CODESKILLS
4ROBOTICS

MODULE 3:

TAKING EDUCATIONAL ROBOTICS COURSES A STEP FURTHER

CODESKILLS4ROBOTICS: Promoting Coding & STEM Skills through Robotics: Supporting Primary Schools to Develop Inclusive Digital Strategies for All

IO2: CODESKILLS4ROBOTICS Dual Digital Educational Back Pack for Primary Schools

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ΙΔΡΥΜΑ ΚΡΑΤΙΚΩΝ ΥΠΟΤΡΟΦΙΩΝ
ΙΚΥ

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CODESKILLS 4ROBOTICS

Table of Contents

CODESKILLS 4ROBOTICS

Chapter 1: Robotic Arm

Aim

The aim of the 1st unit is to help students to familiarize with the construction and operation of a simple robotic composition with a single motor.

Objectives

After the implementation of the teaching scenarios students should be able to:

- use the designs that are given to them to carry out the construction.
- use programming commands (motion, repeat, delay commands) to control the motor, sound sensor and LED light.
- make assumptions about the expected result of their construction and how it will function depending on the order of the programming commands they use.
- verify this reasoning through an experimental process.
- evaluate how they should adjust the parameters of each command in order to have the desired effect on the activities to be performed.
- explain how the force of inertia affects the stopping of motion of a ball according to its mass.

Introduction

The construction of the first module is a simple arm that can rotate its end in a complete circle. The aim is to help students to familiarize with the use of the equipment and, working in groups, to actually assemble a robotic arm themselves. The simplicity of the construction leads to its quick assembly, allowing more time for programming the robot. Students, through the activities, get a complete picture of educational robotics, studying and programming the robotic arm, while they are given the opportunity to play and participate actively in the lesson. The activities of the first teaching scenario are sufficient and, thus, can be divided into two different lessons, always depending on the available teaching time.

It is possible to combine two or more robotic arms in more complex tasks, thus enabling students to program the robots to synchronize their movements. This leads to the creation of a new construction, through which the arms will cooperate, sending the ball to each other successively. Students, though this activity, will have a better chance to understand the concept of synchronization and collaboration by appropriate configuration of commands.

Once students understand the way the robotic arm works and realize that it always hits the ball in a certain way, we can move on to the concept of inertia and its observation.

Questions to study

When learning the motion command, the instructor needs to make sure that students reflect on it through questions. Such questions could be: "how is the motion of the arm affected by the degrees that we will set as a parameter in the command which moves its joint", and "how is the direction of rotation of the arm related to the negative value that we will give as a parameter to the command”.

After the reflection phase, the instructor should analyze the effect that the drive command has on the motor. This should happen without having assembled the robotic arm. The instructor could, for example, have only the motor connected to the basic unit and make a short demonstration using a tablet. Then, in collaboration with the students, the external motor drive command can be configured, giving them the chance to test different variants. Students can be asked to predict what the result of the drive will be for each configuration and before the command is actually executed. The ability to predict the outcome indicates the understanding of the concept. The rest of the commands in the section are presented in a similar way.

In order to present and analyze the concept of inertia two different ping pong balls, one regular and one full of a material that solidifies e.g. plaster, can be used. Students will be able to tell the difference in their weight, despite their resemblance in terms of appearance. Thus, a question arises: "whether the two balls will have the same behavior, if they are hit by the robotic arm in the exact same way".

The preparation of students and the introduction to the concepts need to be short compared to the time in which students will actually engage with the activities and suitable to their educational background. The activities from the teaching scenario should always be selected according to the total teaching time available and the level of the students.

Proposed assembly instructions

To build the arm of Figure 1, students will have to follow the assembly steps as shown in the following photos.

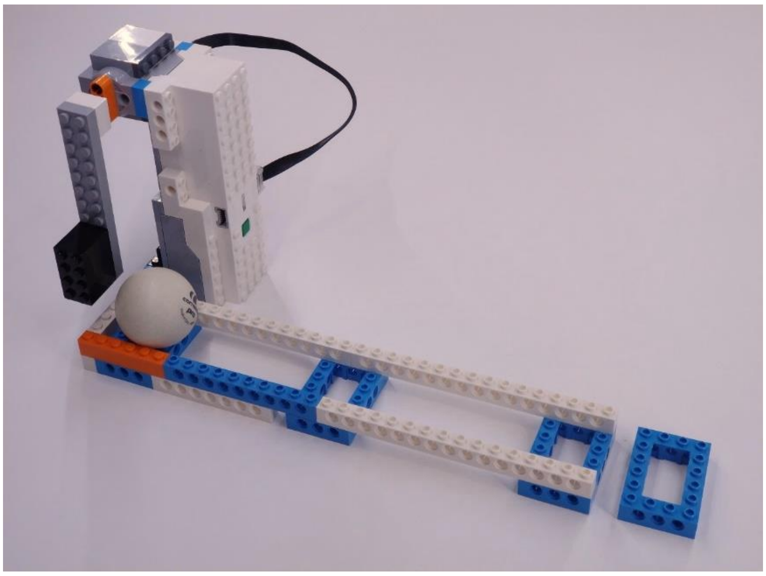
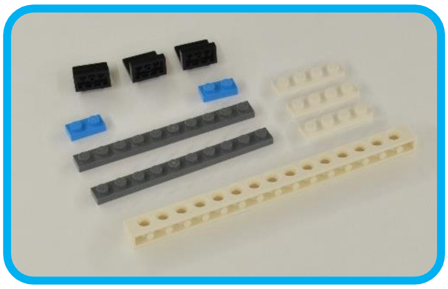
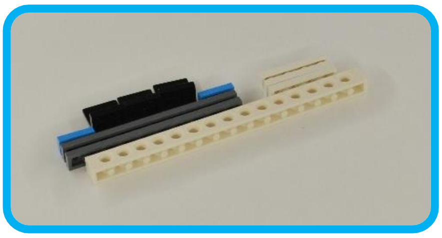
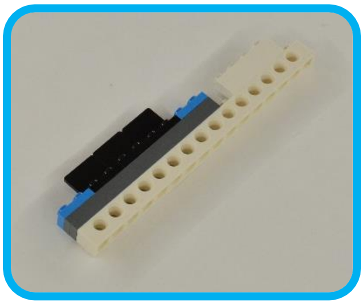
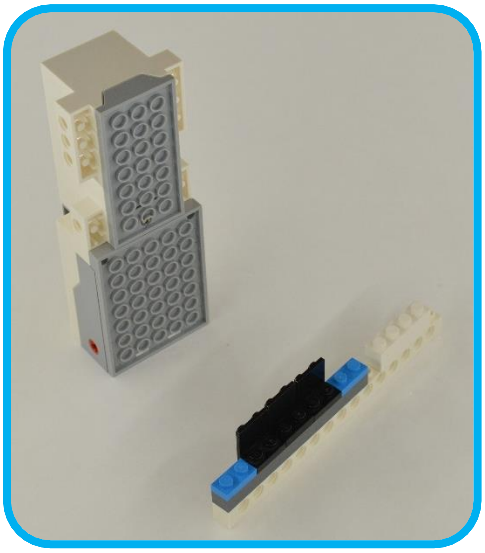


