to climb? Place the plank on an object so the finish line is70, 80, 90 cm or more (≈ 28, 31, 35 in) higher than the floor. Test which of the Power Cars A, B, C or D is best at climbing steep hills.

Power Car C can climb the steepest hills.

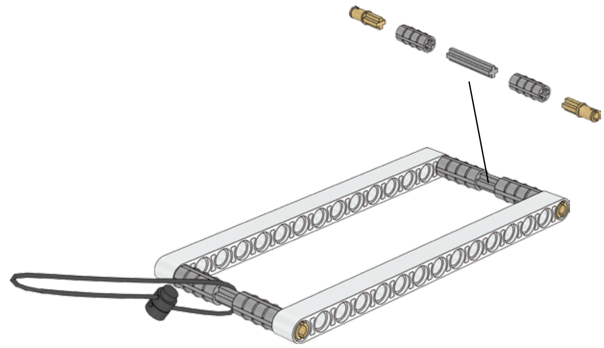
Did you know?
The circumference of the small wheel is 9.6 cm (≈ 3.77 in)

The circumference of the big wheel is 13.6 cm (≈ 5.35 in)

Continue

How strong is your Power Car?

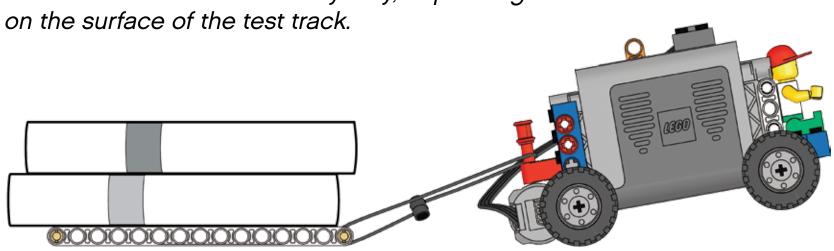
Build a sled and attach it to your Power Car using a string around the hook at the rear.



Load the sled with books.

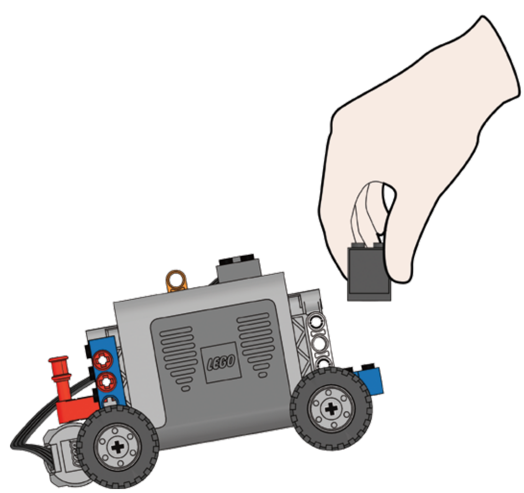
First predict how heavy a load Power Cars A and C can pull.
Then test which Power Car can pull the heaviest load.

Power Car C (page 11, step 12) can pull the heaviest load. Test results may vary, depending on the surface of the test track.



Also try adding counterbalance to the front of the Power Car.

This will keep the front end of the Power Car down and make it more stable.

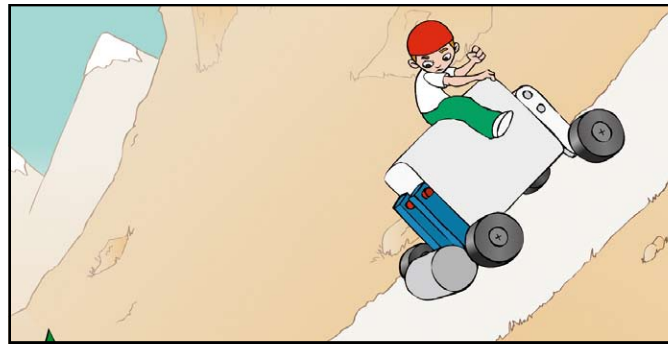


Tip:
Use the weight element as a counterbalance.

Try different combinations of wheels and gearing to achieve the best pulling power.

How heavy a load can your best Power Car pull?

Power Car

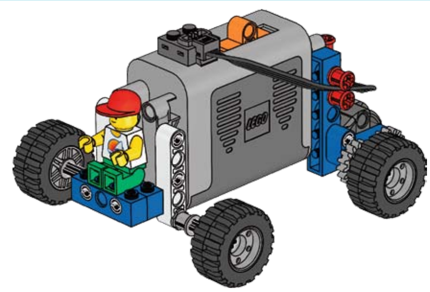


Name(s): ______________________

____

How can you make a Power Car that climbs hills? Let's find out!

Build the Power Car



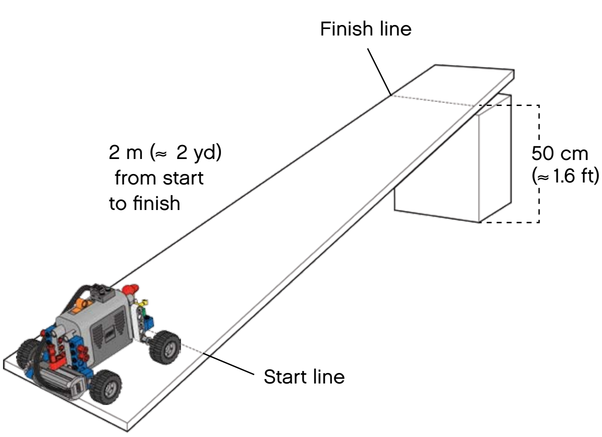
(all of book 11A and book 11B to page 9, step 10)

- Turn on the motor by pushing the battery box switch forward
- Make sure all the wheels turn freely and do not rub on the sides of the Power Car

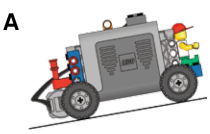
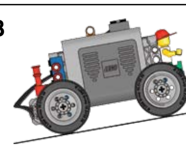
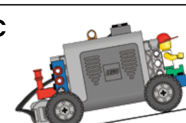
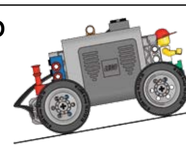
Which is the fastest uphill Power Car?

The Power Car needs to be as fast as possible when driving uphill.

- First predict how fast Power Car A will travel 2 m (≈ 2 yd) uphill. Then test your prediction. Next, follow the same procedure for Power Cars B, C and D.
- Test several times to make sure your results are consistent.



Tip:
The Power Car can travel very fast, even up hills, so it might be a good idea to put the ramp against the wall in a corner to prevent it going over the edge.

	My prediction	What happened?
A 		
B 		
C 		
D 		

Gear Ratios

Car A 16:16
Car B 16:16
Car C 24:8
Car D 24:8

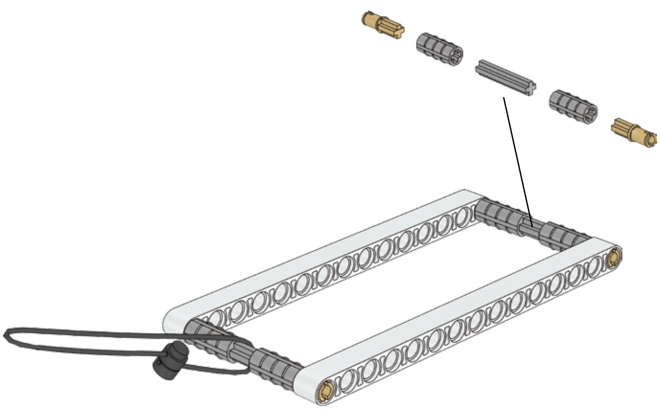
How strong is your Power Car?

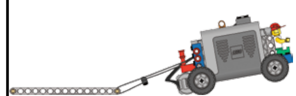
Build a sled and attach it to your Power Car using a string around the hook at the rear.

Load the sled with books.

- First predict how heavy a load Power Cars A and C can pull. Then test which Power Car can pull the heaviest load.

- How heavy a load can your best Power Car pull?



	My prediction	My measurements
		
		

My Power Car

Draw and label your favorite Power Car design.
Explain how the 3 best parts work.

Dragster

Technology
- Gears
- Levers
- Using and combining components
- Wheels

Science
- Energy
- Friction
- Measuring distance
- Scientific investigation

Vocabulary
- Acceleration
- Gears
- Mass
- Momentum

Other materials required
- Meterstick (yard stick) or measuring tape
- Up to 20 m (≈ 20 yds) of floor. You might have to use the corridor!

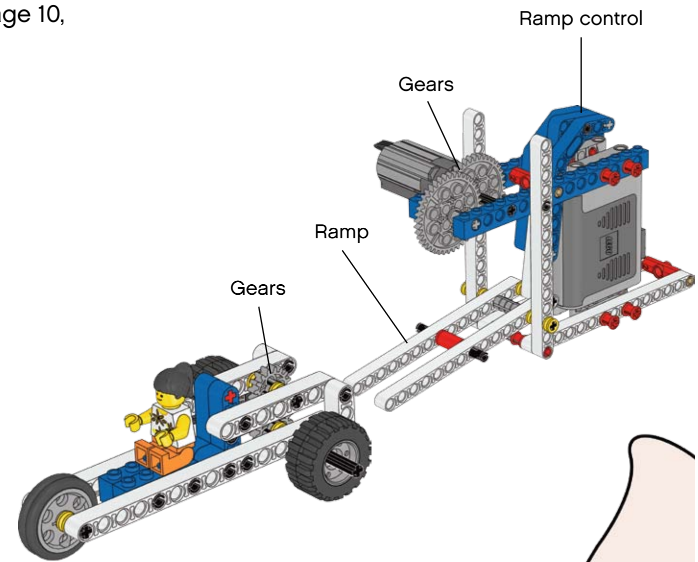
Connect

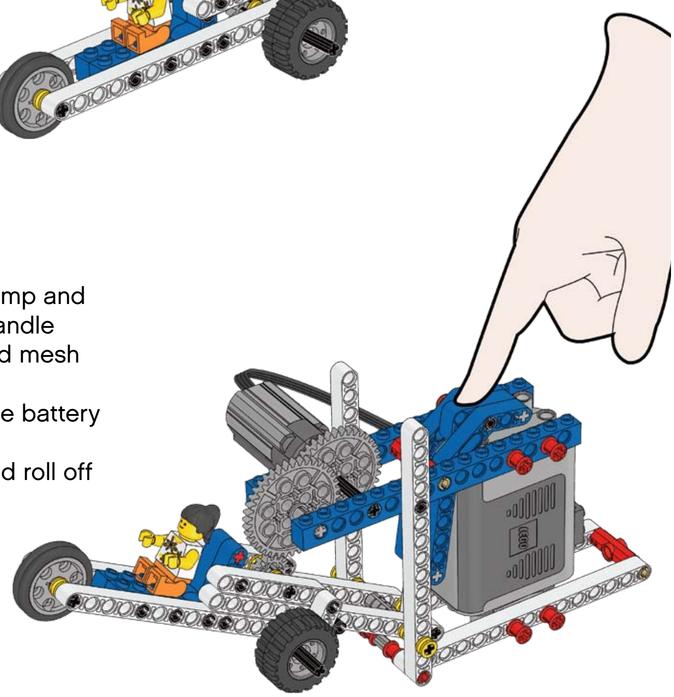
Jack and Jill are experimenting with their dragster. With a great start from a launcher, they hope it will roll all the way from the start to the finish line. But even after a perfect launch it does not go very far.

How can we make the dragster go further?
Let's find out!

Construct

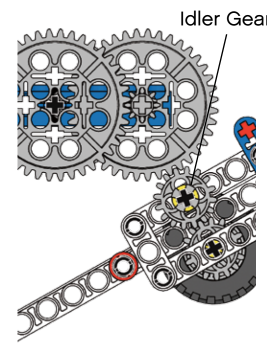
Build the Dragster and Launcher.
(all of book 12A and book 12B to page 10, step 13)





- Place the dragster on the launch ramp and lift it up by pressing down on the handle
- The big gear on the launcher should mesh with the gear on the dragster
- Start the motor by pushing down the battery switch
- Lower the ramp. The dragster should roll off smoothly onto the floor

Did you know?