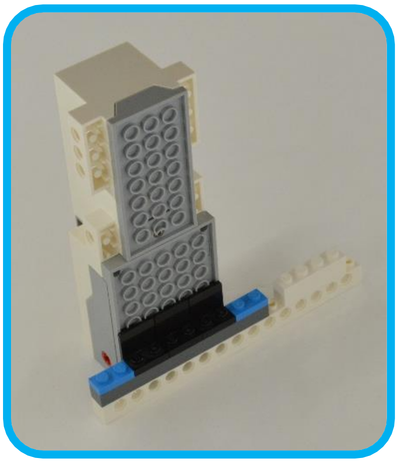
Figure 1 – Robotic Arm

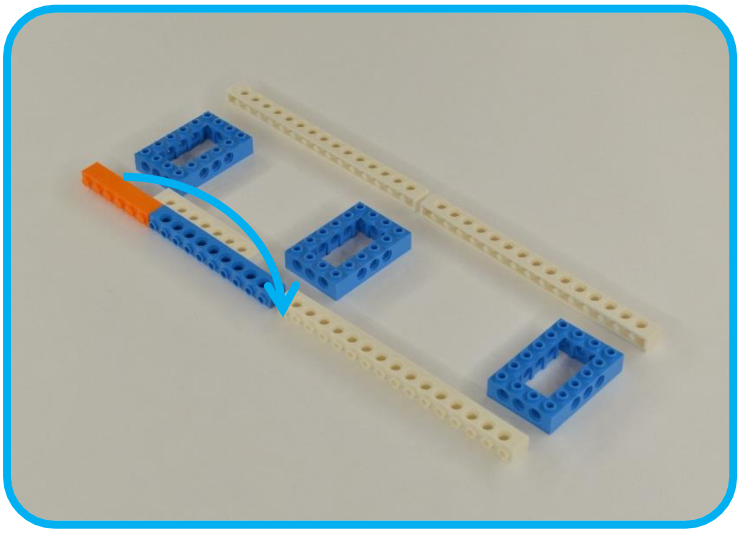


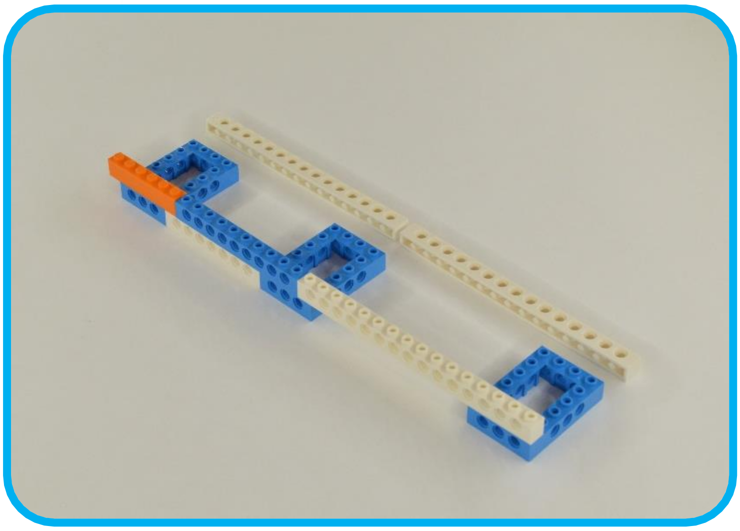


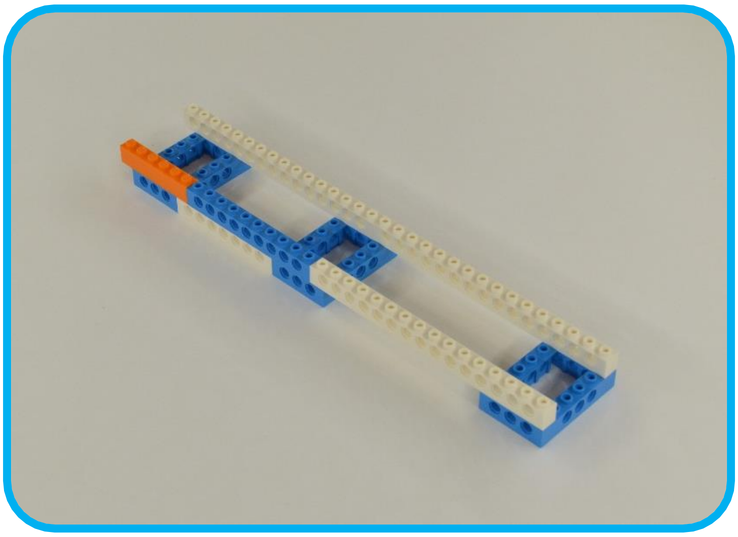


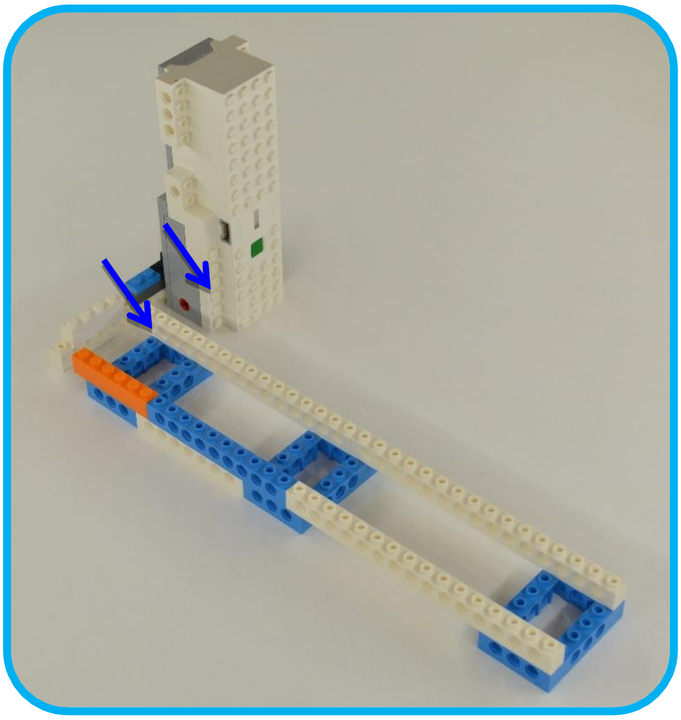


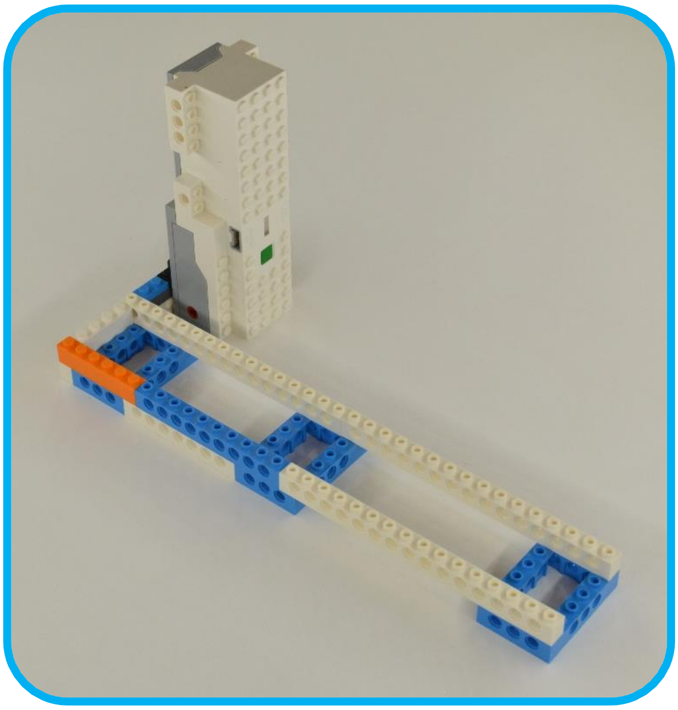


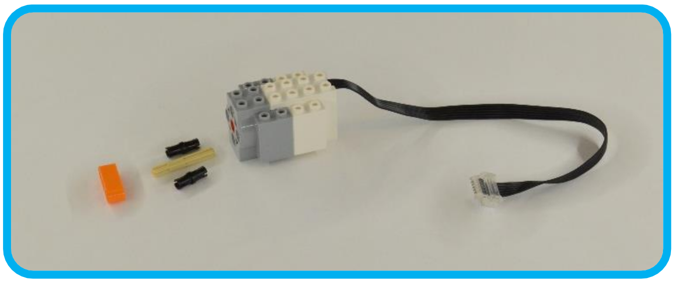


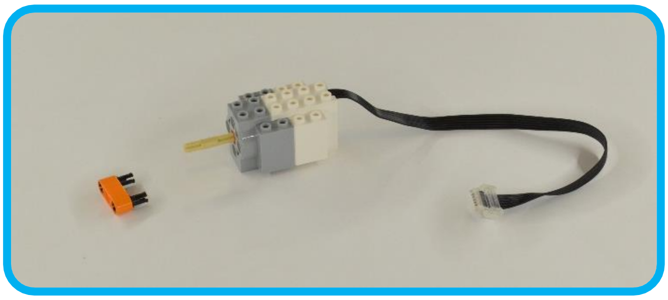


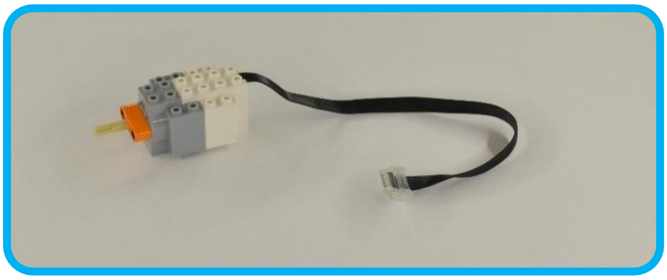


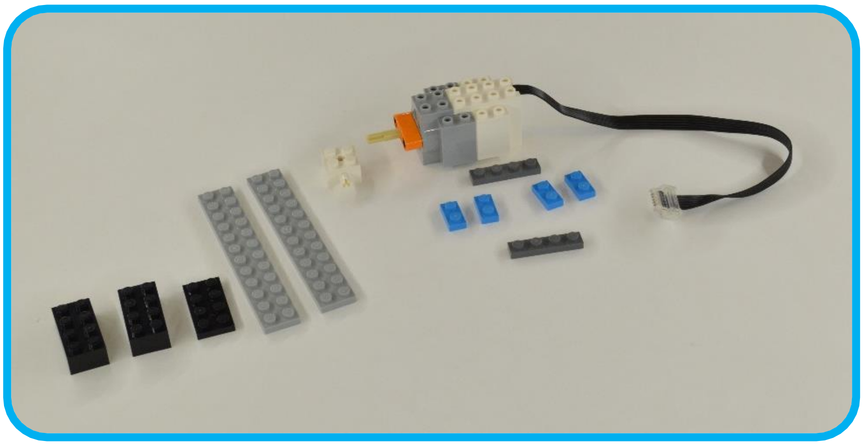


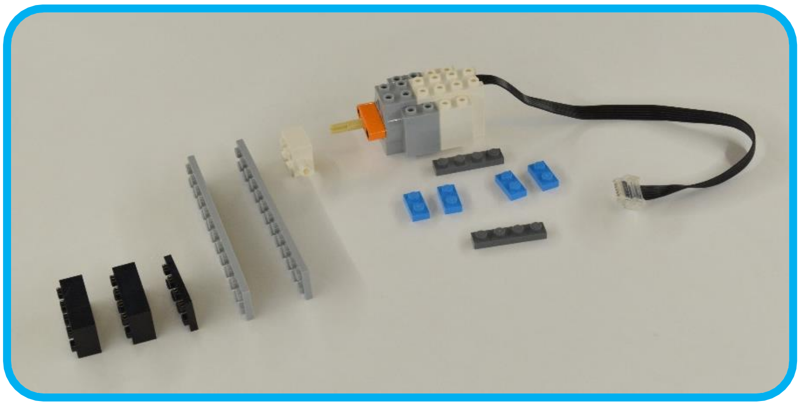


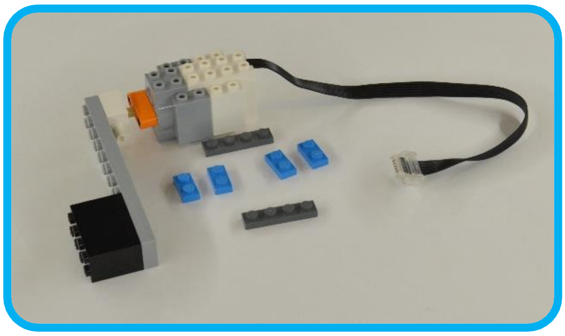


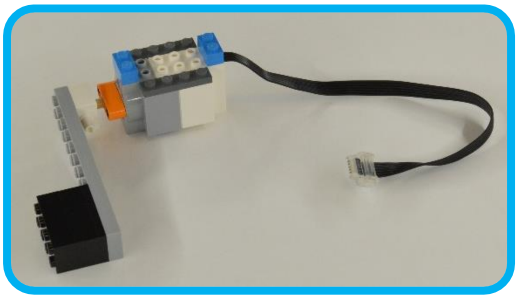


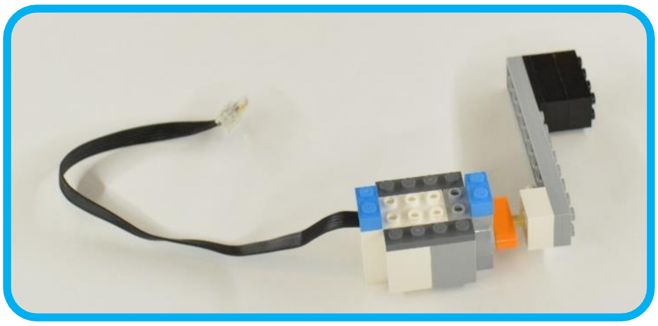


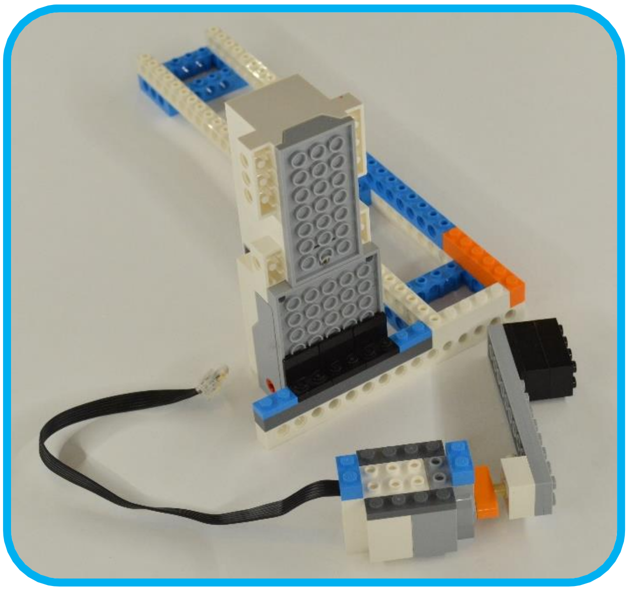


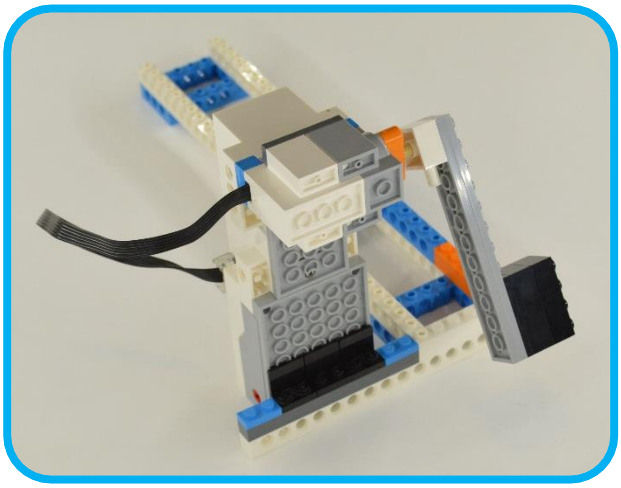






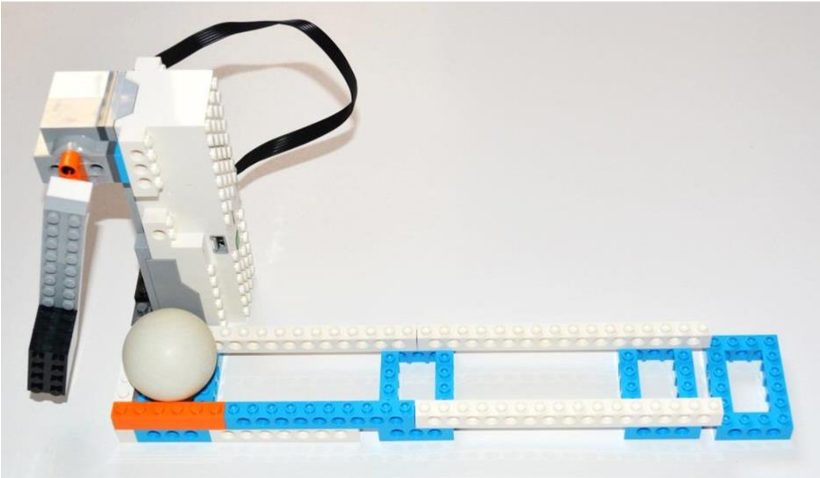






Teaching Scenario “Basic Concepts”

1 Follow the assembly steps in order to build the robotic arm.



2 Program the robotic arm to hit the ball. The ball should roll on the lane.

3 Program the robotic arm to hit the ball again. This time the ball should roll on the lane more slowly.

4 Now we have limited space available. Let’s suppose that the robotic arm is inside a shelf and its moving part is not allowed to exceed the height above that of its base. Program the arm to hit the ball (motion in degrees).

5 Program the robotic arm to hit the ball and then return to its original position, ready to strike it again.

6 Program the robotic arm to make a sound, then hit the ball and finally return to its original position.

7 Program the robotic arm to function in exactly the same way as before, but now repeat the whole process four times.

8 The previous program does not allow us to reposition the ball between repetitions. Extend it appropriately in order to wait for some time giving us the chance to put the ball back in place.

Teaching Scenario “Collaborative creations”

Lane with two robotic arms

Place the two robotic arms opposite each other in such a way that the lane of one is the extension of the other. Join the lanes with blocks (Figure 2 , Figure 3).

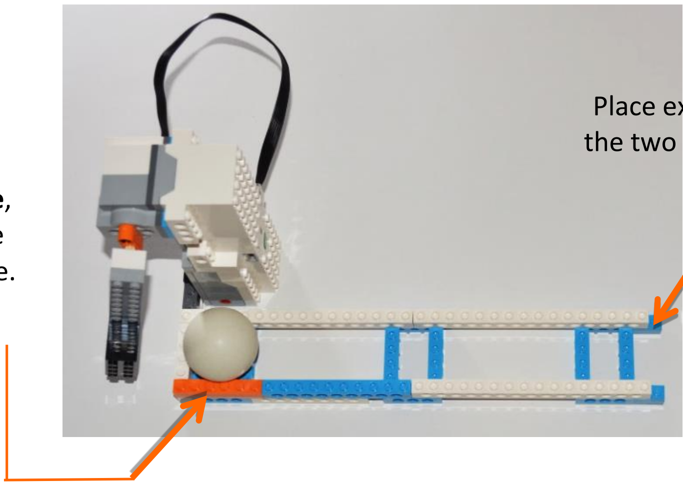


Figure 2 The way of connecting the lanes depending on the desired schema

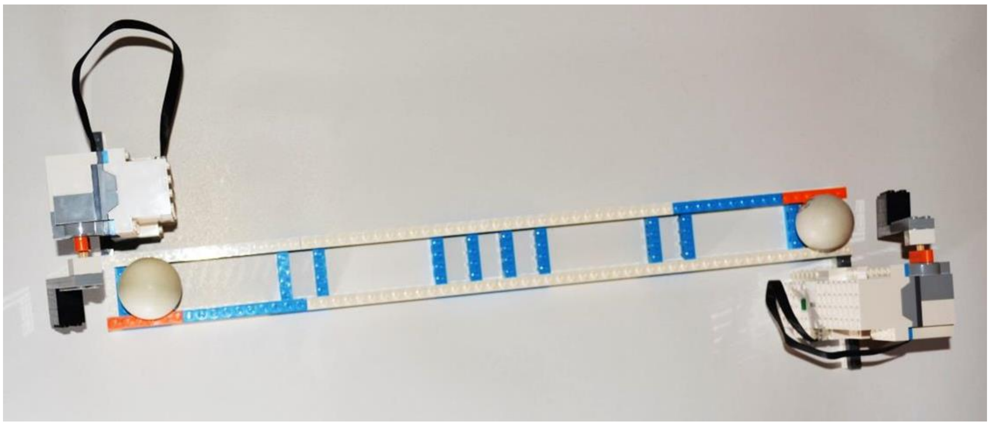


Figure 3 Final form of the two lanes joined together

Each team programs its own robotic arm in order to hit the ball in such a way as to reach the end of the lane and stay there. Try to operate both arms at the same time, using one ball. This way, one arm sends the ball to the other and the second arm sends it back. (Think about where each team should use the delay command).

Can you repeat the aforementioned several times in a row?

Square lane using four robotic arms

Combine four different robotic arms in such a way that their lanes form a square (Figure 4). To join them, you must remove the orange part of each lane (Figure 2) and the end of the lane of the following arm must be placed in the gap that is created. When you are done, in every corner of the square there will be a robotic arm, which will push the ball along its side and so on.

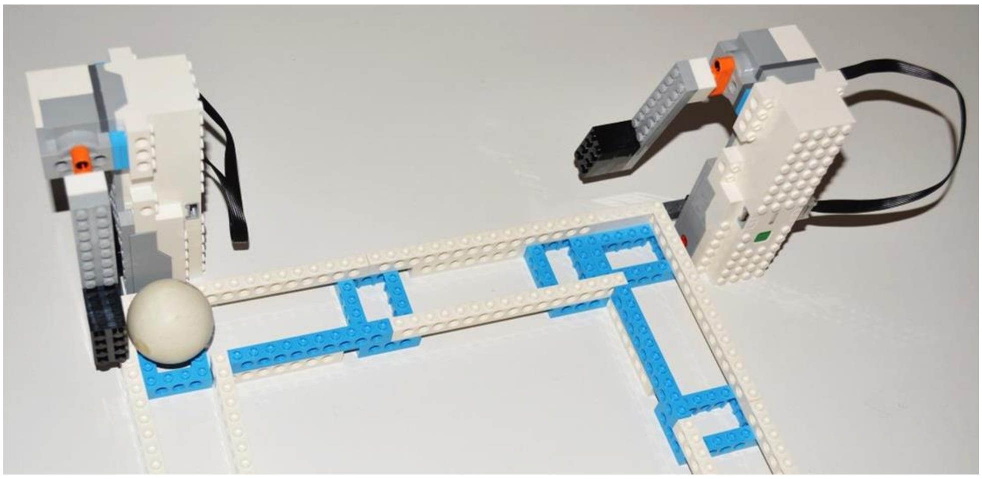


Figure 4 One side of the square lane with arms at its begging and end

Each team will program its own robotic arm. All arms must be activated at the same time. (Imagine that the hitting of the arm should push the ball to the other corner and then it should stay there. Moreover, each arm needs to wait a while until it receives the ball. In order for this to happen, you need to appropriately adjust the force in the motor command, as well as the standby time in the delay command).

Can you repeat the aforementioned several times in a row?

Teaching scenario "Observation of the phenomenon of inertia"

1 For starters, assemble the robotic arm of module 1, and then place a rectangular piece in front of it, without it being connected (Figure 5).

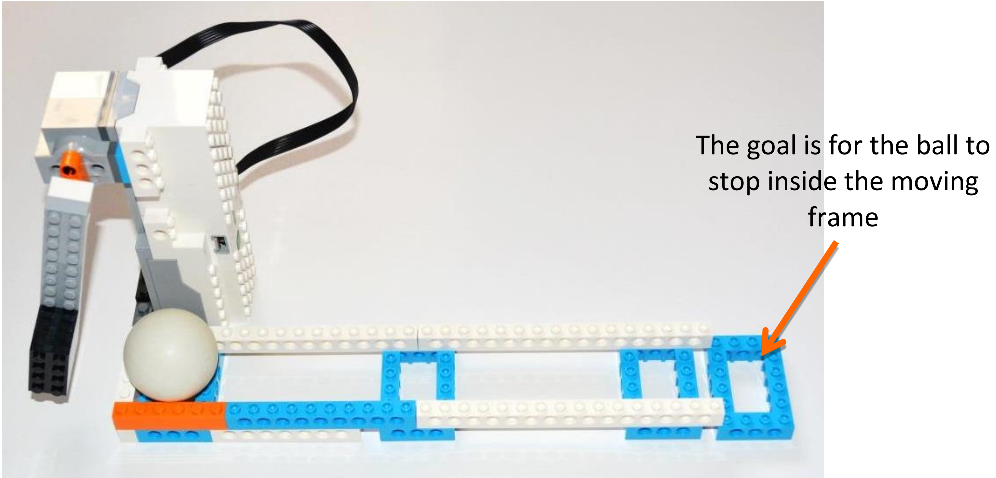


Figure 5 Robotic arm used for the obsevation of the inertia phenomenon

2 Program the robotic arm to:

A hit the lighter ball so that it ends up in the blue rectangular piece placed in front of the lane.

B Repeat the same process with the heavier ball without changing your program. Notice how each ball stops. Is the result the same in both cases? Describe what you observe.

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3 Place both balls on the lane in such a way that:

A at first the arm will hit the lighter ball which will in its turn hit the heavier ball that will enter the blue rectangle.

B Repeat the same by swapping the balls.

Observe what happens and comment below.

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Chapter 2 Vehicle in straight motion

Aim

The aim of the 2nd module is to help students to correlate the geometry of the wheels with the distance that the robotic vehicle will travel. Students will deal with examples applicable to real vehicles and through them they will be able to understand concepts of physics such as sliding.

Objectives

After the implementation of the teaching scenarios students should be able to:

- measure the perimeter of the wheel of the robotic vehicle with a tape measure.
- understand the correlation between the wheel perimeter and the distance which the vehicle will travel in one rotation of the wheel.
- configure the motion command in order for the robotic vehicle to move a certain distance.
- develop their own programs in order for the robotic vehicle to move at a certain distance and direction.
- recognize when the vehicle is slipping and when it has good traction with the ground.
- determine when we have excessive speed in a vehicle.

Introduction

In this module, we will deal with a robotic vehicle that moves only straight ahead, without using sensors. Students will be taught how to calculate the distance and direction in which their vehicle will move, depending on the motion command configuration.

At first, students will measure the perimeter of the vehicle's wheel with a tape measure (Figure 6). Then, they will program both wheels of the vehicle to move simultaneously commanding them to make one rotation. The marker attached to the vehicle will record the distance covered. Therefore, the length of the line made by the marker should match the perimeter of the wheel. However, in the case where the vehicle slips on the ground, the distance traveled will not be equal to wheel's perimeter.

The use of a measuring tape is preferred for any measurements needed, since it can be used to measure both the perimeter of the wheel and also the distance traveled by the vehicle.

Figure 6 Measurement of the wheel's perimeter as well as the distance traveled by the vehicle

The concept of slip error

Lack of traction of the vehicle on the ground results in a deviation from the expected traveled distance (which would normally be equal to the wheel's perimeter). Students are expected to observe this phenomenon. In particular, observing the rotation of the wheel will help them to recognize, on the one hand, the case where the vehicle has good traction on the ground, and on the other hand, the opposite case, where the wheel moves in the air without having good contact.

This can be done by trying different conditions that affect the motion of the vehicle, such as:

1 Using different types of wheels.

A Large wheels (included in the package) which are more slippery (Figure 7)

Figure 7 Large wheels included in the package

B Wheels made of track pieces, on which we can fasten the orange round rubber buttons, to reduce slipping (Figure 8).

Figure 8 Wheels made of track pieces

2 Changing the texture of the surfaces where the vehicle will move. We can either use glossy surfaces such as the desk surface, or paper, velvet, sandpaper.

3 Using high and low speeds in the motion of the robotic vehicle.

4 Combination of all the above.

Road safety

The parameters that affect the driving behavior of the robotic vehicle are related to laws of physics that, also, apply to real vehicles. Therefore, students will be able to see the connection between those parameters of the robotic vehicle and real cars.

When the robotic vehicle is moving at high speeds, it will often deviate from its course and, thus, it will not travel at the predetermined straight motion. Students will be able to link the role played to car accidents by external conditions, such as tires and road quality in combination with speed. This contributes to the immediate understanding of the rule: "excessive speed is the speed which, depending on the circumstances, does not allow us to control the vehicle".

Questions to study

In this module we could ask the following general question:

If two identical vehicles executing exactly the same program have wheels of different diameters, which of the two will travel the longest distance? The one with the bigger wheels or that will the smaller and why?

Another question could be: How can I determine how many centimeters the vehicle will move forward or backward?

The perimeter of the wheel will help us to know the exact distance that the vehicle will travel forward or backward.

Proposed assembly instructions

In order to build the robotic vehicle (Figure 9) students need to assemble vehicle parts as shown in the following photos. As parts they will use one of the two different types of front wheels, simple or non-slip, as well as the rear wheel and the support for the marker.

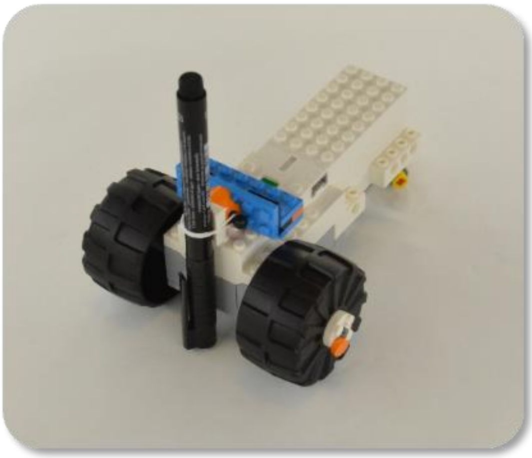
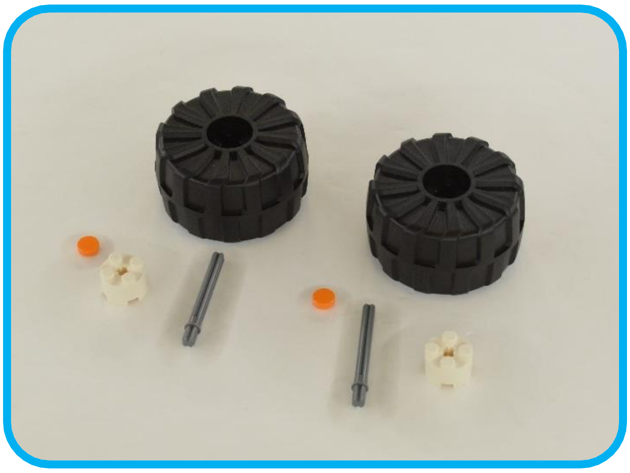
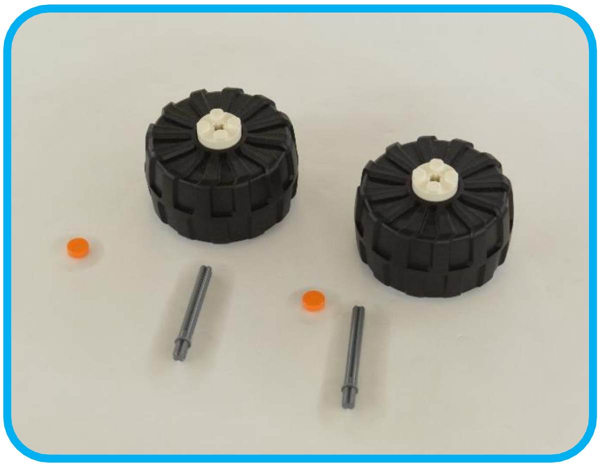