An idler gear changes the direction of rotation, but does not affect the output speed.

Tip:
If your dragster vibrates, one of the tires might be sitting unevenly on its hub. This increases axle friction and leads to large energy losses.

Contemplate

How far will the dragster go?

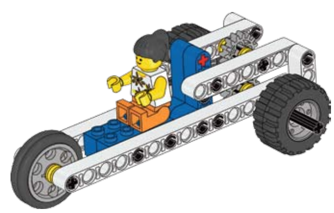
By changing the back wheels of your dragster you can change how far it can travel.

First predict how far Dragster A will travel. Then test your prediction. Next, follow the same procedure for Dragsters B and C. Which will travel the furthest?

Test several times to make sure your results are consistent. Test results may vary depending on surface of your test track.

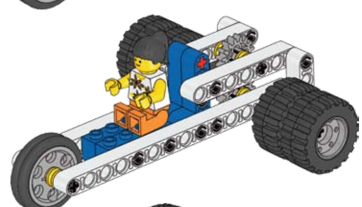
Dragster A (page 9, step 12) will travel approximately 0.7 m (≈ .75 yd).

A



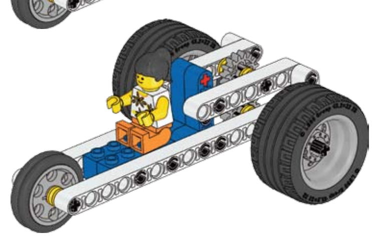
Dragster B (page 12, step 15) will travel approximately 2 m (≈ 2.2 yd).

B



Dragster C (page 12, step 16) will travel even further, approximately 6 m (≈ 6.5 yd).

C



Can you explain what happened when you changed the wheels?

Two small wheels store more energy than one, because they have twice the mass. That is why Dragster B goes further than Dragster A.

Dragster C goes further than Dragster B due to the larger circumference of the bigger tyres, and even though axle speed is the same.

The more tyre mass and the bigger the tyre circumference, the further the dragster will go.

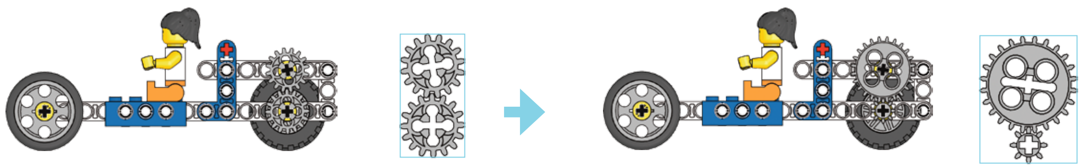
Did you know?
The small wheel weighs 9g (≈ 0.2 oz).

The large wheel weighs 13g (≈ 0.45 oz).

Continue

Can the dragster go even further?

To gear up your Dragster, first disassemble it (book 12B to page 3, step 3), and then:



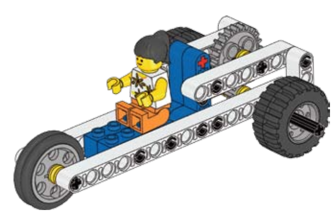
Replace the 16:16 gearing with a 24:8 gearing. Now build your geared-up Dragster (book 12B to page 9, step 12).

First predict how far geared-up Dragster D will travel. Then test your prediction. Next, follow the same procedure for your geared-up Dragsters E and F.
Which will travel the furthest?

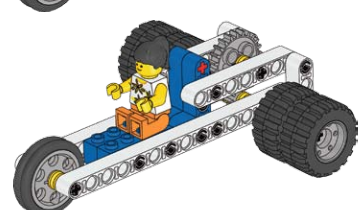
Dragster F will travel furthest, approximately 11 m (≈ 12 yd).

Try other ideas and combinations to make your dragster travel even further.
How far does your best dragster travel?

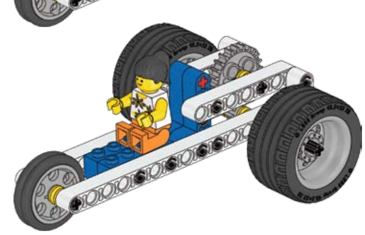
D



E



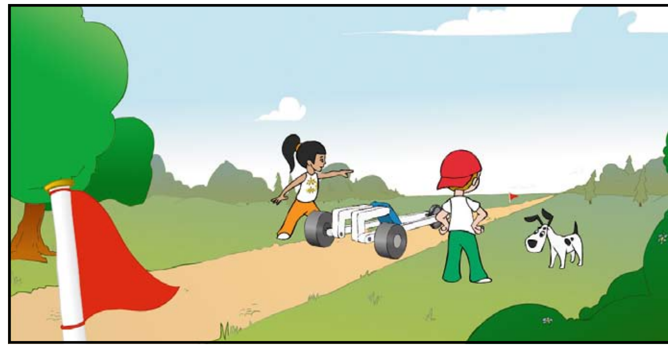
F



Dragster

Name(s):

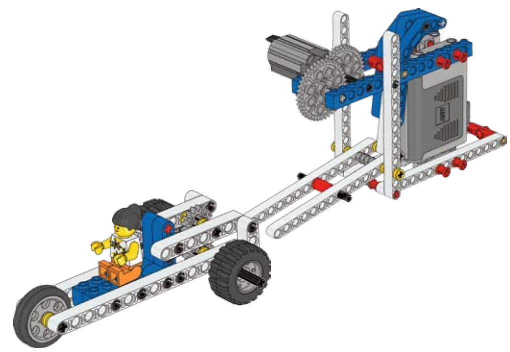
How can we make the dragster go further?
Let's find out!



Build the Dragster and Launcher

(all of book 12A and book 12B to page 10 step 13)

- Place the dragster on the launch ramp and lift it up by pressing down on the handle
- The big gear on the launcher should mesh with the gear on the dragster
- Start the motor by pushing down the battery switch
- Lower the ramp. The dragster should roll off smoothly onto the floor



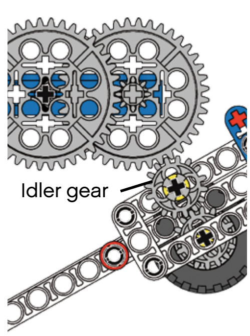
How far will your dragster go?

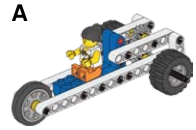
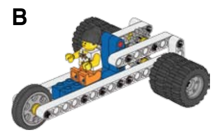
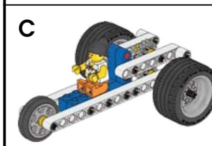
- First predict how far Dragster A will travel. Then test your prediction. Next, follow the same procedure for Dragsters B and C. Which will travel the furthest?

- Test several times to make sure your results are consistent. Test results may vary depending on surface of your test track.

Did you know?

An idler gear changes the direction of rotation, but does not affect the output speed.



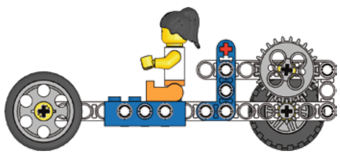
	My prediction	My measurements
A 		
B 		
C 		

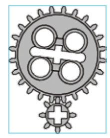
Tip: If your Dragster vibrates, one of the tires might be sitting unevenly on its hub. This increases axle friction and leads to large energy losses.

Can you explain what happened when you changed the wheels?

Can your dragster go even further?

To gear up your Dragster, first disassemble it (book 12B to page 3, step 3), and then:



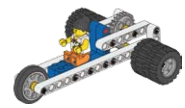
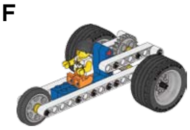


24:8

Replace the 16:16 gearing with a 24:8 gearing. Now build your geared-up Dragster (book 12B to page 9, step 12).

- First predict how far geared-up Dragster D will travel. Then test your prediction. Next, follow the same procedure for your geared-up Dragsters E and F. Which will travel the furthest?

- Try other ideas and combinations to make your dragster travel even further.
  How far does your best dragster travel?

	My prediction	My measurements
D 		
E 		
F 		

My dragster

Draw and label your favorite dragster design.
Explain how the 3 best parts work.

The Walker

Technology
- Gears
- Levers
- Linkage
- Ratchet
- Using and combining components

Science
- Force
- Friction
- Measuring time
- Scientific investigation

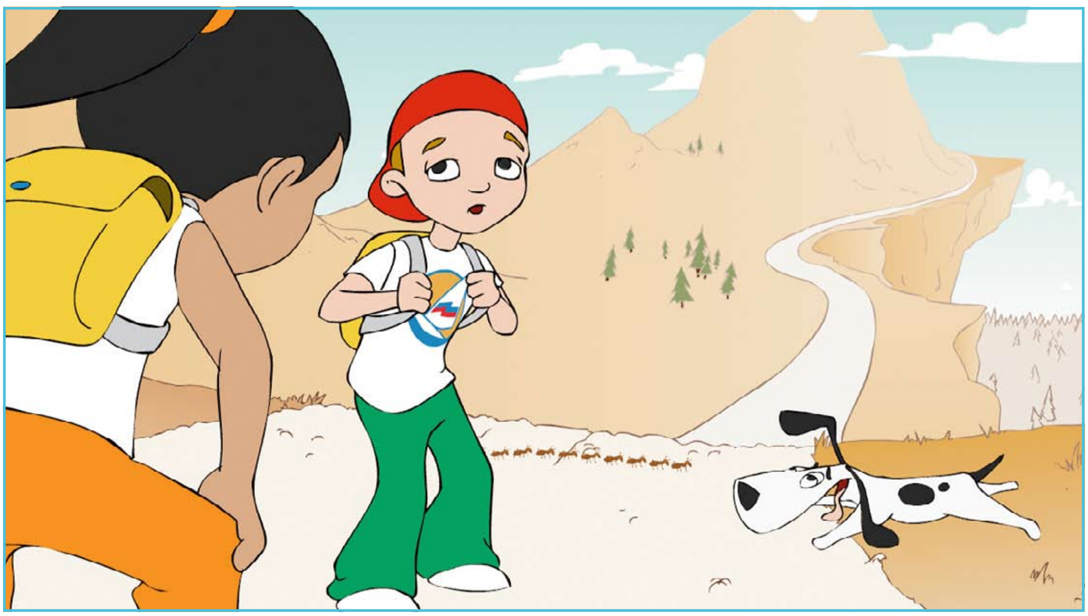
Vocabulary
- Balance
- Gears
- Grip
- Levers
- Linkages
- Ratchet

Other materials required
- Large thin book with a hard cover – big book or ring binder
- Ruler
- Stopwatch or timer
- Up to 1 m (≈ 1 yd) of floor space

Connect

Jack and Jill are having a great day out hiking. But it's hot, they are getting tired and their backpacks seem to be getting heavier and heavier.
When Jack and Jill stop for a short break, a line of ants passes them!
"How can they walk and carry so much so easily?" says Jack.
Jack and Jill think it would be great if an ant could carry them too!

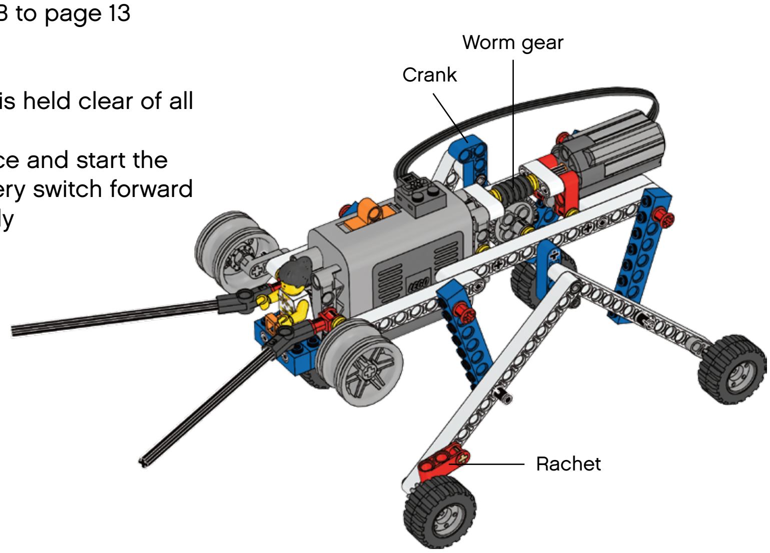
How can you make a Walker that will carry Jack and Jill along the trail?
Let's find out!



Construct

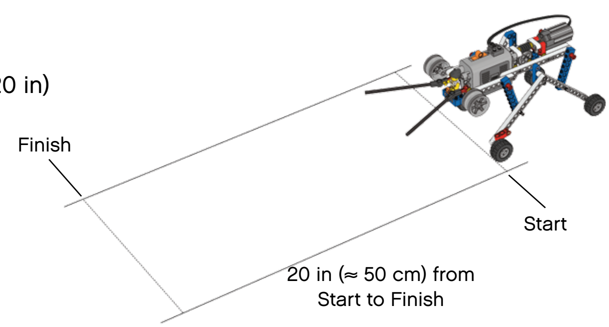
Build the Walker
(all of book 13A and book 13B to page 13 step 18.)

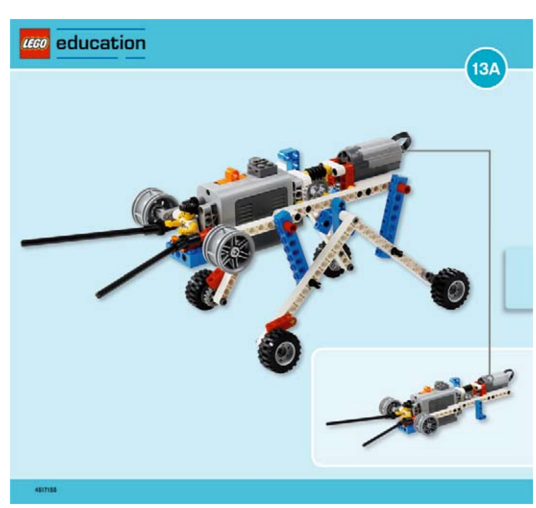
- Make sure the power lead is held clear of all moving parts
- Place it on a smooth surface and start the motor by pushing the battery switch forward
- The legs should move freely



Mark you test track

- Mark a start line and finish line 50 cm (≈ 20 in) apart.





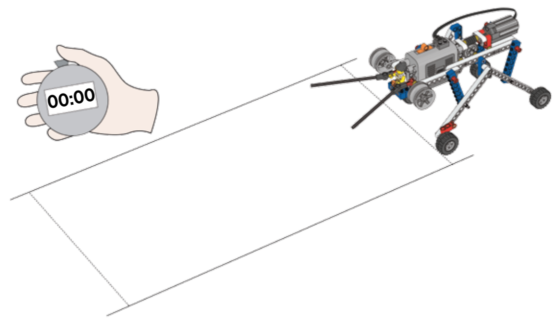
Contemplate

How fast can the Walker walk?

The Walker will walk at different speeds depending on the leg settings.

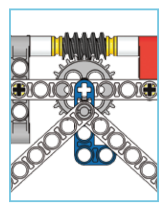
First predict how long it will take the Walker to walk 50 cm (≈ 20 in) using leg setting A. Then test your prediction. Next, follow the same procedure for leg settings B and C.

Test several times to make sure your results are consistent. Test results may vary depending on the surface of your test track.



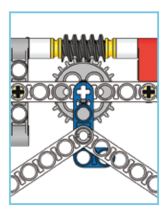
Leg setting A (page 13, step 18) results in the slowest result. It needs about 27 seconds to walk 50 cm (≈ 20 in).

A



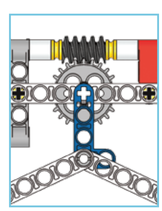
Leg setting B (page 14, step 19) gives the steadiest speed. It needs about 16 seconds to walk 50 cm (≈ 20 in).

B



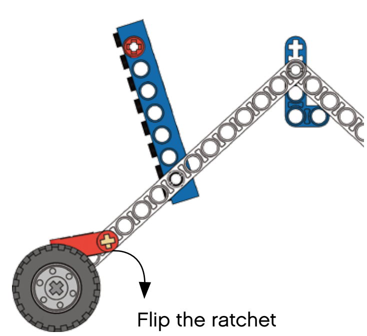
Leg setting C (page 15, step 20) provides the fastest result. It needs about 12 seconds to walk 50 cm (≈ 20 in).

C



Can you explain what the ratchets do?

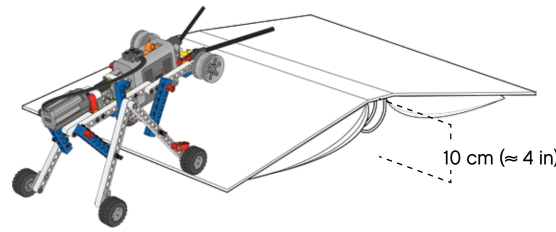
The front feet cannot grip with the ratchet loose. Without the ratchets the leg movements would force the wheels to roll backwards and forwards. The ratchet only allows the wheels to roll one way.



Continue

Which Walker is the fastest hill climber?

Make a 10 cm (≈ 4 in) hill from a big book or ring binder. Place the Walker as shown in the illustration.

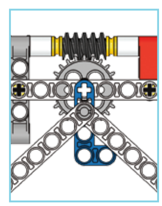


First predict which leg settings A, B or C is fastest for climbing over hills? Then test which in fact is the fastest hill climber.

Did you know?
A walking robot called Dante 2 is designed to climb down very steep rocky slopes into the gas-covered floors of dangerous volcanoes. It can also rappel down ropes and climb over rocks up to 1 m (≈ 1 yd) high!

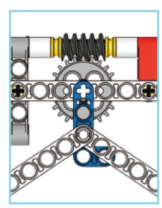
With leg setting A (page 13, step 18) the Walker walks slowly, but steadily climbs the hill.

A



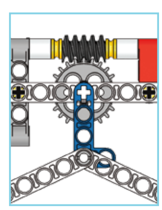
Leg setting B is (page 14, step 19) fast, but more unstable than leg setting A.

B



Leg setting C (page 15, step 20) is the fastest, but very unstable and as such not suited for crossing hills.

C

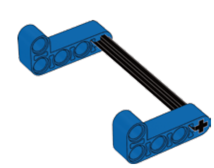


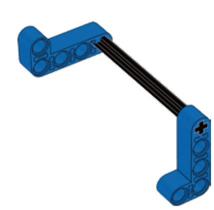
What else happens?

The Walker rolls down the hill! This is because the ratchets only resist forces in one direction, not the other.
The Walker can stand on its antennae.

Optional: Make the Walker move in different ways
Can you make the Walker move in different ways? Try out different settings of the two blue cranks.

Tip:
These crank settings will make the Walker move differently.





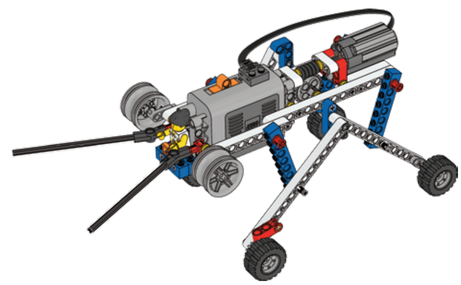
The Walker

Name(s):

How can you make a Walker that will carry Jack and Jill along the trail?
Let's find out!

Build the Walker

(all of book 13A and book 13B to page 13, step 18)

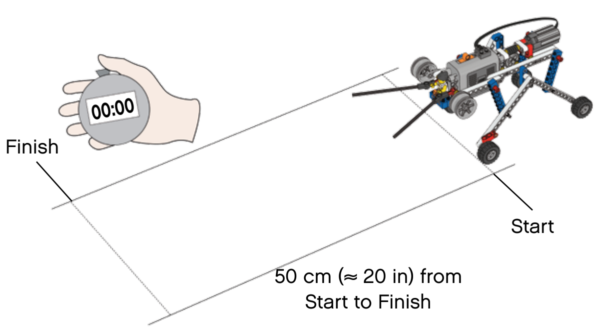


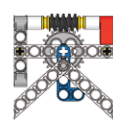
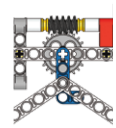
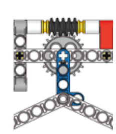
- Make sure the power lead is held clear of all moving parts
- Place it on a smooth surface and start the motor by pushing the battery switch forward
- The legs should move freely

How fast can the Walker walk?

- First predict how long it will take the Walker to walk 50 cm (≈ 20 in) using leg setting A. Then test your prediction. Next, follow the same procedure for leg settings B and C.

- Test several times to make sure your results are consistent.

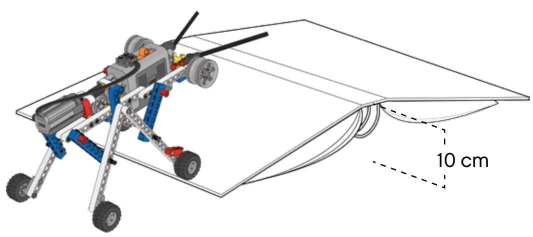


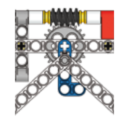
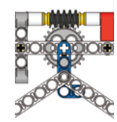
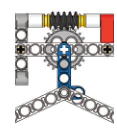
	My prediction	My measurements
A 		
B 		
C 		

Can you explain what the ratchets do?

Climbing over hills

- Make a low hill from a big book or ring binder
- Place the Walker as shown in the illustration
- First predict which leg settings A, B or C is fastest for climbing over hills? Then test which in fact is the fastest hill climber.



	My prediction	My measurements
A 		
B 		
C 		

Slow Fastest Fast

My Walker

Draw and label your favorite Walker design.
Explain how the 3 best parts work.

Dogbot

Technology
- Designing mechanical toys
- Levers and linkages
- Mechanical programming of actions
- Pulleys and gearing
- Using and combining components

Science
- Force and energy
- Friction
- Scientific investigation

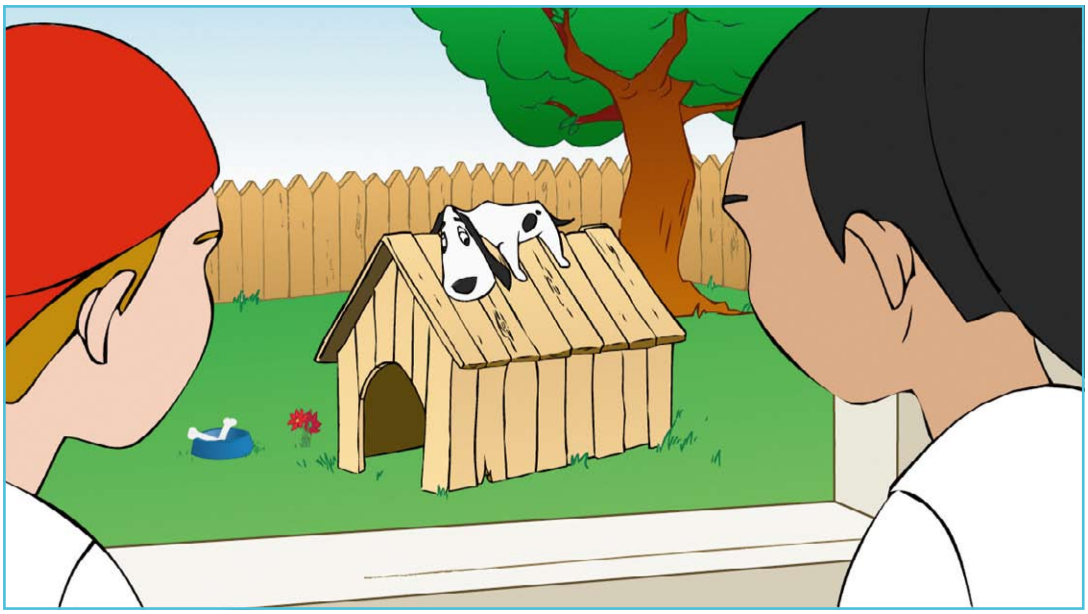
Vocabulary
- Cams
- Gears
- Levers
- Linkages
- Pivots
- Sequencing

Other materials required
- Crayons
- Decorative materials: wool, foil, card, paper, etc.
- Scissors
- Sticky tape

Connect

Zog is very bored. He dreams of a special friend that is always happy, wide awake and with whom he can share a bone. Jack and Jill have an idea.