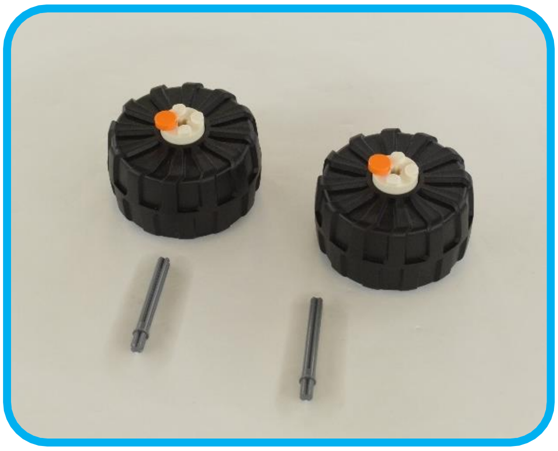
Figure 9

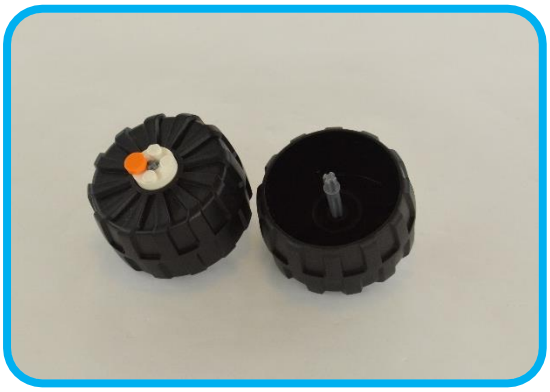
Wheels

Simple wheels

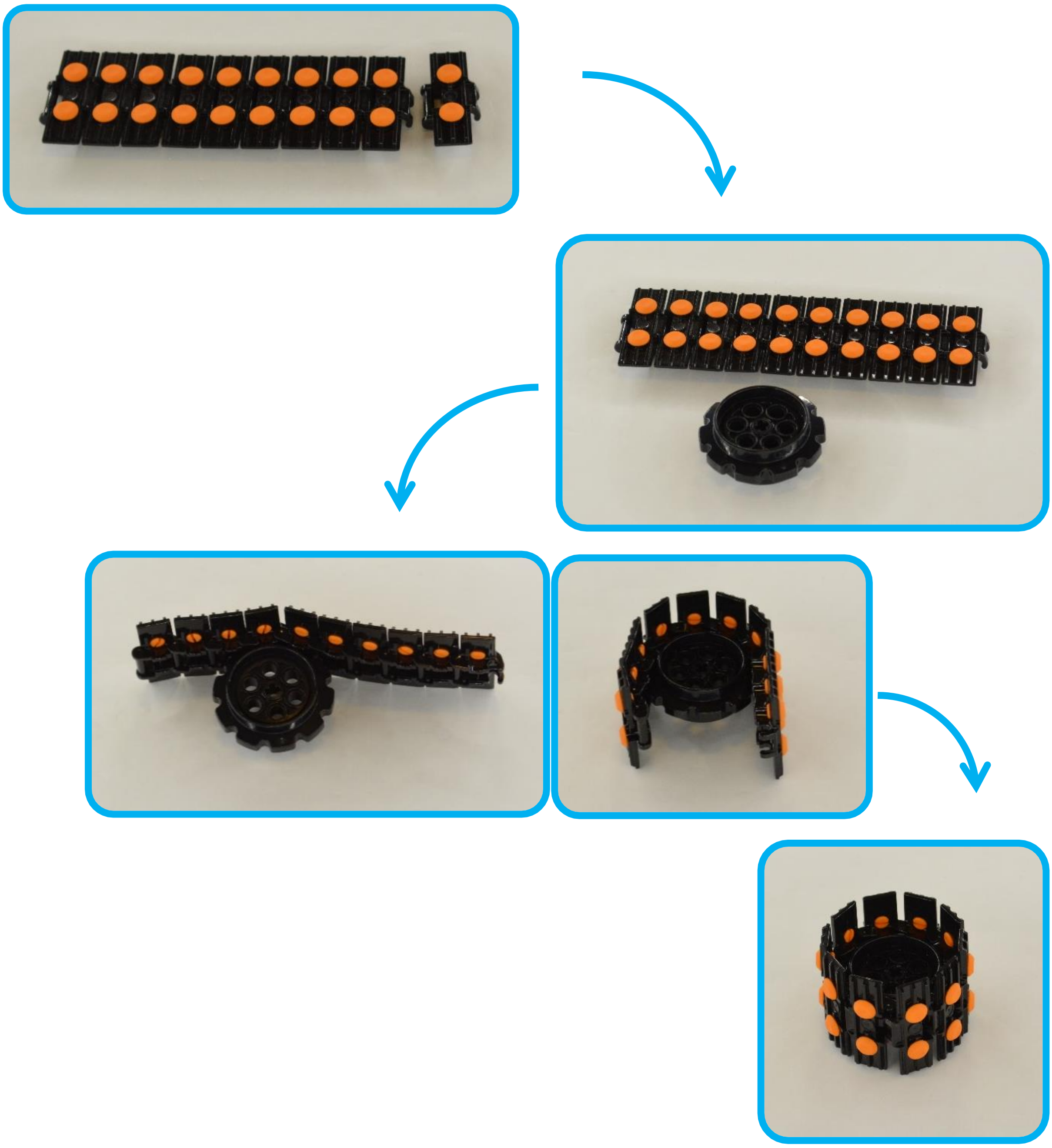








Non-slip wheels



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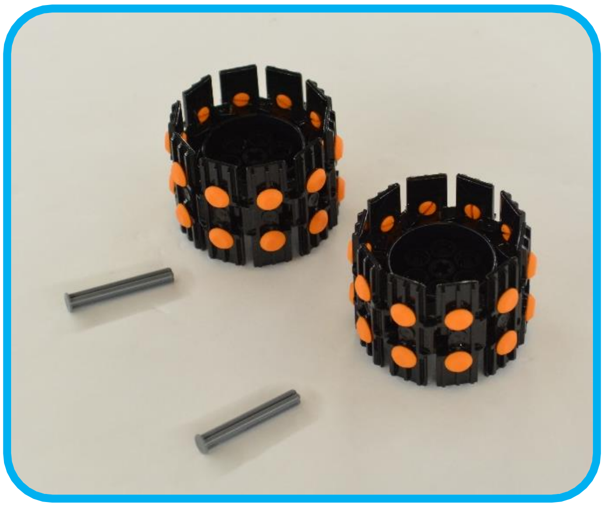
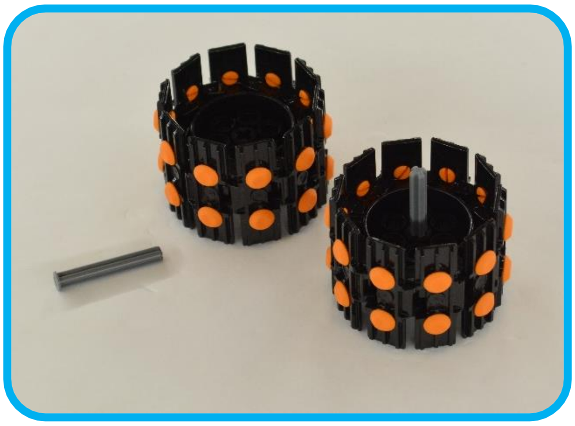
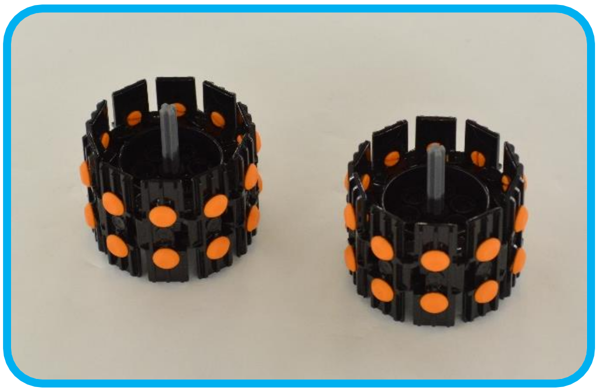
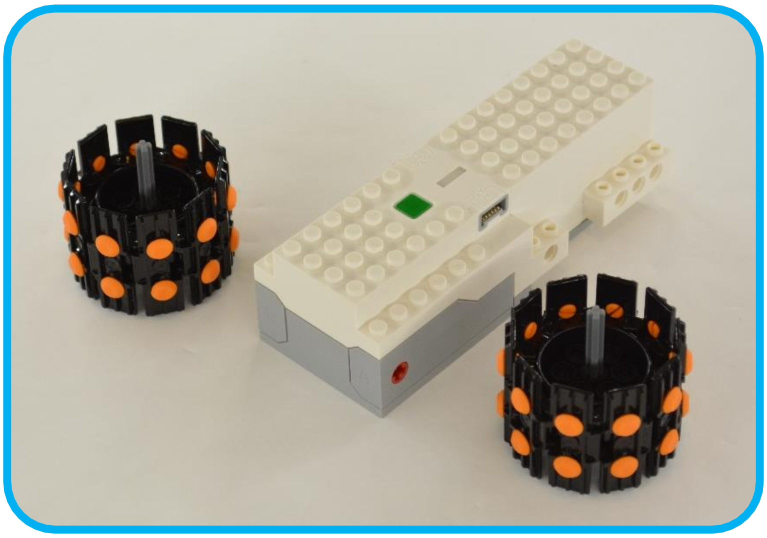
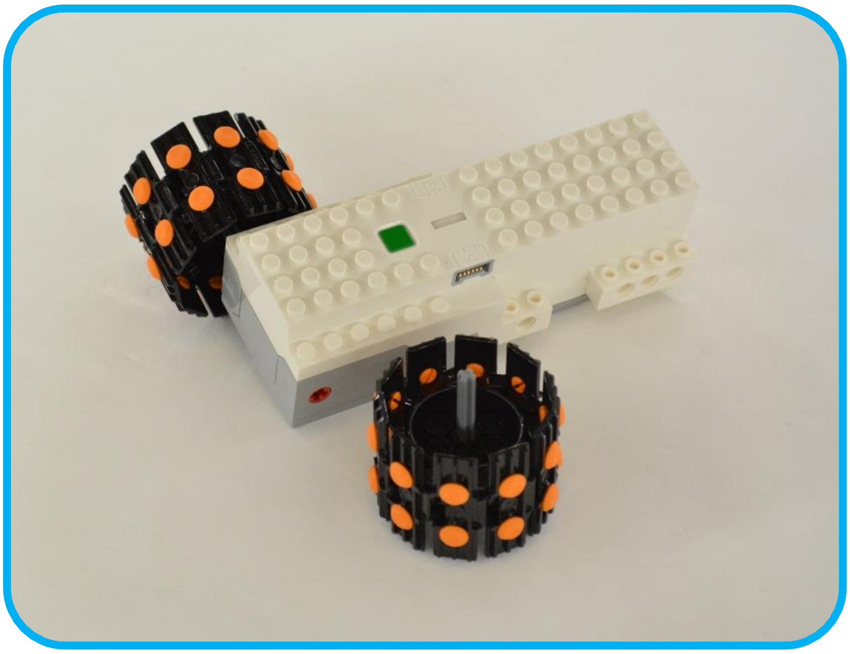
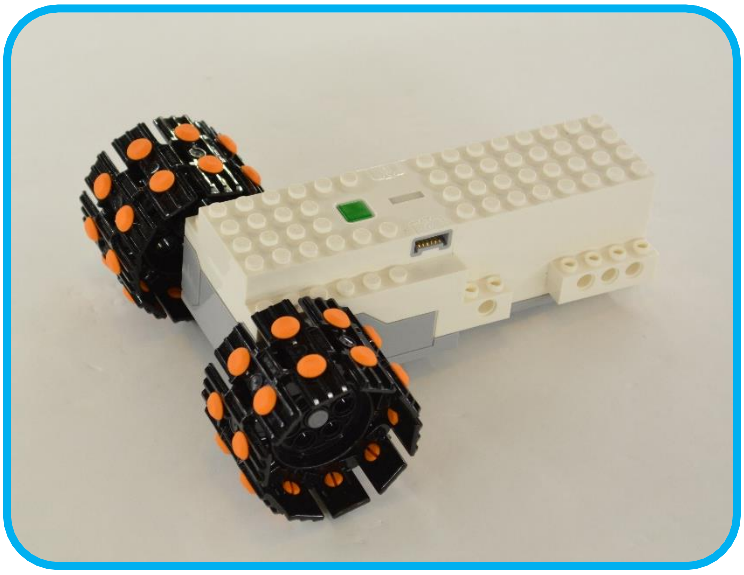




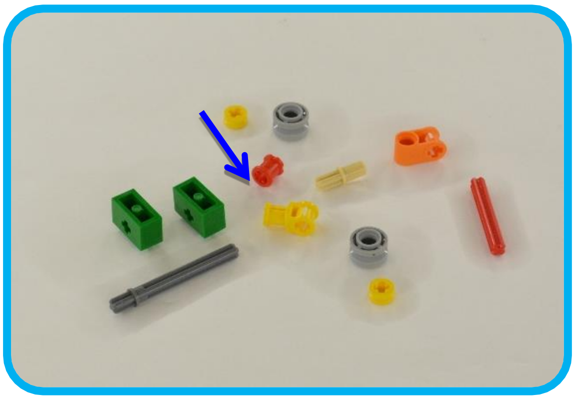


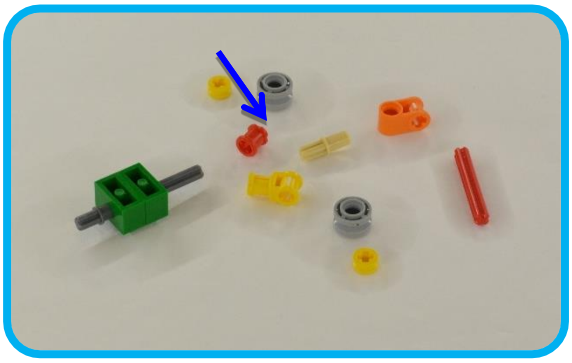


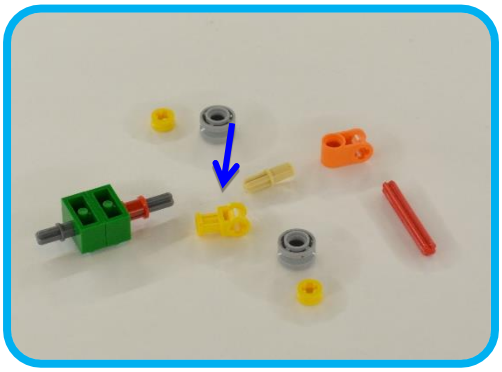


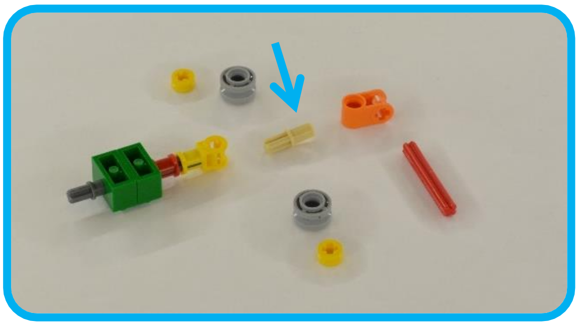


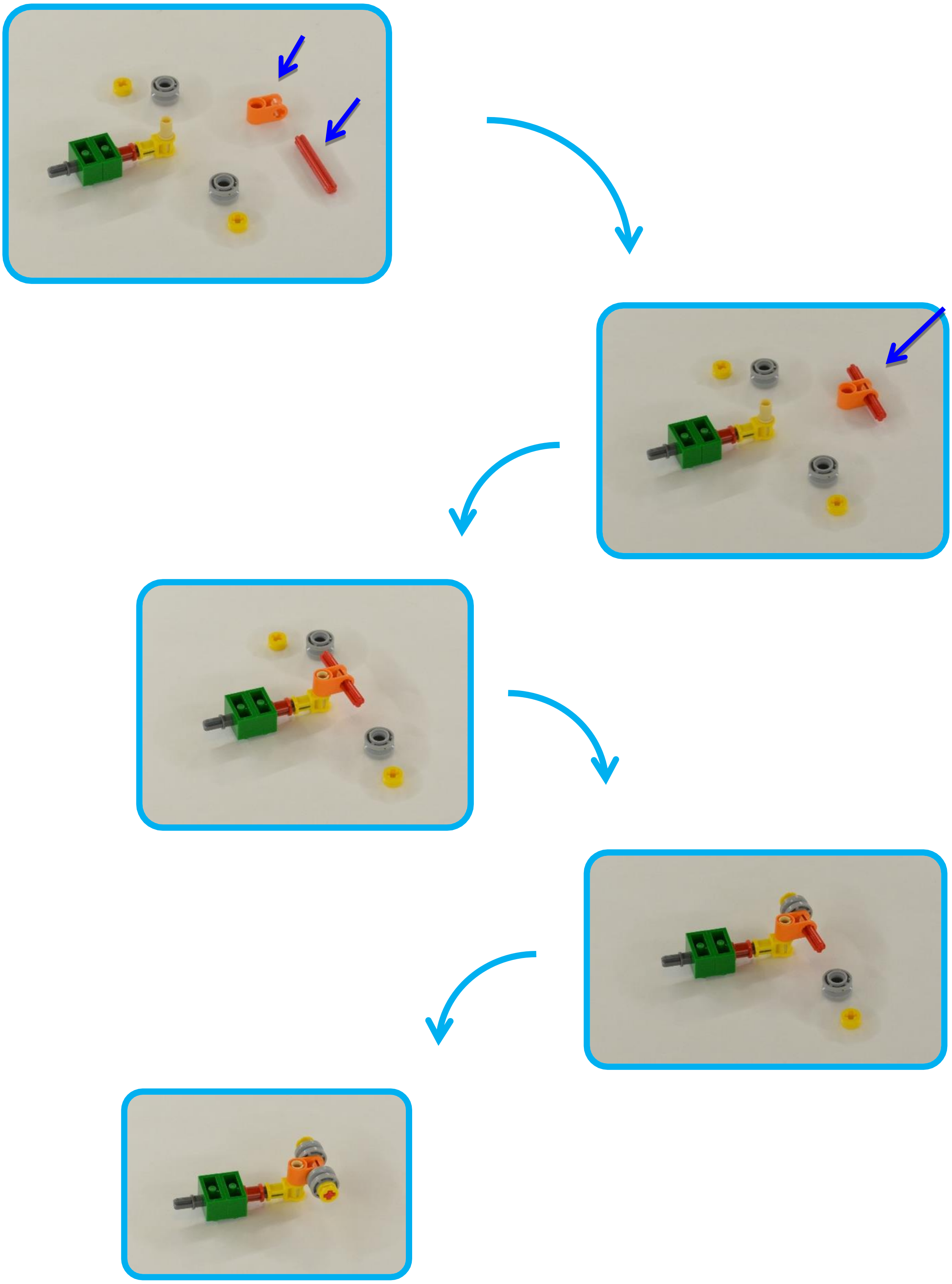
Rear wheel

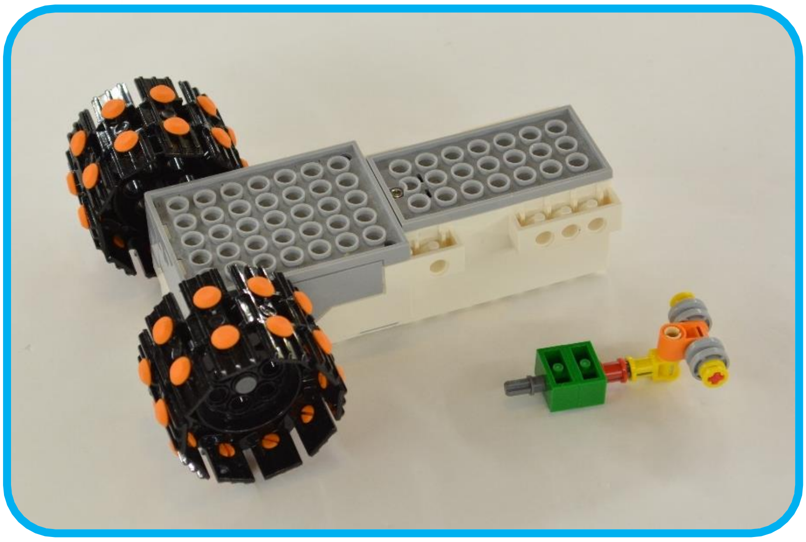


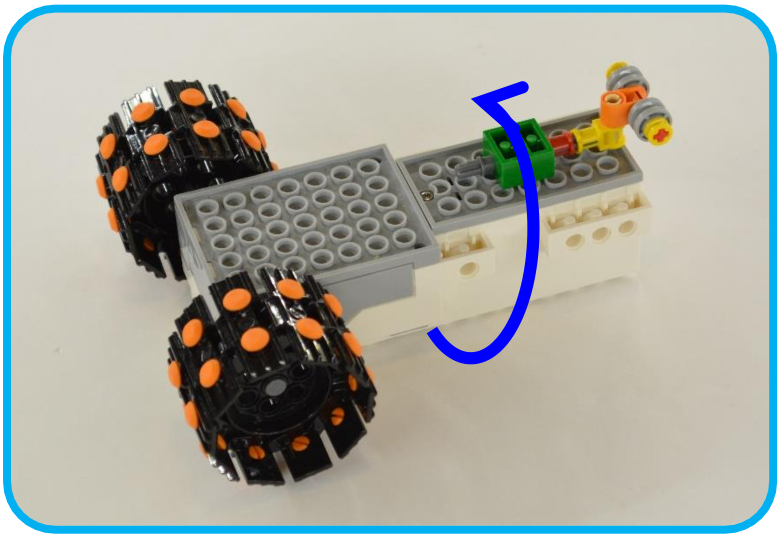


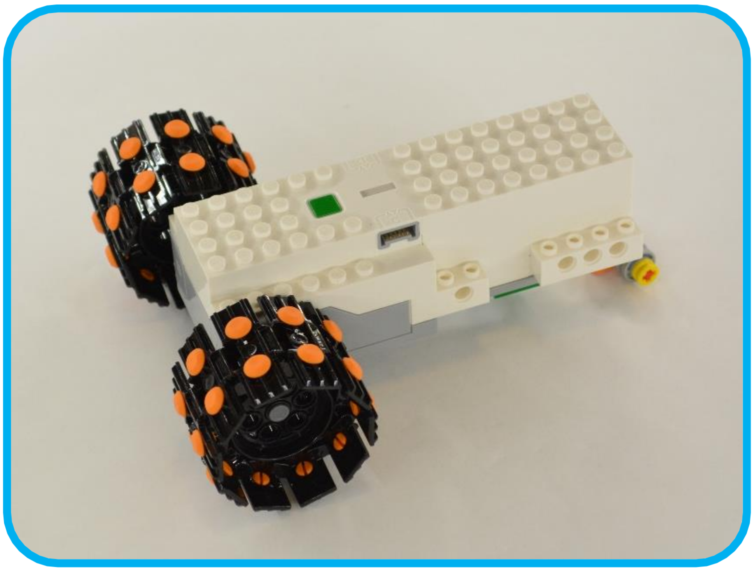




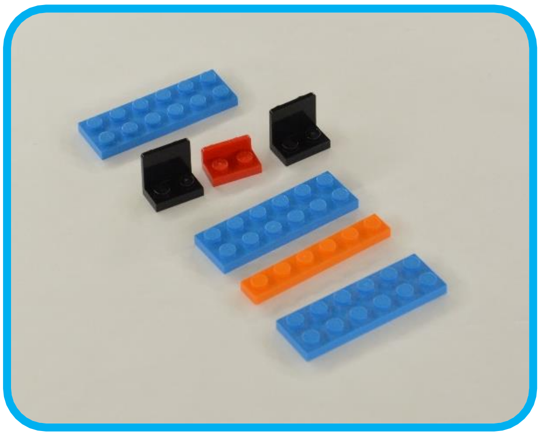


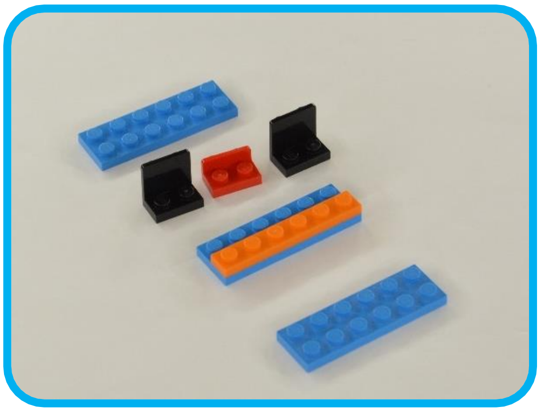


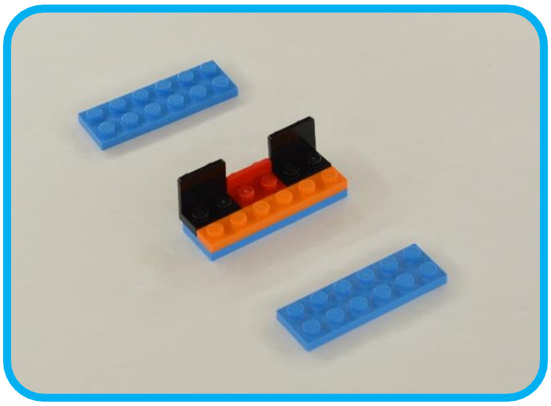


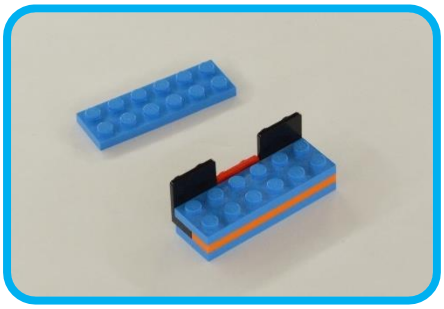


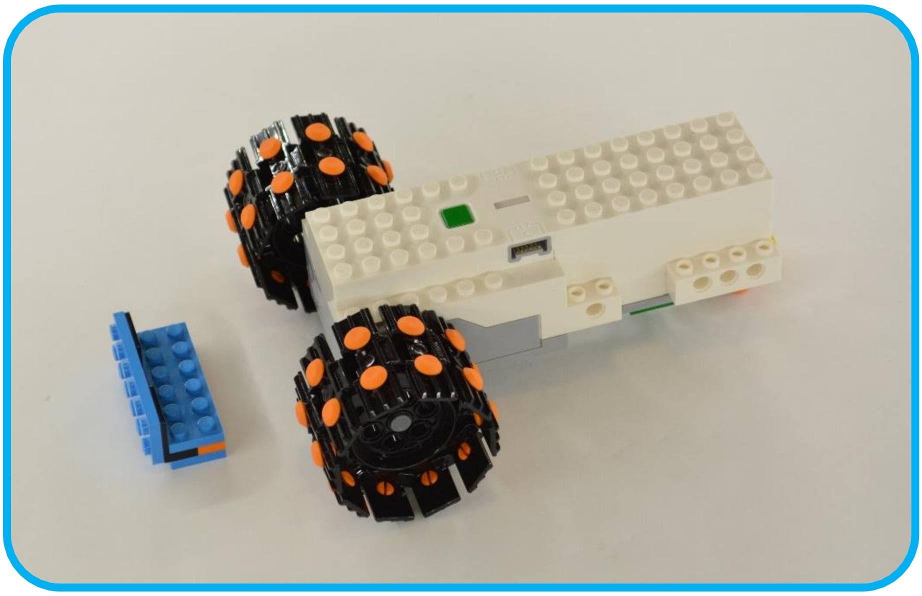
Support for the marker

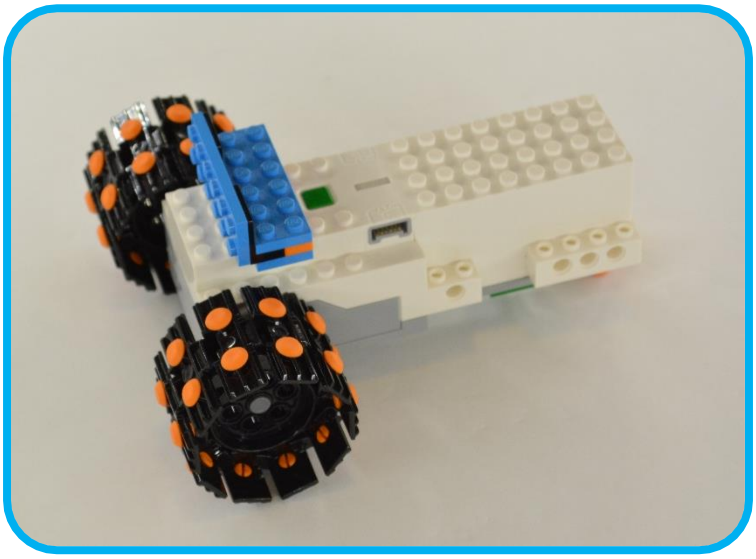




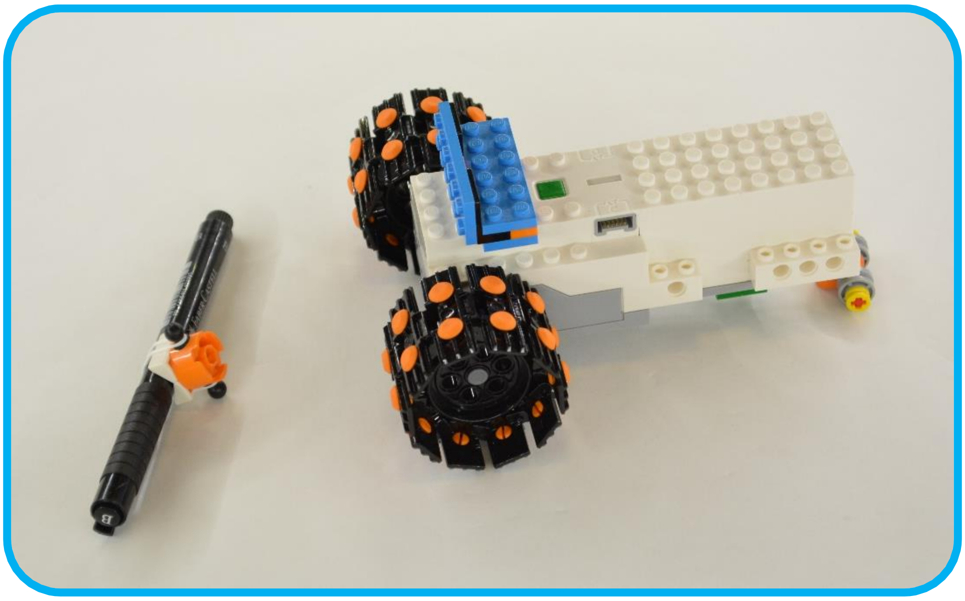


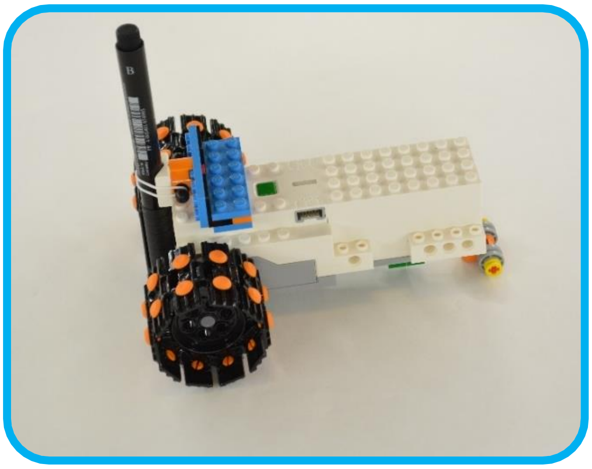


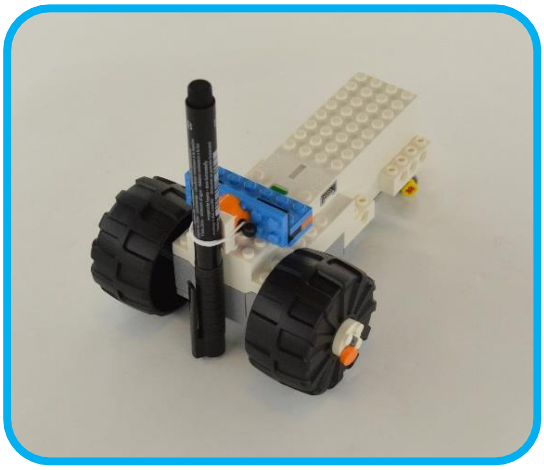




Placement and support of the marker







Teaching Scenario "Vehicle motion in a straight line - distance measurement"

1 Build the robotic vehicle as shown in the assembly instructions of module 2.

2 Using the tape, measure the perimeter of the anti-slip wheel.

Perimeter of the anti-slip wheel __________

3 Program the robot to move forward by one rotation of the wheel setting the speed on 30.

A. Using the tape, measure how far the vehicle has traveled and record it.

____

____

B. Now, reduce the speed at which the wheels move to 20, measure the distance traveled by the vehicle and record it. Is the distance traveled by the vehicle equal to the perimeter of the wheel?

____

____

C. Increase the speed at which the wheels move gradually until you reach 100 and measure the distance traveled by the vehicle. Is the distance traveled by the vehicle equal to the perimeter of the wheel? Can you explain the difference in the distance traveled by the vehicle each time? Do you notice anything related to the course of the vehicle?

____

____

____

____

4 Program the robot to move backwards by one rotation of the wheel at different speeds (20, 30, 40, 50, 100). Is the distance traveled equal to the perimeter of the wheel?

____

____

5 Repeat these steps (steps 1 to 4), using the simple wheels.

6 Program the robot to move about 160 cm by selecting the appropriate speed. (ten times of one rotation of the wheel).

7 Program the robot to move about 20 cm forward, then make a sound.

8. Program the robot to move about 40 cm forward, make a sound and then move backwards for another 40 cm.

9. Program the robot to turn on the red LED light, move about 32 cm forward, make a sound, move backwards for another 32 cm and finally turn off the LED.

Chapter 3 Controlling the motion of the vehicle

Aim

The aim of the 3rd module is to help students to develop programming skills in order to program the robotic vehicle appropriately to travel specific routes.

Objectives

After the implementation of the teaching scenarios students should be able to:

- calculate the average speed of the robotic vehicle when it's moving in a straight line.
- identify the three types of turns a robotic vehicle can make.
- identify the space that the robotic vehicle will need in order to make any kind of turn.
- locate the center of a circular path, depending on the type of turn.
- implement programs using the motion command, so that the robotic vehicle follows specific paths which take the form of geometric shapes.
- implement a program and configure its commands so that the robotic vehicle moves from one point to another, calculating its route suitably to bypass obstacles.

Introduction

Vehicle in a circular orbit

A vehicle can move freely in space, ie it has the ability to steer anywhere on the ground, by controlling at least two motors. This can be done in the following two ways.

The first way is to use motors like the ones in real cars. In this case, one motor is used to propel the vehicle (engine of the car) and the other to define its direction (steering wheel of the car). In real cars, the driver plays the role of the second motor by controlling the steering wheel by his hands, while the "computer" that decides on the motion of the car is the driver's brain. This method requires many and difficult calculations, but the human brain has learned to work this way.

The second way is to use a different motor on each side of the vehicle. This means that the vehicle will have one motor for the wheel on the left side of the car and one for the wheel on the right side, the way tanks work. As we will see soon, the vehicle turns when one side is set on lower speed than the other. To make it easier to understand this let us give an example. The students in the parade move in a straight line when everyone is walking at the same speed. However, when they have to turn, something else happens. Students on the inside of the turn move at a slower speed, while those on the outside move faster as they have a greater distance to travel than the first.

For our robotic vehicle, we will use the second choice, as the controlling is easier and the vehicle is more flexible, compared to the first.

The determination of the course of the vehicle will be done by the students approximately. They will be asked to find solutions through observation. Otherwise they would have to use high level math calculations. When, for example, the vehicle has to bypass an obstacle by turning, the motion command configuration will initially be approximate. By increasing or decreasing the values given as parameters in the command, through successive efforts and by observing the result, the students will reach the goal and the vehicle will be driven to the desired point.

It is important for students to understand which parameter of the command needs to be configured, as well as whether they will increase or decrease the corresponding value. Students will find the exact value needed through experimentation, treating the challenge as a game.

Decorating the vehicle

The build given to the students in this module is simple and includes only the necessary parts for studying the behavior of the robotic vehicle. Once students manage to study its motion, they can proceed to its decoration in the way they consider best. Their interventions need to be such that the functionality of the vehicle does not change. For this reason, it is best to do the decoration after completing some exercises. This way students will be able to check if their interventions have changed the structural and functional elements of the robotic vehicle. They need to check, for example, if after the new shape of their vehicle the wheels can rotate, if they touch the ground, if they move freely, etc. The stability and the balance of the vehicle are also important (students need to make sure that the center of the vehicle's gravity is correct) so that it continues to move as before.

Measuring the average speed of a vehicle moving in a straight line

A new motion command will be used to measure the average speed. When using it, we can set the time for which the wheels will rotate, in order to see the distance traveled by the vehicle.

Questions to study

In order to introduce the students to the way the robotic vehicle turns, we could refer to the aforementioned example of the way the children turn during the parade.

We could also play the following experiential game with the students:

We ask three or four students to shape a row next to each other, holding arms so that it is not possible to move away from one another. At the beginning we ask them to face the board. Then they are asked to change the direction they are looking at and turn their backs on the board, but without separating from each other. The way the two children on the edges will move will simulate the motion that the wheels of the vehicle make in order to change its direction. There are several ways they can move. They can turn, with one walking slower and the other faster, or one rotating while staying in the same place and the other walking, or one walking forward and the other walking backwards. The motion that they will choose will be affected by the available space. How children in the middle move does not concern us, they just follow the others so that they don't get separated. In this sense, the children in the middle play the role of the body of the vehicle.