How can we make an exciting friend for Zog to play with?
Let's find out.

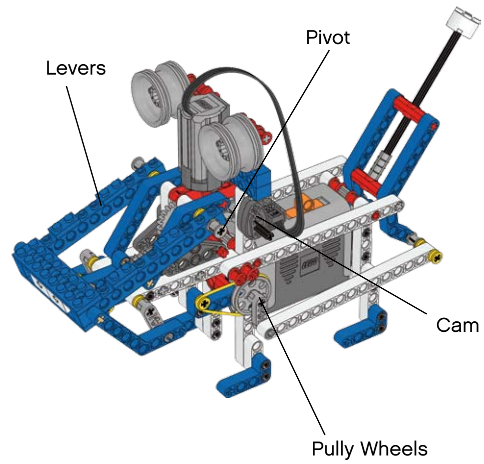


Construct

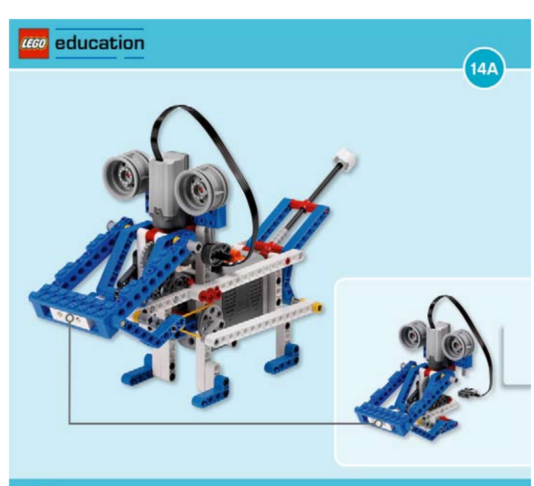
Build Dogbot
(all of book 14A and book 14B to page 19, step 27).

There are many moving parts on Dogbot, but only one motor. Turn on Dogbot by pushing backwards on the battery switch. If the motor is not turning freely, you need to check several parts of the Dogbot:

- The lever on the upper jaw should move up and down
- The cams should rotate freely, moving the eyes attached to the axles up and down
- The lever on the tail should wag up and down



Did you know?
The jaw and tail movements both feature compound levers with several pivots.



Contemplate

Is Dogbot wide awake?

When Dogbot is wide awake its eyes move about a lot!

Which cam setting will produce a Sleepy, Awake and Wide Awake Dogbot?

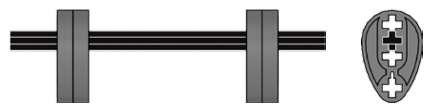
Predict first which eye action cam setting A will produce. Then test your prediction. Next, follow the same procedure for cam settings B and C.

Cam setting A (page 19, step 27) results in a sleepy Dogbot, i.e. only one eye bounce per turn of the cam.

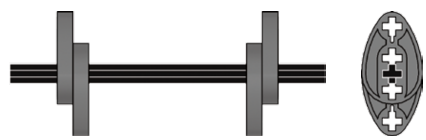
Cam setting B (page 20, step 28) results in a Dogbot that is awake, i.e. the eyes bounce twice per turn but at regular intervals.

Cam setting C (page 21, step 29) gives us a Dogbot who is wide awake, i.e. the eyes bounce twice per turn but at irregular intervals – one eye is up when the other is down!

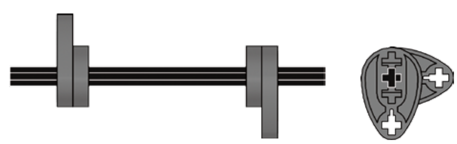
A



B



C



Did you know?
Cams work inside car engines, clocks, toys, sewing machines, and locks – in fact anywhere complex, timed actions are required.

How wide can Dogbot's jaws open?

By changing the peg position you can change the extent to which Dogbot can open his jaws.

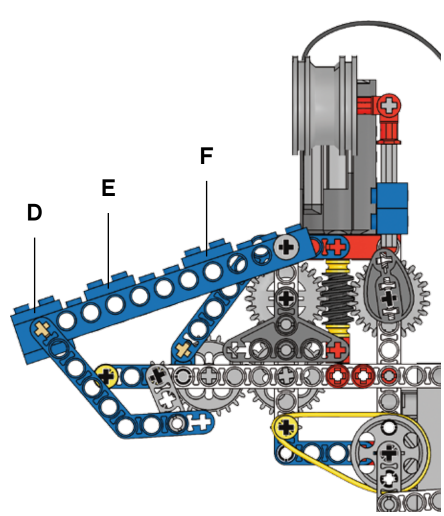
First predict how wide peg position D will make Dogbot's jaws open. Then test your prediction. Next, follow the same procedure for peg positions E and F.

Position D (page 22, step 30) allows Dogbot to open his jaws wide.

Position E (page 23, step 31) means Dogbot can open his jaws even wider.

Position F (page 24, step 32) is the widest possible setting for Dogbot's jaws.

The closer the peg position is to the pivot, the wider the jaws open. The upper jaw is a 3rd class lever.



Did you know?
Your lower jaw is a lever. Feel where the muscle connects to the bone of the lower jaw. Your jaws are 3rd class levers just like Dogbot – just upside down!

Continue

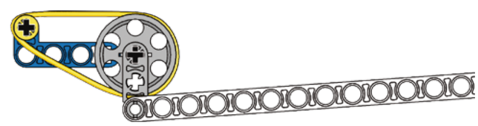
Can Dogbot be happier?

Dogbot wags its tail when it's happy. The faster the wag, the happier it is.

First predict how happy Dogbot is using pulley setting A. Then test your prediction.
Next, follow the same procedure with pulley settings B and C.

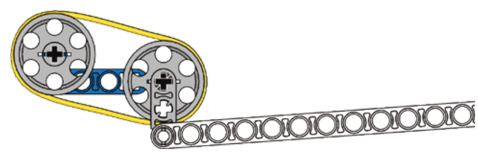
Pulley setting A results in a slow wag, i.e. a happy Dogbot.

A



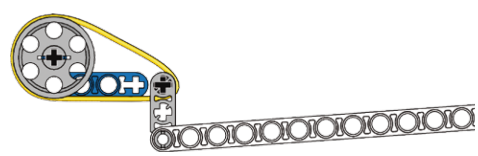
Pulley setting B results in a faster wag – in fact three times faster than pulley setting A. Dogbot is now even happier.

B



Pulley setting C gives the fastest wag – three times faster than pulley setting B. This is the happiest Dogbot can be!

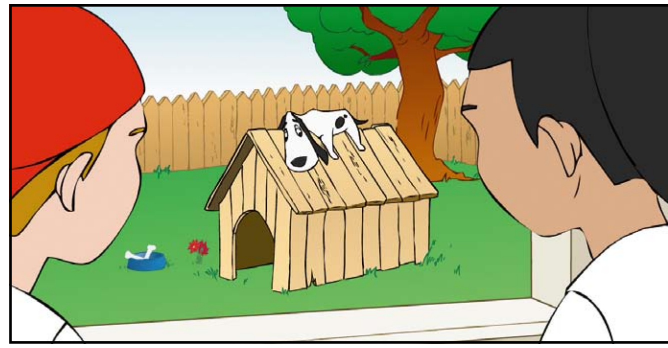
C



Dogbot

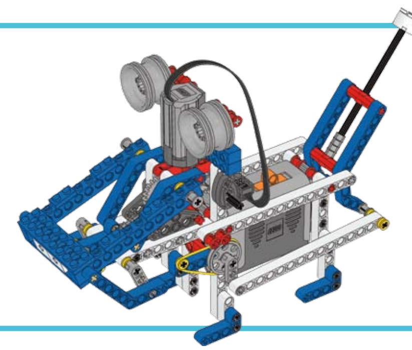
Name(s):

How can we make an exciting friend for Zog to play with?
Let's find out!



Build Dogbot

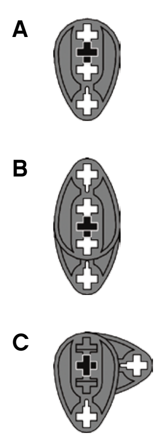
(all of book 14A and book 14B to page 19, step 27)
- The lever that forms the upper jaw should move up and down
- The cams should rotate freely moving the eyes attached to the axles up and down
- The lever that acts as a tail should wag up and down



Is Dogbot wide awake?

Which cam setting will produce a sleepy, awake and wide awake Dogbot?

- Predict first which eye action cam setting A will produce. Then test your prediction. Next, follow the same procedure for cam settings B and C.

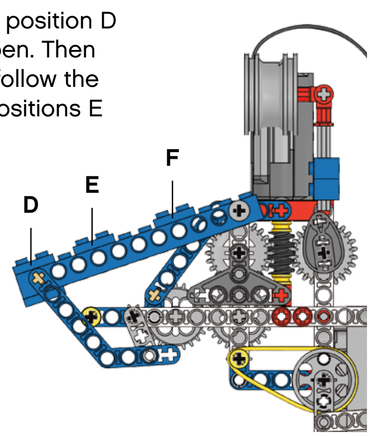


	My prediction	What happened?
A		
B		
C		

Sleepy Awake Wide awake

How wide can Dogbot's jaws open?

- First predict how wide peg position D will make Dogbot's jaws open. Then test your prediction. Next, follow the same procedure for peg positions E and F.



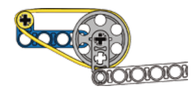
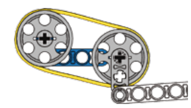
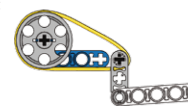
	My prediction	What happened?
D		
E		
F		

Wide Wider Widest

How happy is Dogbot?

Dogbot wags its tail when it is happy. The faster the wag, the happier it is.

• First predict how happy Dogbot is using pulley setting A. Then test your prediction. Next, follow the same procedure with pulley settings B and C.

	My prediction	What happened?
A 		
B 		
C 		

Also try:
• Dress Dogbot up
• Make a cardboard tongue and ears

Happiest Happier Happy

Did you know?
Your lower jaw is a lever. Feel where the muscle connects to the bone of the lower jaw. Your jaws are third class levers just like Dogbot – just upside down!

My Dogbot

Draw and label your favorite Dogbot design.
Explain how the 3 best parts work.

Uphill Struggle

The problem

Jack and Jill have made a luxury double-seater cart, but it is very heavy to push up the hill.

Can you design a way to stop the cart from rolling back down the hill when they stop to catch their breath?

Design brief

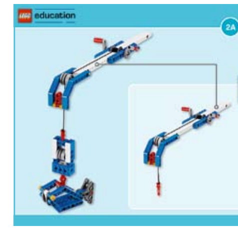
Design and make a vehicle that:
- can carry at least 50 g (≈ 1.75 oz) (or approximately 1 weight brick)
- has a safety feature that does not prevent the vehicle from rolling forwards

1. Make a sketch of the idea you designed and made.

2. Label the three most important parts, explaining how they work.

3. Suggest three improvements.

Need help?
Look at:



Fishing Rod

Freewheeling

Principle Models Building Instructions booklet for wheels and axles

Uphill Struggle

Objectives

Applying knowledge of:
- Wheels and axles
- Friction
- Ratchets and gears
- Predicting and measuring
- Applying principles of fair testing and product safety

Other materials required

- A meter rule or measuring tape
- A plank to make a sloping hill
- Card and tape to make a runoff ramp at the bottom of the hill
- A desk fan to provide the energy for wind-assisted carts
- Optional: playdough for making test pilots

Fair testing and fun

- Can the cart carry the weight of at least one weight brick?
  Test to see, then add more weight. What are the criteria for success?
  The cart should not break and the load should not rub against the wheels, etc.

- Does it roll freely?
  Set the hill at any slope angle you like, (e.g. 30 cm [≈ 12 in] high at one end of a 1 meter [≈ 1 yard] plank) and run the cart forwards down it. The further it rolls along the floor the better.

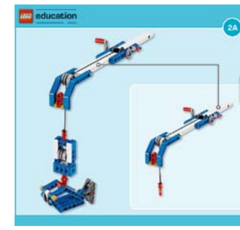
- Does the autostop feature work?
  Turn the cart around without touching anything on board so it faces backwards down the hill. Let go! Does it stay still? Keep increasing the steepness until the cart slips. The steeper you can go before it slips, the better.

- How safe and comfortable is your luxury cart?
  Make two play dough riders with very smooth skin. Place them gently on the cart in whatever seats are supplied. Let the cart run down the hill until it stops. Now check the riders for bumps, cuts, and bruises – the less, the better.
  How will they survive bumping over an all-terrain course?
  Would your cart be a good ambulance?

Extra challenges

- Harness wind energy to help push the cart uphill. Make sure that the autostop will stop it rolling down the hill again if the wind stops.
- All Terrain Cart! Can you find a way to make the cart climb over rulers and maybe even pencils that are put in its way on the hillside?
  Tip: Create a means of storing things on board the cart.

Need help?
Look at:

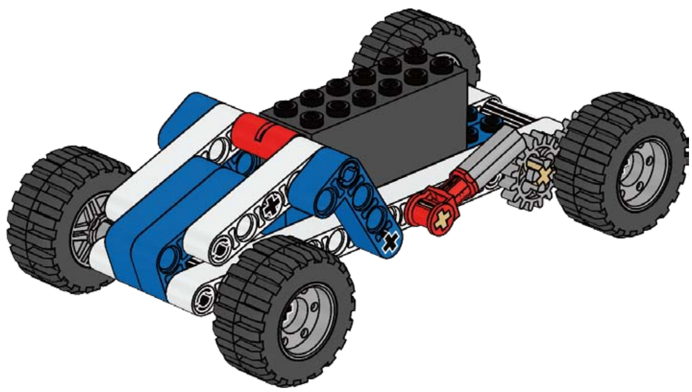


Fishing Rod

Freewheeling

Principle Models Building Instructions booklet for wheels and axles

Suggested model solution



The Magic Lock

The problem

Jack wants to keep his secret treasure locked away in a box. But he knows Jill can undo almost any lock and she is always so curious and wants to know his secrets!

Can you design a secret way to 'lock' a box that does not use a key?

Design brief

Design and make a box:
- with a secret or hidden lock or catch
- that can be 'locked' and 'unlocked' in a very simple way

1. Make a sketch of the idea you designed and made.

2. Label the three most important parts, explaining how they work.

3. Suggest three improvements.

Need help?
Look at:

Principle Models Building Instructions booklet for levers

The Magic Lock

Objectives
Applying knowledge of:
- Levers, structures and hinges
- Observing and investigating
- Applying principles of fair testing and product reliability

Need help?
Look at:

Principle Models Building Instructions booklet for levers

Other materials required
- Cardboard
- Markers
- Scissors

Fair testing and fun
- Does the box stay shut when it is 'locked'?
  Lock the box. Now try and see if it opens by pushing it or shaking it a little. Remember it is still just a prototype!

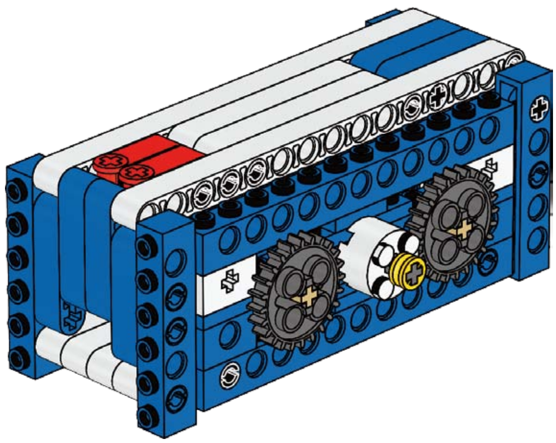
- Does it open properly?
  Test to find out. The easier it opens, the better.

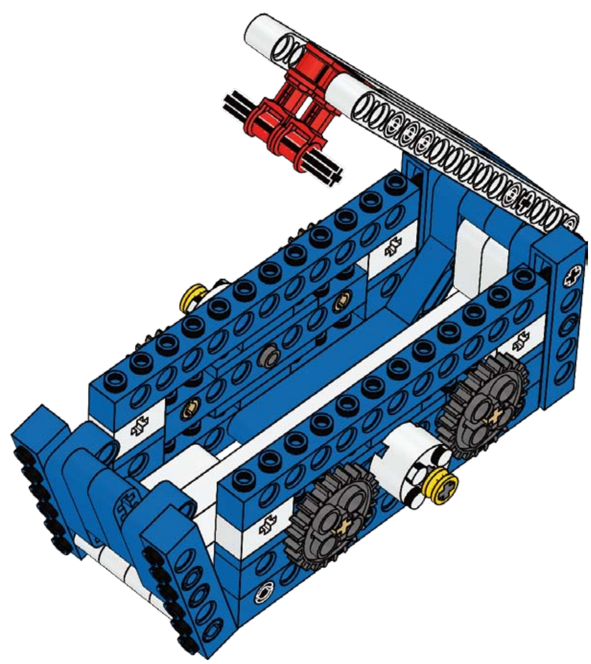
- How reliable is it?
  Lock, unlock and open it three times in a row. Is it still working OK? Keep going! The more times it can be locked and unlocked, the more reliable it is.

- How secret is it?
  Ask volunteers from another group to step forward and try and point out how you open the box. You may want to time it. The less people can guess how and where to open the box, the better!

Extra challenges
- Design and make different box sides so that the content is totally hidden.
- Using cardboard and markers, personalise the sides of your box.

Suggested model solution





Stamping Letters

The problem

It is too windy to play outside so Jill is helping out in the post office stamping letters. Her arm is getting sore from stamping, she is very tired and she wishes there was a way of using the wind to help her!

Can you think of a way to help her out?

Design brief

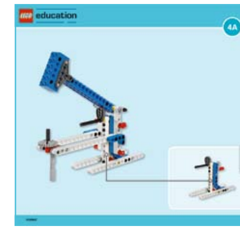
Design and make a wind-powered stamping machine:
- it must make a mark on thin paper
- the more times it stamps the mark within one minute, the better
- it must be powered by the wind from a desk fan placed approximately one meter (≈ one yard) away

1. Make a sketch of the idea you designed and made.

2. Label the three most important parts, explaining how they work.

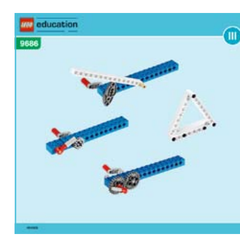
3. Suggest three improvements.

Need help?
Look at



The Hammer

Windmill



Principle Models Building Instructions booklet for levers and gears

Stamping Letters

Objectives
Applying knowledge of:
- Renewable energy
- Levers
- Cams
- Gears
- Observing, improving, and measuring
- Applying principles of fair testing and product safety

Other materials required
- Paper
- Scissors
- Tape

Fair testing and fun
- Does the stamper mechanism work in the wind?
  Start the fan one meter away from the stamper and see if the mechanism moves. You don't need to actually test with paper yet.

- Does it actually stamp paper?
  Cut up several pieces of paper to be the letters. Stamp half of them with the machine. Give all the pieces to someone else. Can he or she tell you which ones are stamped and which ones are not?

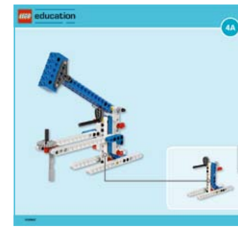
- How productive is it?
  Have a stamping race. With the stamper one meter (≈ one yard) from the fan, how many letters can your model stamp in one minute? The more the better.

- How energy efficient is it?
  How far can you move the stamper away from the wind and still stamp letters? The further away it works, the more energy efficient it is.

- How safe is it?
  Check to see if you can get your finger stamped by mistake. The safest stamper will be easy to use but hard to hurt yourself on.

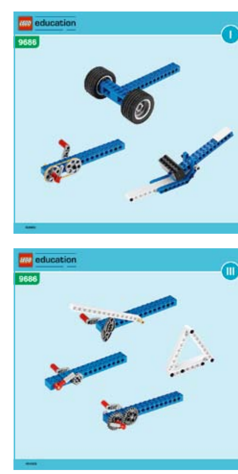
Extra challenges
- Make a special conveyor system to carry letters under the stamper.
- Make a real ink transfer stamp out of an old eraser with a ballpoint ink message on it. Can you write in mirror writing so you can read the message? How many times will it stamp before you need to re-ink it?
- Design and make a system that will tell you automatically how many times the stamper has stamped.

Need help?
Look at:



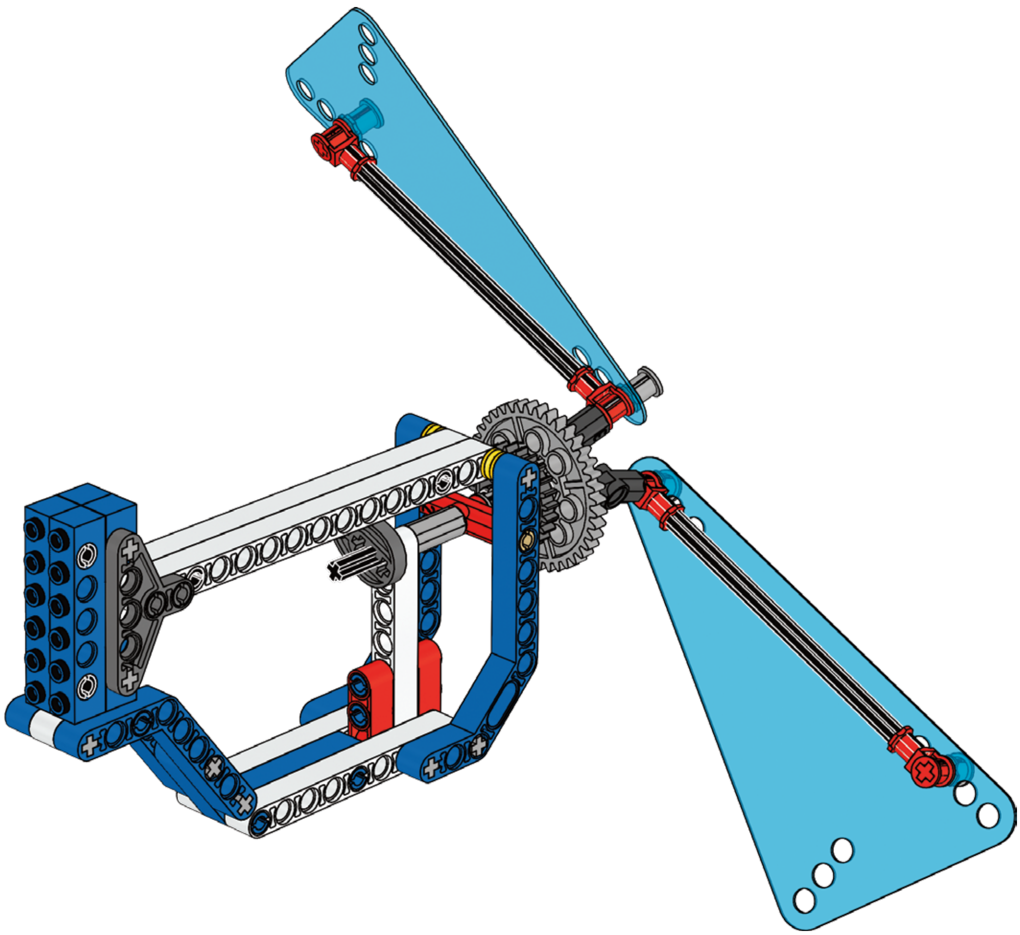
The Hammer

Windmill



Principle Models Building Instructions booklet for levers and gears

Suggested model solution



Beaten

The problem

Granny is scared of electric mixers, but she gets tired when she uses a whisk to beat eggs for pancakes or cake mixes. Is there a better way for Granny to beat eggs?