Necessary knowledge

Turning of the vehicle

In order for the robotic vehicle to make a turn, we will use the motion command defining specific degrees as in the previous module. Next, we will explain how to configure the speed value so that the vehicle turns. For reasons of simplicity, we will explain three types of turns, depending on the required available space.

Open turn

To make an open turn the vehicle's wheel on the inside has to have a lower speed than the wheel on the outside which needs to have a higher speed (Figure 11). These turns require a lot of space, like when real cars are moving on the roads.

The exact space that the vehicle will need in order to make a turn depends on the size of its orbit, ie the track that the vehicle travels. In an open turn, the track is a circle with its center away from the vehicle, as shown in the image below.

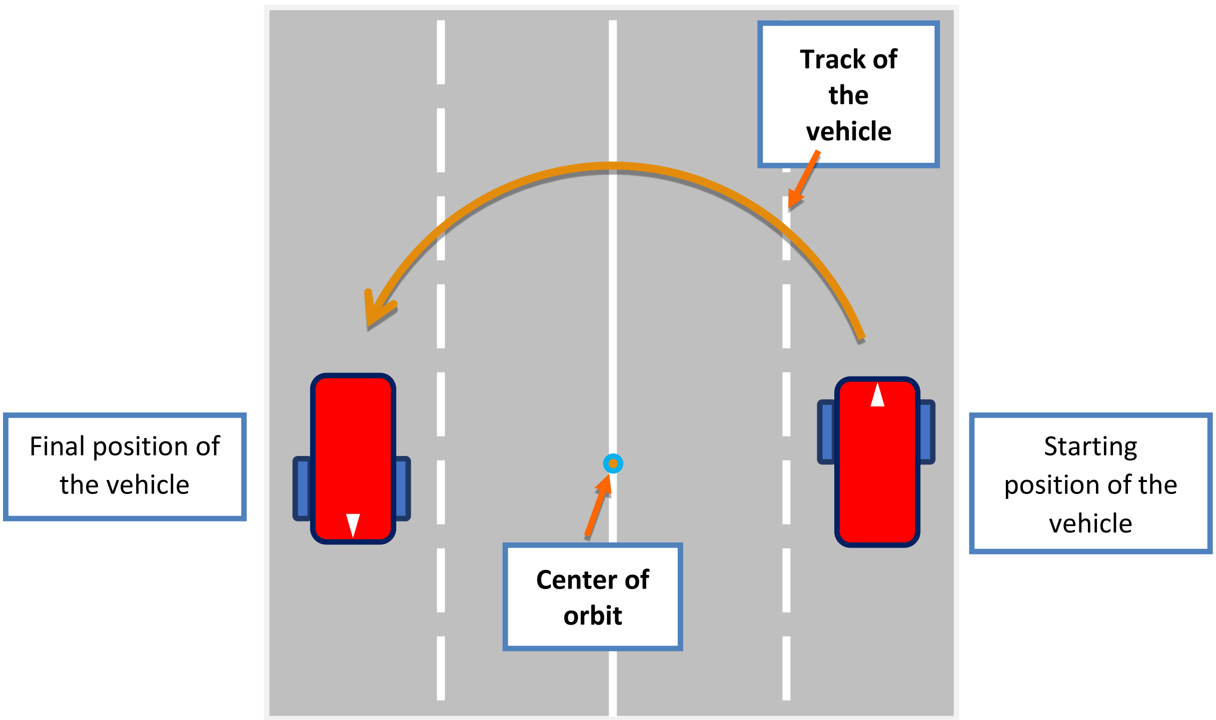
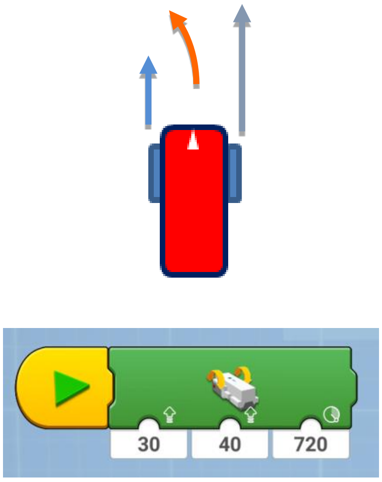
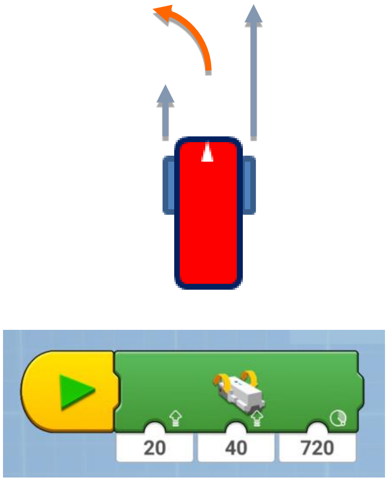


Figure 10 The orbit of the vehicle in an open turn. The center of the orbit is away from the vehicle

The orbit is smaller as the difference in speeds between the two wheels increases, as they are inversely related.



Longer trajectory because 40-30 = 10 is a small difference



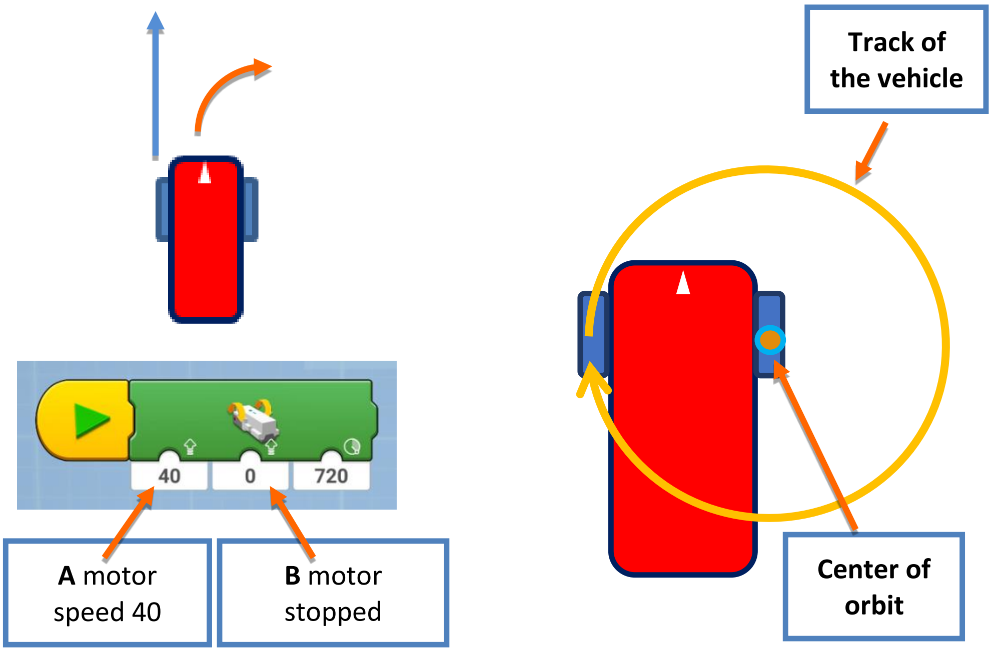
Shorter orbit because 40-20 = 20 is a bigger difference

Figure 11 Left turn commands.

The degrees we will set, will either make the robotic vehicle move on just a part of the orbit or on the whole track. It can even lead the robotic vehicle to make the circular orbit many times.

Sharp turn

If one wheel is stopped while the other is moving, then the vehicle moves in an orbit centered on the fixed wheel and a radius equal to the distance up to the other wheel (Figure 12). The sharp turn has a shorter orbit than the open turn.



(α) (β)

Figure 12 (α) Right sharp turn command, (β) The whole orbit of the sharp turn

The space required for the vehicle to turn will be about twice the size of the vehicle. If the vehicle travels half its orbit, then it will have reversed its direction (Figure 10)

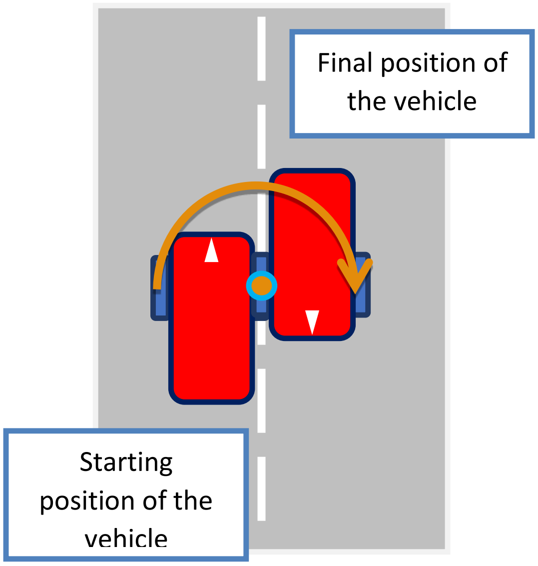


Figure 13 Changing the course of the vehicle, traveling half the orbit of the sharp turn

U- turn

For a u-turn, the speed on both wheels must be set at the same value but the opposite direction (Figure 14a).

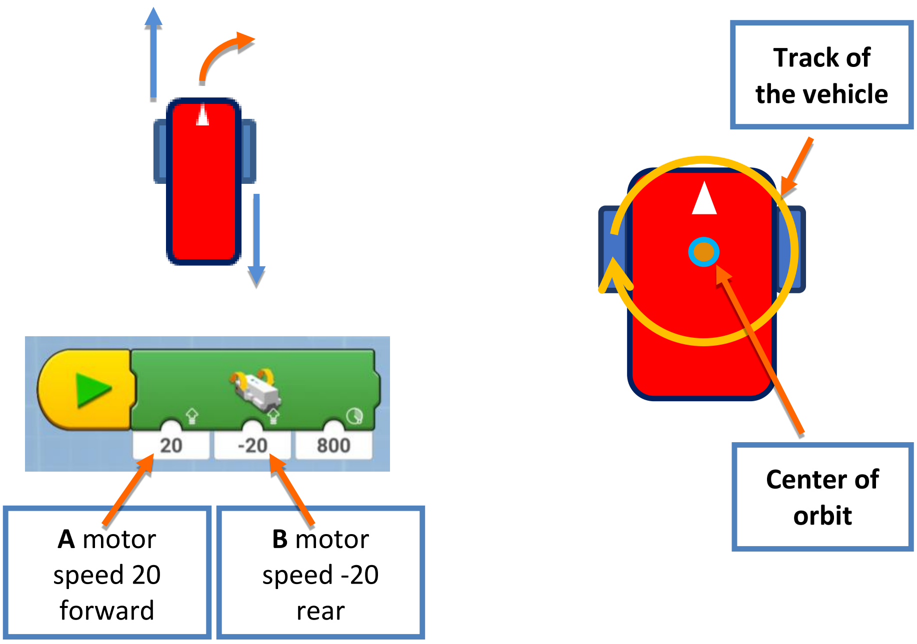


Figure 14 (α) U-turn motion command (β) Orbit of U-turn

This turn requires the smallest space of all in order for the vehicle to turn. The center of the orbit that the robotic vehicle will travel is located between its two wheels (14b).

The vehicle does not change position after turning, as in the other cases (Figure 15).

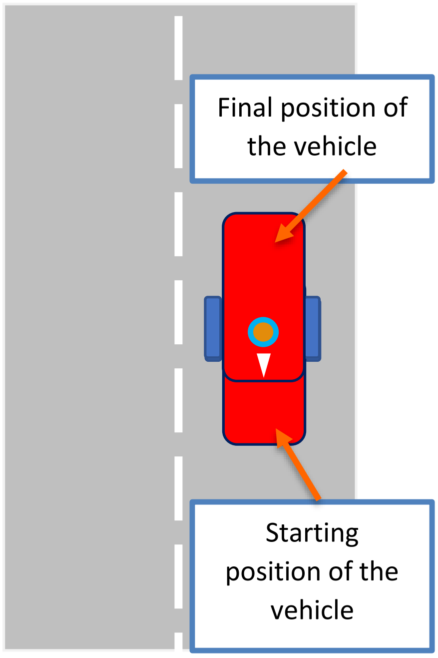


Figure 15 The vehicle needs the least space for a U-turn

If there is no obstacle to limits us, we may choose whichever turn we want from the three turns described above. If there are obstacles, we have to choose the appropriate turn based, each time, on the available space.

Measuring the speed of the vehicle

The speed of the robotic vehicle depends on the distance that it will travel in the unit of time, i.e. in one second (sec). Therefore, if we program the robotic vehicle to move for a second (sec) and then measure the distance traveled, we can find its average speed (Figure 16, Figure 17).

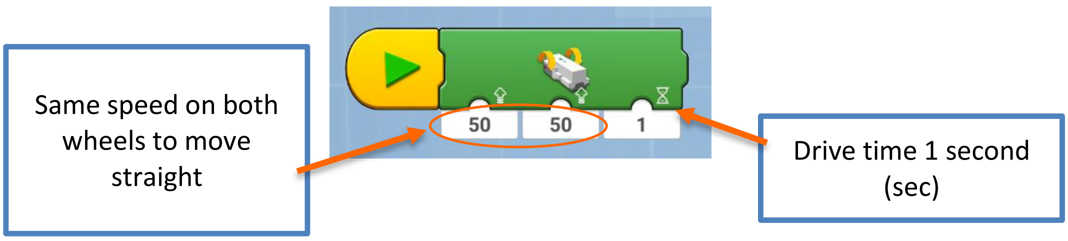


Figure 16 Motion command with time definition. By defining the time at 1 second we can measure the speed of the vehicle

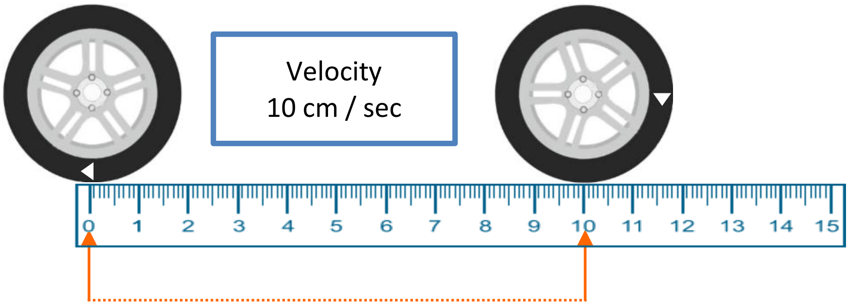


Figure 17 If the time is set on 1 second and in this time the vehicle travels 10 cm then the vehicle speed if 10 centimeters per second (10 cm/sec)

The measurement unit for the speed of the robotic vehicle, in which the students will measure, is centimeters per second (cm/sec). However, the speed of real cars is in kilometers per hour (Km h). To make a comparison we could convert the units.

Where $1sec = \frac{1}{3600}h$, ie one of the 3600 piecies in which we have divided the hour.

Also where $1cm = \frac{1}{100000}Km$, and, respectively, $10cm = \frac{10}{100000}Km$

So if the speed of the robot is 10 cm/sec we will have:

$$\frac{10cm}{1sec} = \frac{\frac{10}{100000}Km}{\frac{1}{3600}h} = \frac{10 * 3600Km}{100000h} = \frac{36000Km}{100000h} = 0{,}36\frac{Km}{h}$$

This is a reasonable speed for the robotic vehicle we use in the class, bearing in mind that people walk with an average speed of 5 Km/h.