Can you help Jack and Jill come up with a solution.

Design brief

Design and make a hand mixer:
- that is easy to hold and use
- that really works
- with beaters that spin much faster than the handle you turn
- in which the beaters are at least 10 cm (≈ 4 in) away from the nearest part of your hand

1. Make a sketch of the idea you designed and made.

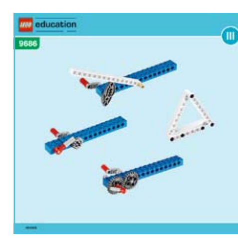
2. Label the three most important parts, explaining how they work.

3. Suggest three improvements.

Need help?
Look at:

Sweeper

Flywheeler



Principle Models Building Instructions booklet for gears and pulleys

Beaten

Objectives

Applying knowledge of:

- Gears and/or pulleys
- Energy efficiency
- Evaluating efficiency
- Applying principles of fair testing and product safety

Other materials required

- Ruler
- Stopwatch
- Cups or small bowls half full of warm water and a few drops of washing-up liquid
- Trays to stop spills
- Volunteers from another group to test the mixers
- Towels to dry up

Fair testing and fun

- Safety first: How close are your hands to the beaters?
  Hold the mixer and turn the handle. Measure the closest distance from hand to beater with a ruler. It should be at least 10 cm (≈ 4 in).

- How fast do the beaters turn?
  Turn the handle once. Count how many turns of the beaters – the more the better.
  Your beaters should be able to turn at least five times faster than the handle.

- How well does the mixer work? How efficient is it?
  Each mixer must mix the same amount of soapy water for the same time to constitute a fair test. Place your test volunteers in front of the test bowls (with NO BUBBLES on top). Start the stop watch and start the mixers. Stop after one minute.
  Quickly measure the depth of bubbles – the more the better.

- How comfortable, easy, and safe to use is it?
  Check the volunteer's hands. Count the marks left from gripping the mixer – the more there are, the more uncomfortable it is to use. Ask them to rate how easy it was to use (1 for hard; 5 for very easy). How many accidents did they have – the less the better!
  The most efficient mixer will make more bubbles, more quickly with greater comfort and ease of use.

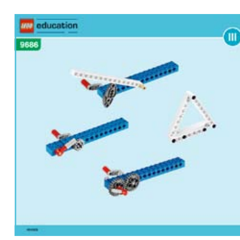
Extra challenges

- Make a super-safe mixer with a drive mechanism that slips if you get a finger or a tie stuck in the beaters.
- Turn it into a dough mixer! The beaters should turn as slowly as possible compared to the handle. Try it for real with flour and water.
- Can you adapt your mixer to become a washing machine? Make a top-loading washing machine in a cup. Use tiny squares of cloth with sauce as the test clothes. As you turn the handle one way, the beaters should rotate back and forth.

Need help?
Look at:

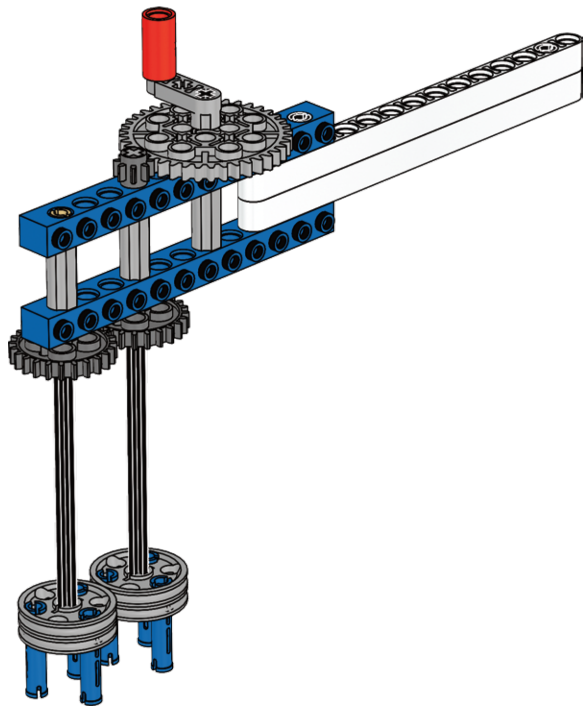
Sweeper

Flywheeler



Principle Models Building Instructions booklet for gears and pulleys

Suggested model solution



The Lifter

The problem

Jack, Jill and Zog have a wonderful tree house, but it’s hard work climbing up and down.
It’s even more difficult if they want to stock up with supplies.

Can you help Jack and Jill come up with a solution?

Design brief

Design and make a motorised lift that can carry:
• at least 50 g (or approximately 1 weight brick)
• an object at least 20 cm into the air

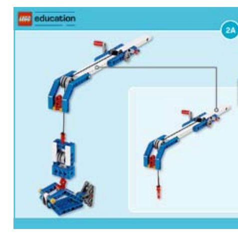
1. Make a sketch of the idea you designed and made.

2. Label the three most important parts, explaining how they work.

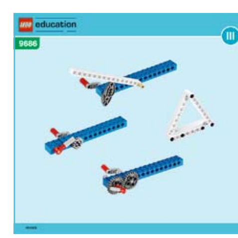
3. Suggest three improvements.

Need help?
Look at:

Power Car



Fishing Rod



Principle Models Building Instructions booklet for gears and levers

The Lifter

Objectives
Applying knowledge of:
- Pulleys
- Gears
- Forces
- Applying principles of fair testing and product safety

Other materials required
- A ruler

Fair testing and fun
- Does it lift smoothly and at a safe speed?
  The smoother it lifts, the better. If the lift is too fast, it is not safe.

- Without supporting or stopping it from tilting, test how much the lift can carry.
  The more it can carry without tilting, the better.

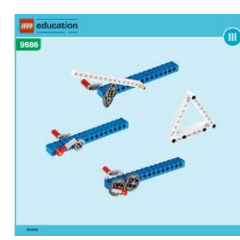
- Load the lift and test how much it can carry before the motor stalls.
  The more, the better.

Extra challenges
- Construct a mechanism that makes a sound when the supplies have reached the tree house.

Need help?
Look at:

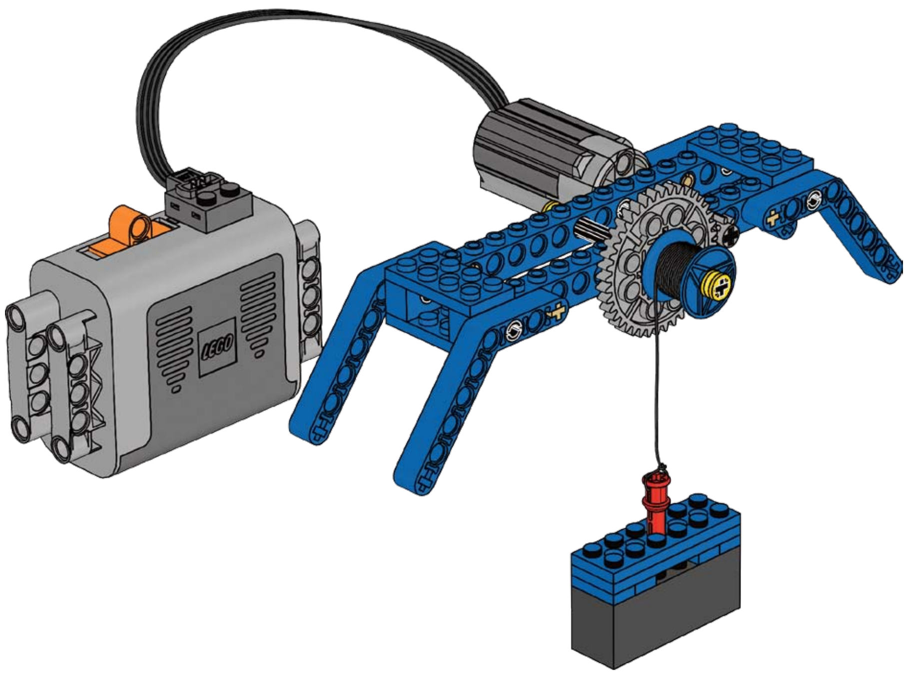
Power Car

Fishing Rod



Principle Models Building Instructions booklet for gears and levers

Suggested model solution



The Bat

The problem

Jack, Jill and Zog are at school performing their own play called Ghost of the Bat Cave.
Zog doesn't want to be the bat; he would much rather be a ghost or a dangerous dragon.

Can you help Jack and Jill design a bat for their play?

Design brief

Design and make a motorised bat that:
- can flap its wings
- has eyes
- is easy to hold

1. Make a sketch of the idea you designed and made.

2. Label the three most important parts, explaining how they work.

3. Suggest three improvements.

Need help?
Look at:

The Walker

Principle Models Building Instructions booklet for gears and levers

The Bat

Objectives
Applying knowledge of:
- Levers and gears
- Cams, cranks and timing actions
- Applying principles of fair testing and product reliability

Other materials required
- A ruler
- Stopwatch or timer
- Decorative materials: wool, foil, card, paper, etc.
- Sticky tape

Fair testing and fun
- How wide is the bat's wingspan?
  Measure with a ruler. The wider, the better.

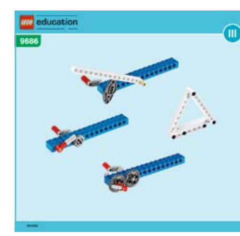
- How many times per 15 seconds does the bat flap its wings?
  The more flaps per 15 seconds, the better.

- Can the bat flap at different intervals?
  Have the children show how this is done if possible?

Extra challenges
- Add another movement to the bat – it could be eye or ear movement.
- Decorate the bat to make it look as realistic as possible.

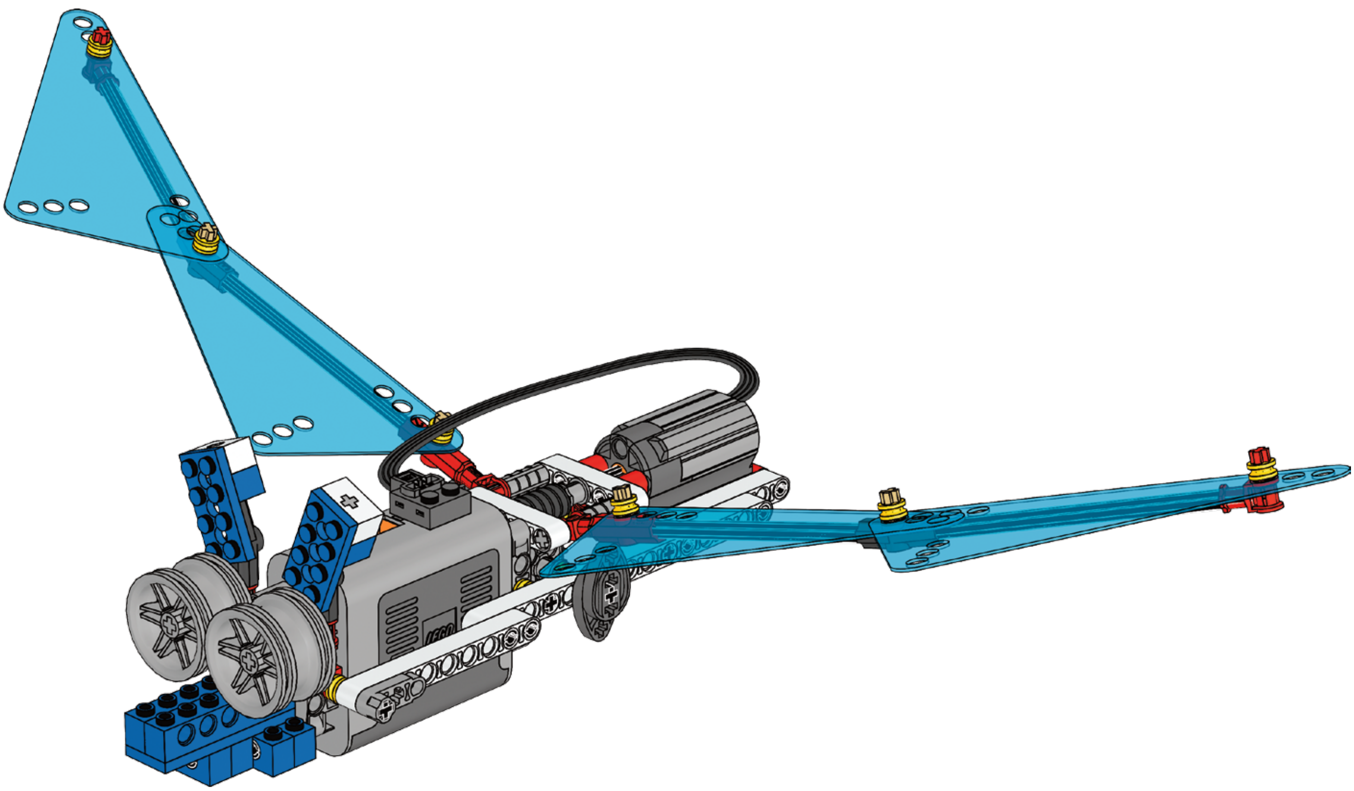
Need help?
Look at:

The Walker



Principle Models Building Instructions booklet for gears and levers

Suggested model solution



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.

Anvil — A very heavy, flat, block of steel or iron on which heated metals are shaped by hammering.

Axle — A rod through the center 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.

Block and tackle — An arrangement or system of pulleys and line so that the ability to lift a very heavy object requires far less force

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 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-center on a shaft is used as a cam.

Compression forces — Forces in a structure that push in opposite directions, trying to crush 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.

Counter balance 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.

Crank An arm or handle connected to a shaft (or axle) at right angles enabling the shaft to be easily turned.

D

Driven gear See Follower.

Driver The part of a machine, usually a gear, pulley, lever, crank or axle, where the force first comes into the machine.

E

Efficiency 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.

Effort The force or amount of force that you or something else puts into a machine.

Energy The capacity to do work.

Escapement A control mechanism in a timer that stops energy from escaping too quickly; for example, a spring or falling weight. Usually it ticks!

F

Fair testing Measuring the performance of a machine by comparing its performance under different conditions.

Flywheel 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.

Follower Usually a gear, pulley, or lever driven by another one. It can also be a lever driven by a cam.

Force A push or a pull.

Friction The resistance met when one surface is sliding over another, for example, when an axle is turning in a hole or when you rub your hands together.

Fulcrum See Pivot.

G

Gear A toothed wheel or cog. The teeth of gears mesh together to transmit movement. Often called a spur gear.

Gear, crown 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°.

Gear, rack 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.

Gear, bevel — Gear with teeth that are cut at a 45° angle. When two bevel gears mesh, they change the angle of their axles and movement through 90°.

Gear, worm — A gear with one spiral tooth resembling a screw.
Mesh it with a pinion to deliver large forces very slowly.

Gearing down — A small driver turns a larger follower and amplifies the force from the effort, but the follower turns more slowly.

Gearing up — A large driver turns a smaller follower and reduces the force from the effort, but the follower turns more quickly.

Gearing, compound — 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.

Grip — The grip between two surfaces depends on the amount of friction between them. Tires grip dry road surfaces better than wet road surfaces.

I

Idler — A gear or pulley that is turned by a driver and then just turns another follower. It does not transform the forces in the machine.

Inclined plane — 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.

J

Jib — A triangular sail at the very front of a sailing boat.

K

Kinetic energy — The energy of an object that is related to its speed.
The faster it travels, the more kinetic energy it has.
See also potential energy.

L

Lever — A bar that pivots about a fixed point when an effort is applied to it.

Lever, first class — The pivot is between the effort and the load.
A long effort arm and short load arm amplifies the force at the load arm, for example, when prying the lid off a can of paint.

Lever, second class — The load is between the effort and the pivot.
This lever amplifies the force from the effort to make lifting the load easier, for example, in a wheelbarrow.

Lever, third class — The effort is between the load and the pivot.
This lever amplifies the speed and distance the load moves compared to the effort.

Linkages — 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.

Load — 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.

M

Machine — A device that makes work either easier or faster to do. It usually contains mechanisms.

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 you still have a mass of 70 kg. Mass is often confused with weight.

Mesh — The way gears contact each other by fitting together

Member — The name given to individual parts of a structure, for example, 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 example, 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 is used, not weight because momentum isn't dependent on gravity.

N

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

O

Oscillating — Moving back and forth in steady pattern

P

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 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.
	Pulley, movable	Changes the amount of applied force needed to lift the load. A movable pulley moves with the load.
R	**Rack (gear rack)**	A specialized gear in the shape of a flat bar with teeth.
	Reciprocating	Moving back and forth over and over again
	Renewable energy	Energy from a renewable source such as sunlight, wind or flowing water.
	Resetting	Turning a pointer on a scale back to zero again.
	Rigid	A rigid material does not easily stretch or bend and does not deform under load.
	Rotary movement	Motion in a circle like a wheel moving around an axle
	RPM	Revolutions or turns per minute. This is usually the measure of speed of a motor. The LEGO® motor turns at about 400 rpm unloaded (when it is not driving a machine).
S	**Sequencing**	Setting up actions to happen in the right order and at the correct time intervals. Cams are often used for this purpose.
	Sheave	A pulley wheel with a grooved rim. The groove is used to hold a rope, belt, or cable so that it does not slip off the wheel.
	Slip	A belt or rope slipping, usually on a pulley wheel as a safety feature.
	Speed	Rate or measure of motion; To calculate the speed of a vehicle, we divide the distance travelled by the time taken, 45 mph.
	Strut	A member of a structure that is in compression. Struts prevent parts of structures from moving towards each other.
T	**Tare**	Adjust the weight on a scale so that the weight of the container is removed and only the weight of the product is measured.
	Tensile forces	Forces in a structure that pull in opposite directions trying to stretch the structure.
	Tie	A member of a structure that is in tension. Ties prevent parts of structures from moving apart, in other words, they 'tie' the members together.
	Torque	The turning force coming from an axle.
	Transmission	A system of gears or pulleys with an input and one or more outputs. A gearbox contains a transmission, and so does a clock.
U	**Unbalanced force**	A force that is not opposed by an equal and opposite force. An object feeling an unbalanced force must begin to move in some way.

V

Velocity — The rate of at which an object changes position; for example, velocity is given in a rate and direction 45 mph west.

W

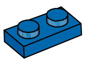
Weight — How much an object weighs based on the force of gravity pulling on the object; an object can have different weights based on location such as on Earth or Moon.

Wind resistance — The force that air (wind) creates by pushing back on a vehicle or object that is trying to push through it.
A streamlined shape creates less air (wind) resistance.

Work — Product of the force needed to move an object by the distance it is moved (force x distance). See also Power.

education

LEGO® Element Survey



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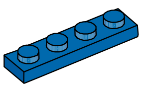
Plate, 1x2, blue
302323



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Plate, 1x4, blue
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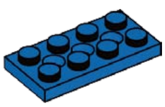

6x
Plate with holes, 2x4, blue
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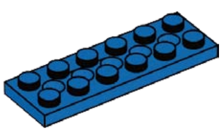
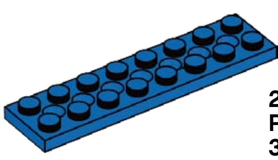
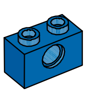


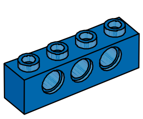
8x
Plate with holes, 2x6, blue
4114027



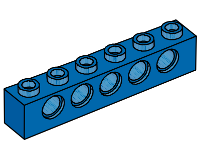
2x
Plate with holes, 2x8, blue
373823



4x
Studded beam, 1x2, blue
370023



4x
Studded beam, 1x4, blue
370123



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Studded beam, 1x6, blue
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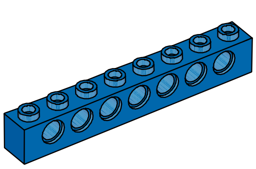
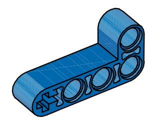
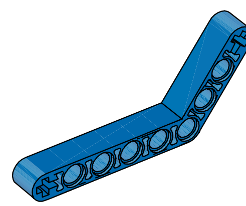


4x
Studded beam, 1x8, blue
370223

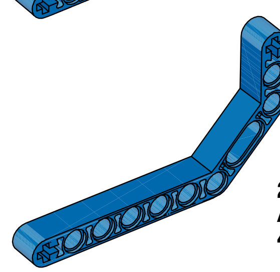
10x
Connector peg with friction,
3-module, blue
4514553



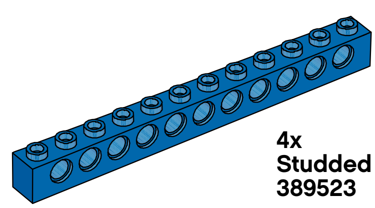
8x
Angular beam, 4x2-module, blue
4168114



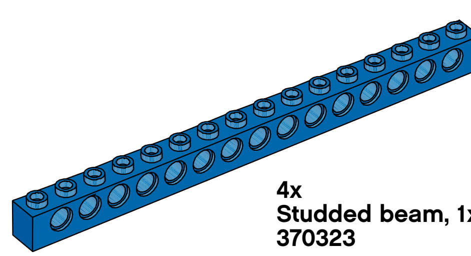
4x
Angular beam, 4x6-module, blue
4182884



2x
Angular beam, 3x7-module, blue
4112000

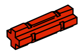


4x
Studded beam, 1x12, blue
389523

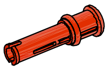


4x
Studded beam, 1x16, blue
370323

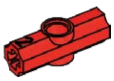
2



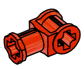
14x
Axle, 2-module, red
4142865



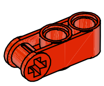
14x
Connector peg with bushing, red
4140806



4x
Angular block, 2 (180°), red
4234429

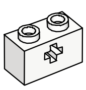


10x
Angular block with crosshole, red
4118897

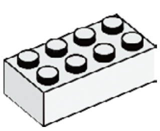


4x
Cross block, 3-module, red
4175442

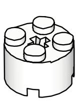
2x
Tube, 2-module, red
4526984



4x
Studded beam, 1x2 with crosshole, white
4233486



2x
Brick, 2x4, white
300101



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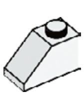
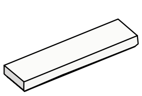
Brick, 2x2 round, white
614301