Teaching Scenario "Turning of the vehicle"

For this teaching scenario we will use the build of the robotic vehicle according to the assembly instructions of module 2.

1 Program the robot:

   A. to move forward by one rotation of the wheel

   B. then make an open turn

   C. and, finally, to move forward by one rotation of the wheel

2 Program the robot:

   A. to move forward for 32 cm

   B. then make a sharp turn

C. and, finally, move forward for 32 cm

3 Program the robotic vehicle by giving it the appropriate motion command so that it makes a sharp turn for 360°.

A. Measure the distance of the arc traveled by the vehicle with the tape measure.

____

B. Calculate the degrees that are needed as a parameter in order for thr vehicle to go in the opposite direction.

____

4 Program the robot to move forward for about 50 cm, then make a 180° u-turn and return to where it started.

5 Program the robot to move forward for about 40 cm and then turn 90° to the right.

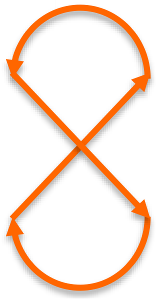
6 Program the robot to move forward for about 40 cm, then make a warning sound and finally turn 90° to the left.

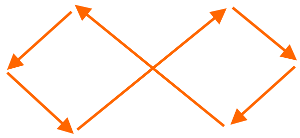
7 Program the robot to move making a square track and, then, return to where it started. (use the repeat command)

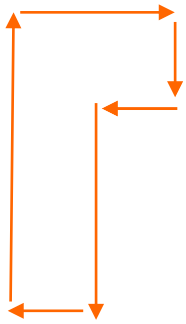
8 Program the robot to move making a rectangle track, and, then, return to where it started. (use the repeat command)

9 Program the robot to move making various polygon tracks.

10 Program the robot to make the following tracks.:







CODESKILLS 4ROBOTICS

Teaching Scenario "Measuring the average speed of the vehicle moving in a straight line"

1 Program the robot to move forward for one second setting the speed on 20.

A. How far did the vehicle travel in one second?

____

B. What is the speed of the robotic vehicle?

____

2 Program the robot to move forward for one second, this time faster than the previous step.

A. How far did the vehicle travel?

____

B. What is the speed of the robotic vehicle?

____

C. If the speed of the vehicle is reduced, how will the distance traveled change in one second? Will it decrease or increase?

____

____

D. Can we determine the distance the robotic vehicle will travel using the motion command based on the time? Justify your answer.

____

____

Teaching scenario "Configuration of the external form of the robotic vehicle"

After completing the exercises, you can change the robotic vehicle by doing whatever modifications you can imagine, provided it remains functional and can perform all the activities as before.

Chapter 4 Torque and Gears

Aim

The 4th module aims to introduce students to the concept of torque as well as the way gears operate, and how they apply to the robotic vehicle.

Objectives

After the implementation of the teaching scenarios students should be able to:

- identify a gear system.
- calculate the rotations of the wheel according to the gear ratio.
- calculate the increase or decrease of the robotic vehicle's driving distance depending on the combination of gears.
- calculate the increase or decrease of the robotic vehicle's speed depending on the combination of gears.
- calculate the increase or decrease of the robotic vehicle's torque depending on the combination of gears.
- estimate the values required while configurating motion commands in order for the vehicle to travel a certain distance.
- develop their own programs for moving the robotic vehicle over specific distances.
- program the robotic vehicle to move in orbits according to what is requested.

Introduction

In the 4th module we will deal with the concept of torque. This concept seems to be difficult to understand even though it is encountered daily. The torque determines the position of the knob on an opening door. When we need to go uphill with our vehicle, we choose the right speed in the gearbox, so that it gives us the required torque and not speed.

We will therefore study the concept of torque and how it affects the ease of rotation of an object, in our case the wheels of the robotic vehicle. We will analyze the meaning of the gear ratio and the way it affects the motion of the wheel and, also, the final distance in which the robotic vehicle will travel (similar to real cars). The wheels of the robotic vehicle are driven by the motor through a gear system. Thus, we can try to change the gear system to make observations.

Questions to study

Torque is affected by the point at which force is applied to rotate an object around an axis. If the force application distance from the axis of rotation is large, the object rotates more easily while if it is short the object rotates more difficult.

To increase the torque, we could simply increase the force applied. But if, for some reason, this cannot be done, what can we do?

Let's look at the above with a simple example

The door of a room rotates in order to open or close. This happens because the force we apply is converted into torque and turns it.

So we can ask the question: How will the door of the room open more easily? If I push it at point A near the knob or at point B near the door support. (Figure 18)

- Students can try pushing the door with their finger at point A near the knob.
- Then they can do the same applying the same force as before, but now on point B, close to the point that supports the door in order to rotate.

All students can try applying the same force in both parts of the door. Then we can discuss what they observed.

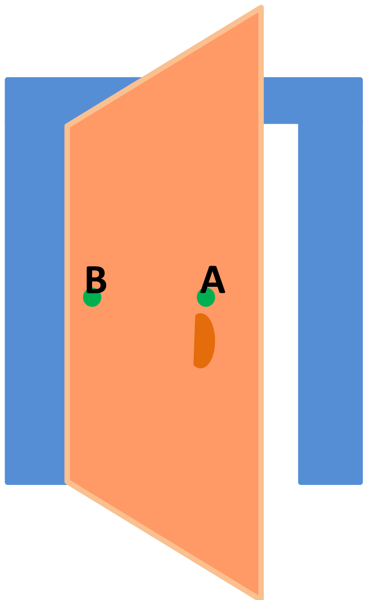


Figure 18 The door and the points where the force will be applied in order to open it

This experiment can be used as an introduction to help students to understand the concept of torque which will then be applied to the robotic vehicle.

Necessary Knowledge

The commands that will be used are the same as in the previous module. In this module we will approach a part of the mechanical field, namely the gears and the torque.

Torque

Torque rotates objects. We need to apply torque, to unscrew a nut, to open a door, to rotate a wheel or a gear.

Let's have a closer look at the concept of torque.

In Figure 19 we see a screw getting unscrewed with a wrench. The force we apply is on the edge of the key. To calculate the torque value, we just have to multiply the force applied by the distance between the point where it is applied and the point of rotation.

Suppose we cannot unscrew it with this key, because it is very tight and our strength is not enough. What could we do to increase the torque?

We could "extend" the key.

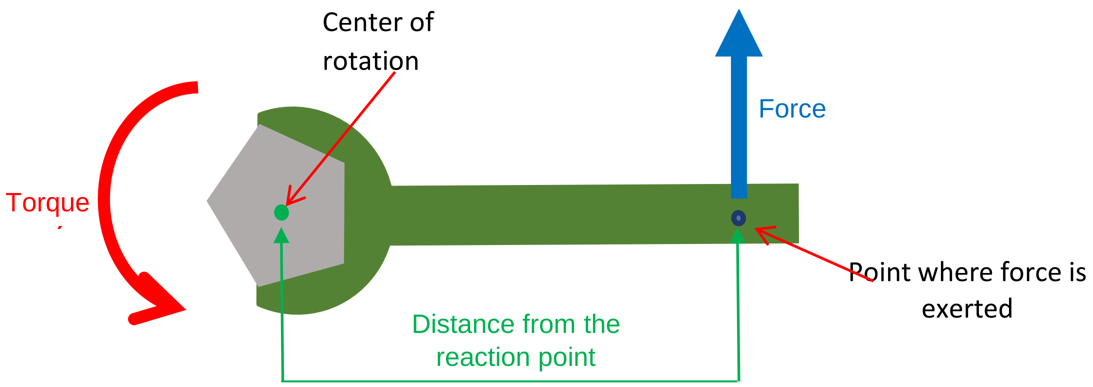


Figure 19 A wrench unscrews a screw

The torque depends on the force but also on the distance between the point where the force is applied and the point of rotation. Therefore, if we cannot increase the force, we could increase the distance. In other words, we get a longer key that allows us to hold it further back, i.e. at a greater distance from the point of rotation. This way the torque will increase and we will be able to unscrew the screw.

Gear system

Robotics uses electric motors that rotate at a certain speeds and exert certain torques. We need to take advantage of these features in the best and most effective way. To do this we use a system, made with gears. There are many different systems:

A Gear systems that can increase the rotation speed of the motor, reducing the torque at the point where the rotational motion is transmitted, and vice versa. Such systems can increase the torque given by the motor, reducing the rotations at the point where motion is transmitted. This happens, for example, at bicycle speeds. Depending on the choice of gears, the bike can climb uphill with ease, ie having high torque but low speed. Instead, it can run at high speed downhill, where its wheels can spin quicker but do not have much torque.

B We can also change the direction of rotation's axis as well as the direction of rotation. In the example (Figure 20), the motion is transferred from the windmill sails, which have a horizontal axis of rotation, to the grinding stones, which have a vertical axis of rotation. Therefore, the motion is transferred using gears from the sails to the stones, and thus its characteristics change.

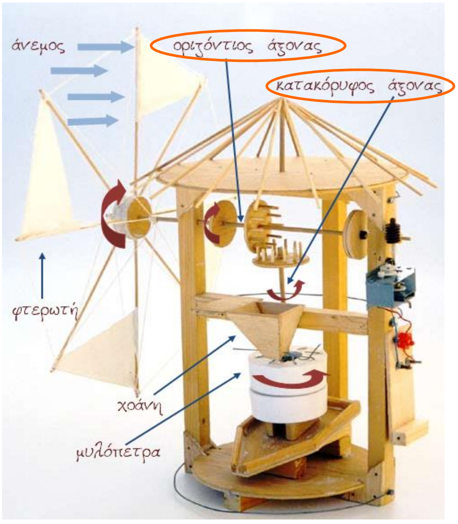


Figure 20 Windmill – the motion is transmitted from the sails to the grinding stones

Gears

But what is a gear?

The gear is a disk with protrusions ("teeth") around it (Figure 21).

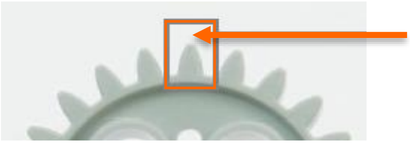


Figure 21 Protrusions of a gear

The gears are divided according to the type of protrusions ("teeth") they have as well as the size of their disc. In Figure 22 we see some examples of gears with different types of protrusions. Such gears cannot be combined with each other to build a gear system.

Figure 22 Gears with different types of protrusions which cannot be combined with each other

In Figure 23 we see four different gear sizes, with protrusions of the same type. These gears can be combined with each other to make a gear system. It is therefore necessary that the gears that we will use have the same type of protrusions

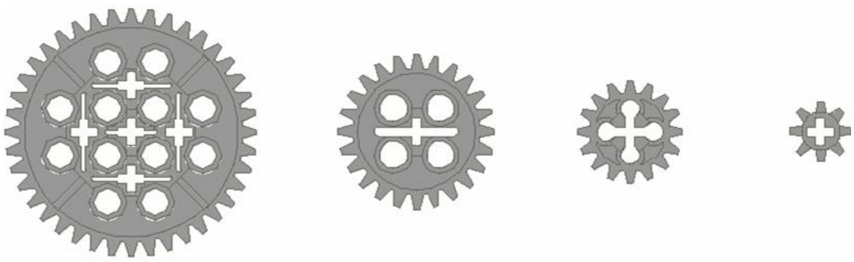


Figure 23 Gears with the same type of protrusions but different sizes

A gear system is used in bicycles (Figure 24). One gear is attached to the pedals and is moved by the force of the cyclist's feet. This gear is called the drive gear. The other is attached to the rear wheel of the bike and it is called the moving gear. The rotational motion from the cyclist's legs is transmitted to the rear wheel of the bicycle through the chain.

Figure 24 The bicycle has a gear system in order to move

When we have a gear system that uses a chain, it is not possible to change the direction of rotation of motion from the drive gear to the moving one (Figure 25). If the two gears are of the same size, neither the rotation speed nor the torque of the moving gear can change.

Figure 25

If we had a gear system without a chain, the gears would engage directly through their protrusions. What if the two gears are of different size?

In Figure 26 we see a gear system for transmission of motion, where the drive gear is larger and the moving gear is smaller. The rotanional motion is transferred from the large gear to the small one. During the transmission of motion, the torque decreases and the speed increases. Therefore, when the drive gear completes one rotation, the moving gear will complete more. The number of rotations it will complete depends on the number of protrusions. For example, if the drive gear has 24 protrusions and the moving gear has 8, for each rotation of the drive gear, the moving gear will complete 3 rotations, because 3x8 = 24.

The direction of rotation of the motion is reversed.

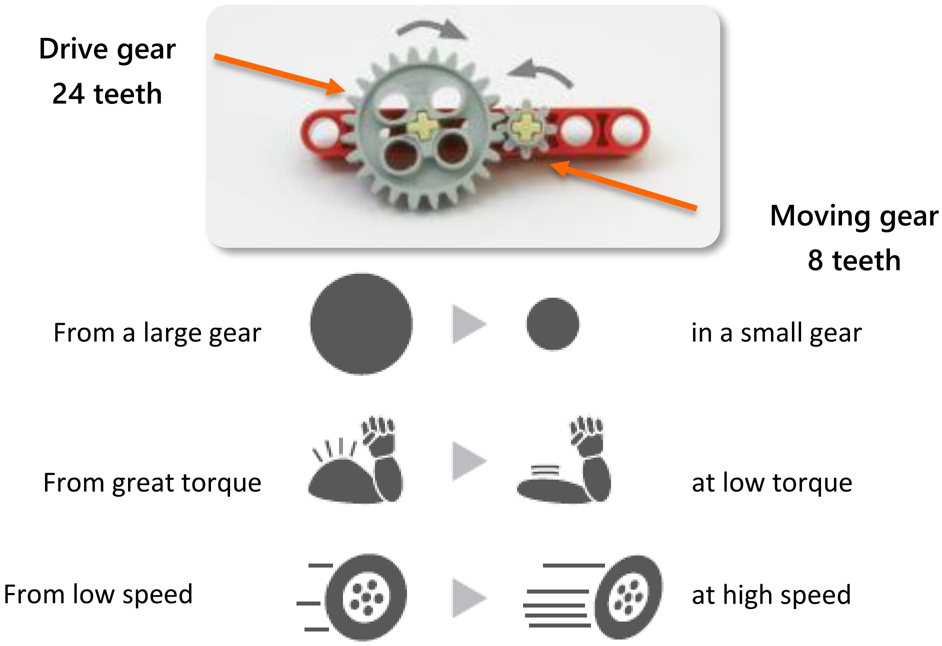


Figure 26 Gear system for the transmission of motion form bigger gear to smaller one

In Figure 27, we see the opposite gear system. In this case, the drive gear is smaller and the moving gear is larger, which results in the torque increasing and the speed decreasing in the moving gear. Therefore, the moving gear will rotate more easily due to its larger size, but at a slower speed than the drive gear. The ease of rotation of the large gear is due to the fact that the point where the force is applied is at a greater distance from its point of rotation. Like the example we mentioned earlier of the knob on the door. As before, if the number of protrusions of the drive gear is 8 and the corresponding number of the moving gear is 24, for one rotation of the drive gear we will get 1/3 of a rotation of the moving gear. In other words, every three turns of the drive gear the moving gear completes one turn.

The direction of rotation will, once again, be reversed.