4x
Roof brick, 1x2/45°, white
4121932



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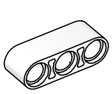
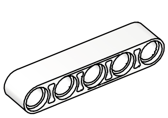
Tile, 1x4, white
243101



2x
Beam, 3-module, white
4208160



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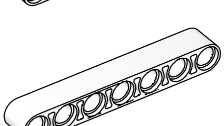
Beam, 5-module, white
4249021



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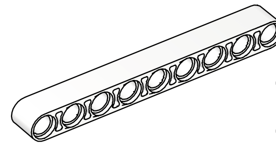
Beam, 7-module, white
4495927



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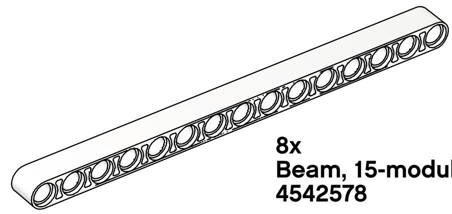
Beam, 9-module, white
4156341



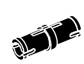
8x
Beam, 15-module, white
4542578

2x
Steering arm, black
4114670

2x
Bearing for steering arm, black
4114671

4x
Angular block, 1 (0°), dark grey
4210658

4x
Angular block, 3 (157,5°), black
4107082

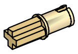


28x
Connector peg with friction, black
4121715

4x
Tyre, 30,4x4, black
281526

4x
Tyre, 30,4x14, black
4140670

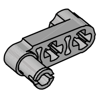
4x
Tyre, 43,2x22, black
4184286



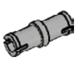
12x
Connector peg with axle, beige
4186017

4x
Connector peg, 3-module, beige
4514554

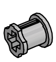
16x
Bushing, ½-module, yellow
4239601



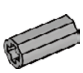
4x
Connector peg, handle, grey
4211688



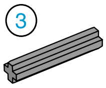
8x
Connector peg, grey
4211807



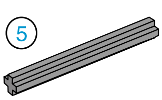
16x
Bushing, grey
4211622



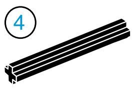
8x
Axle extender, 2-module, grey
4512360

3


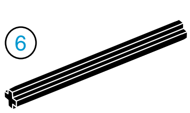
8x
Axle, 3-module, grey
4211815

5


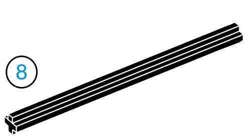
4x
Axle, 5-module, grey
4211639

4


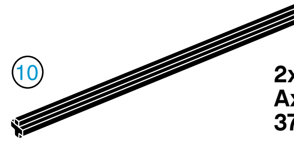
8x
Axle, 4-module, black
370526

6


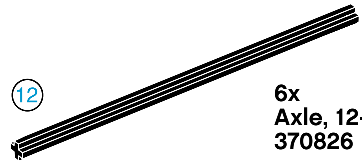
2x
Axle, 6-module, black
370626

8


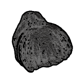
2x
Axle, 8-module, black
370726

10


2x
Axle, 10-module, black
373726

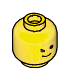
12


6x
Axle, 12-module, black
370826

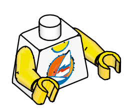


1x
Minifigure, ponytail wig, black
609326

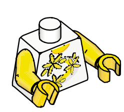
1x
Minifigure, cap, red
448521



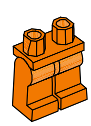
2x
Minifigure, head, yellow
9336



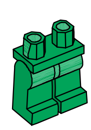
1x
Minifigure, body, white with surfer
4275606



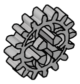
1x
Minifigure, body, white with flowers
4275536



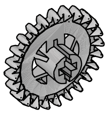
1x
Minifigure, legs, orange
4120158



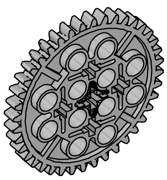
1x
Minifigure, legs, green
74040



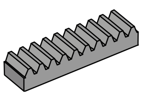
2x
Gear, 16-tooth, grey
4211563



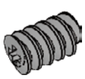
4x
Gear, 24-tooth crown, grey
4211434



2x
Gear, 40-tooth, grey
4285634



2x
Gear, 10-tooth rack, grey
4211450



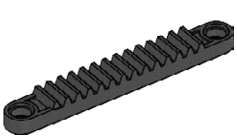
2x
Worm gear, grey
4211510

1x
Differential, 28-tooth, dark grey
4525184

4x
Gear, 24-tooth, dark grey
4514558

6x
Gear, 8-tooth, dark grey
4514559

2x
Gear, 12-tooth double bevel, black
4177431

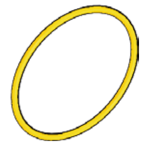


1x
Gear, 14-tooth rack, black
4275503

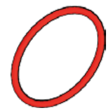
6x
Gear, 12-tooth bevel, beige
4514556

2x
Gear, 20-tooth bevel, beige
4514557

2x
Gear, 20-tooth double bevel, beige
4514555

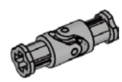


2x
Belt, 33 mm, yellow
4544151

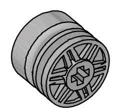


2x
Belt, 24 mm, red
4544143

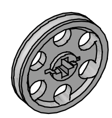
2x
Belt, 15 mm, white
4544140



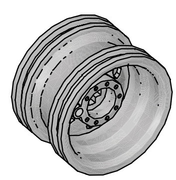
1x
Universal joint, 3-module, grey
4525904



4x
Hub, 18x14, grey
4490127

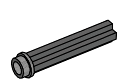


4x
Hub, 24x4, grey
4494222



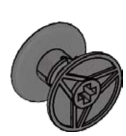
4x
Hub, 30x20, grey
4297210

6x
Connector peg, 1½-module, dark grey
4211050

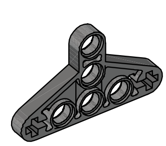


4x
Axle with knob, 3-module, dark grey
4211086

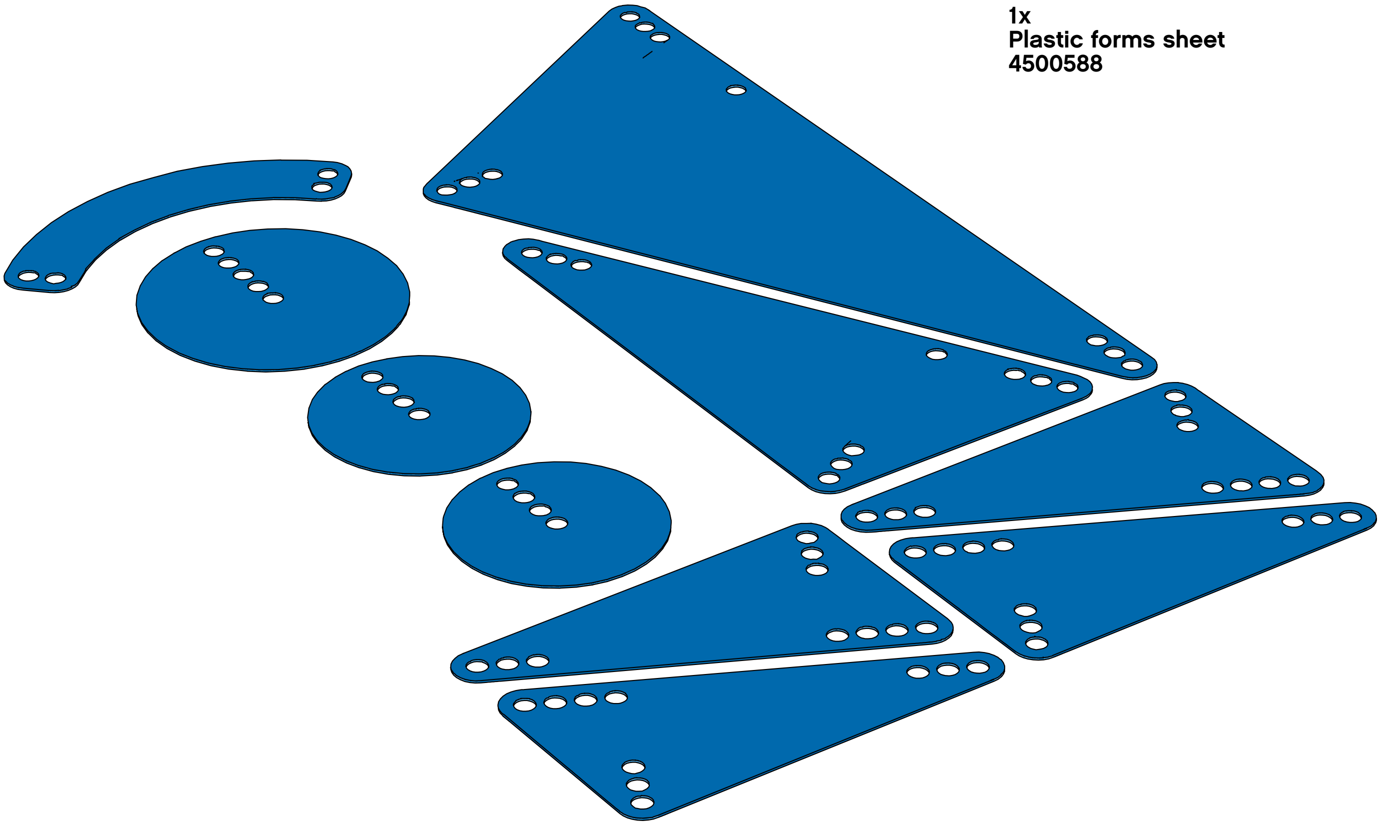
4x
Cam wheel, dark grey
4210759



1x
Bobbin, dark grey
4239891

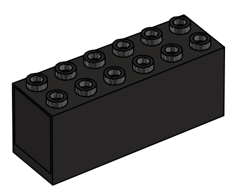


2x
½ beam, triangle, dark grey
4210689

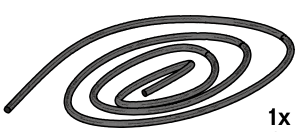


1x
Plastic forms sheet
4500588

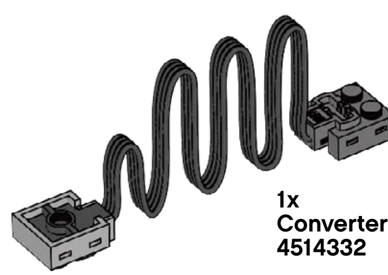
2x
String, 40-module with knobs, black
4528334



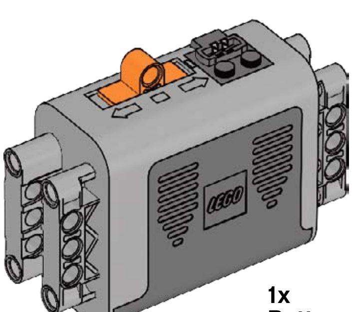
1x
Weight element, black
73843



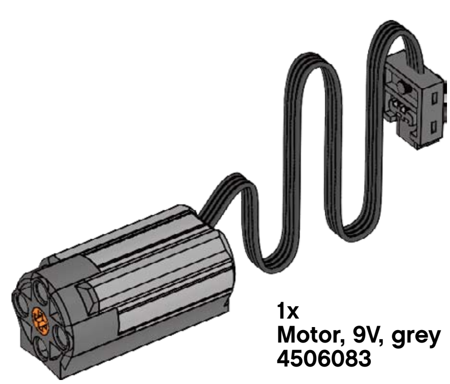
1x
String, 2 m, black
4276325



1x
Converter cable, black
4514332



1x
Battery box, 9V, grey
4506078



1x
Motor, 9V, grey
4506083

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