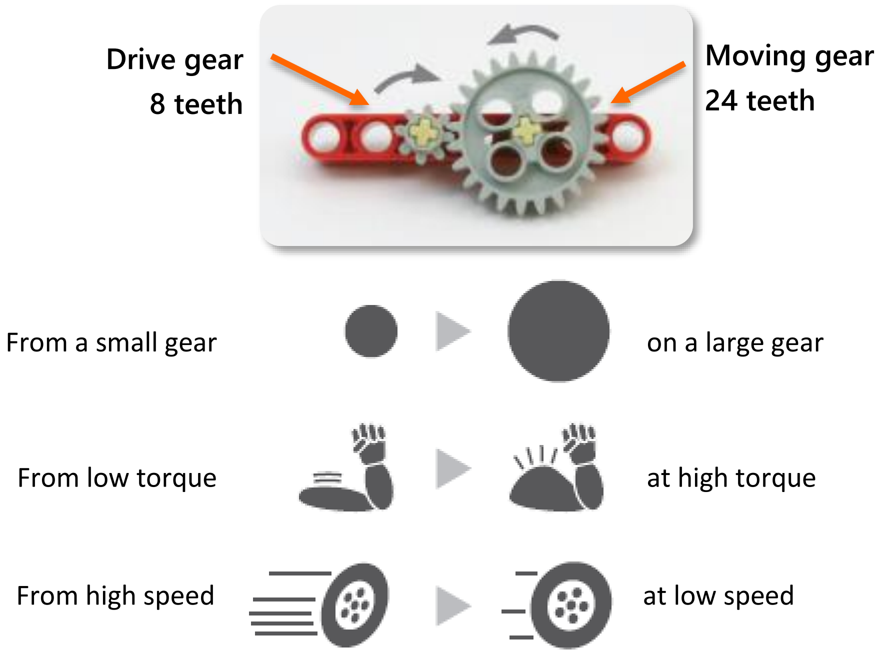


Figure 27 Gear system for the transmission of motion from smaller to a bigger one

Gear ratio

Gear ratio helps us to easily calculate changes in rotations or torque from one gear to another. To calculate it, we use the number of protrusions of each gear.

Specifically, the gear ratio which is also called motion transmission ratio, as it correlates the number of protrusions that the gears have with their rotations.

The drive ratio

$$\frac{number of protrusions of drive gear}{number of protrusions of moving gear} = \frac{number of rotations of moving gear}{number of rotations of drive gear}$$

Applying the drive ratio in the first example, we have:

$$\frac{number of protrusions of drive gear}{number of protrusions of moving gear} = \frac{24}{8} = \frac{3}{1}$$

And, finally, due to the aforementioned relation we will have

$$\frac{3}{1} = \frac{number of rotations of moving gear}{number of rotaions of drive gear}$$

Therefore, if we fill in the fraction the protrusions corresponding to each gear and simplify it, then the numerator gives us the number of rotations that the moving gear will complete while the denominator gives us the number of rotations that the drive gear will complete.

Respectively, if we apply the drive ratio in the second example where the drive gear had 8 protrusions and the moving gear 24 we will have:

$$\frac{number of protrusions of drive gear}{number of protrusions of moving gear} = \frac{8}{24} = \frac{1}{3}$$

And, continuing with the second part of the relation, we will have:

$$\frac{1}{3} = \frac{number of rotations of moving gear}{number of rotations of drive gear}$$

Therefore, using the drive ratio we see that for one rotation of the drive gear, the moving gear will complete less than half of a rotation, as it will move only by 1/3 of a rotation. In other words, we could say that for 3 rotations of the drive gear we will have one rotation of the moving gear. This results in the decrease of speed of rotation in the second gear.

The gear ratio is also related to torque, but this time the ratio is proportional.

$$\frac{number of protrusions of drive gear}{number of protrusions of moving gear} = \frac{torque of drive gear}{torque of moving gear}$$

By applying the gear ratio for the gear system of the second example, where the drive gear had 8 protrusions and the moving gear had 24, we have:

$$\frac{number of protrusions of drive gear}{number of protrusions of moving gear} = \frac{8}{24} = \frac{1}{3}$$

And, continuing with the second part of the relation, we have:

Therefore, the moving gear will have three times more torque than the drive gear.

Concluding, in Figure 27, the gear systems and their relation to the rotational speed and torque are presented. The direction of rotation is always reversed, since the gears are directly engaged.

Figure 28 shows the overall combinations of the transmission systems with gears.

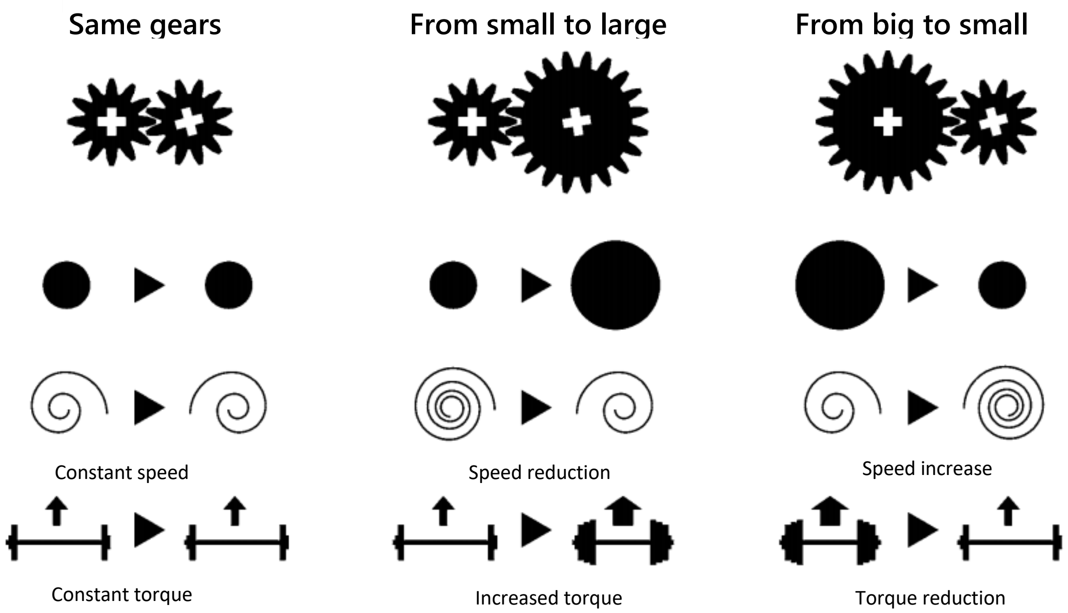


Figure 28 Set of simple gear combinations and their relation to speed and torque.

Proposed Assembly Instructions

For building the robotic vehicle with gears (Figure 29) students need to assemble it based on the steps as shown in the following photos. The assembly instructions of the parts, such as the rear wheel and the marker holder, are the same as in the previous module (there are references where required).

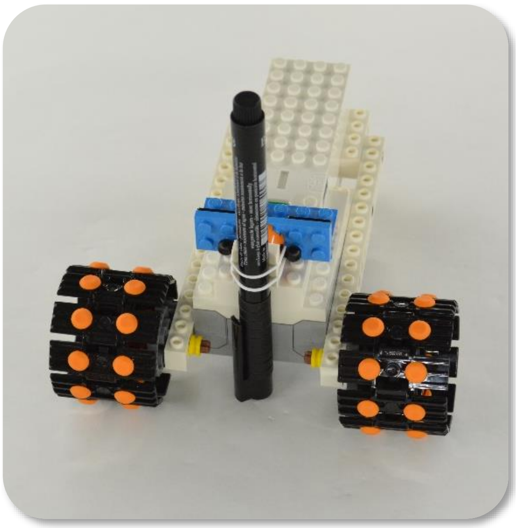
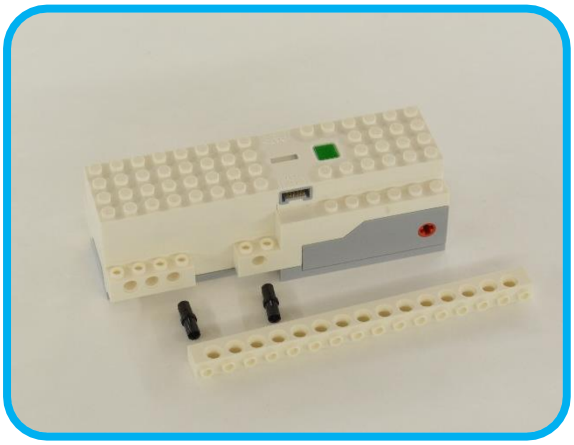
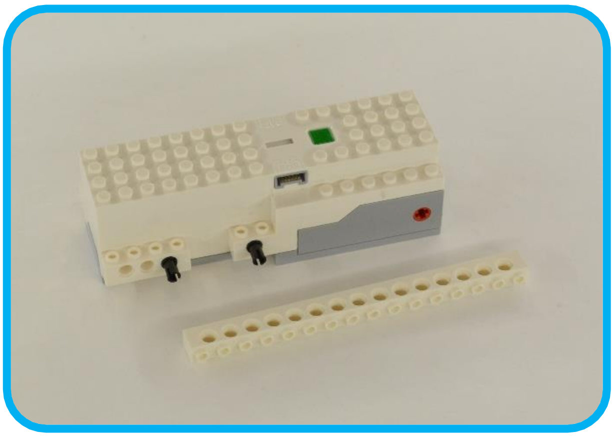
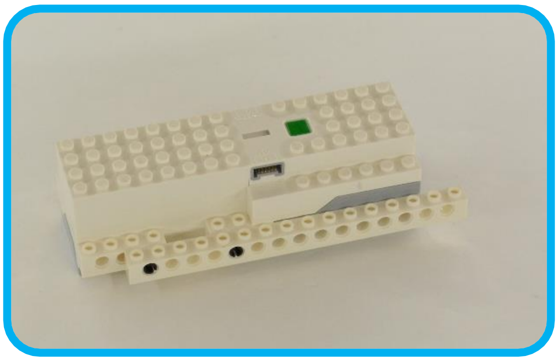
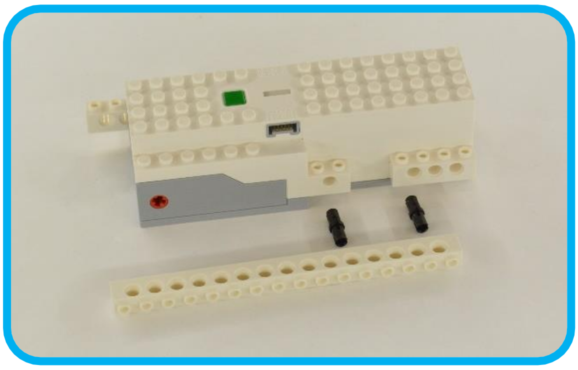


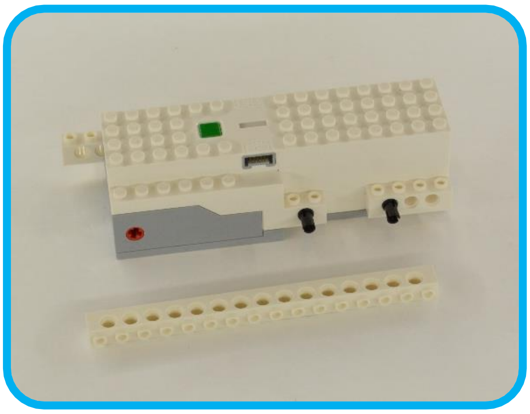
Figure 29

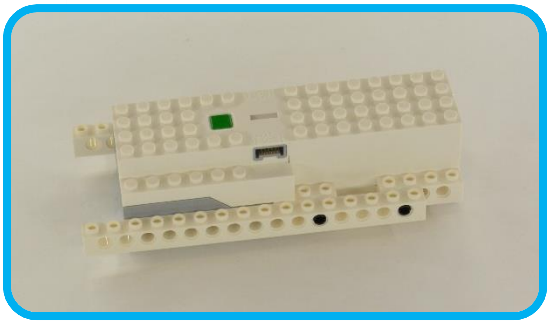


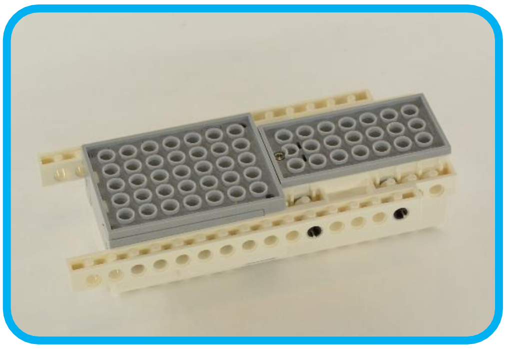


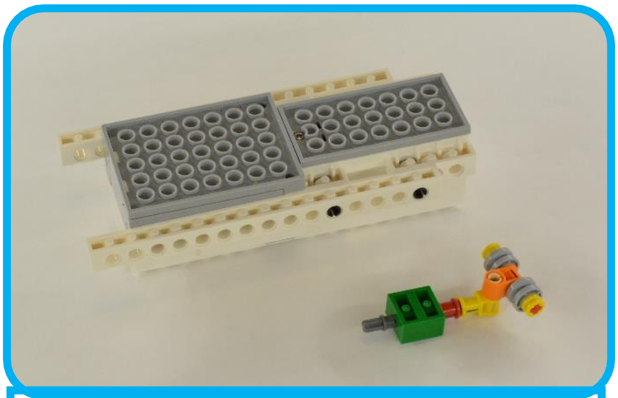




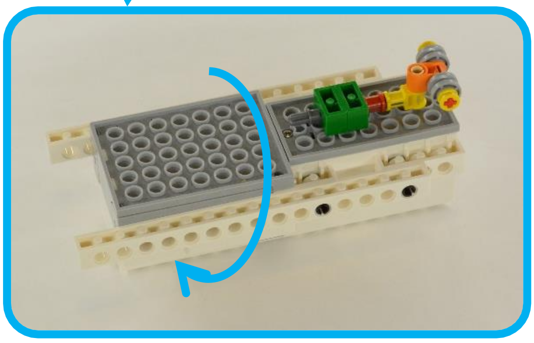


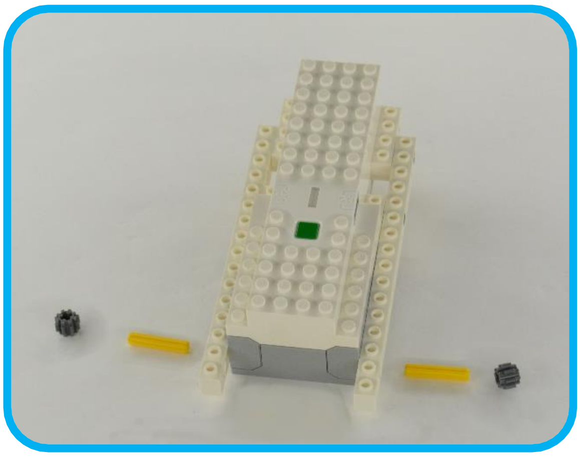


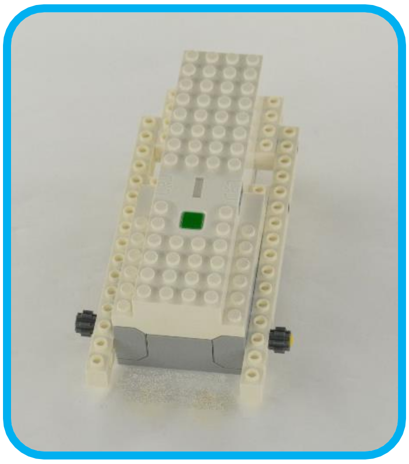




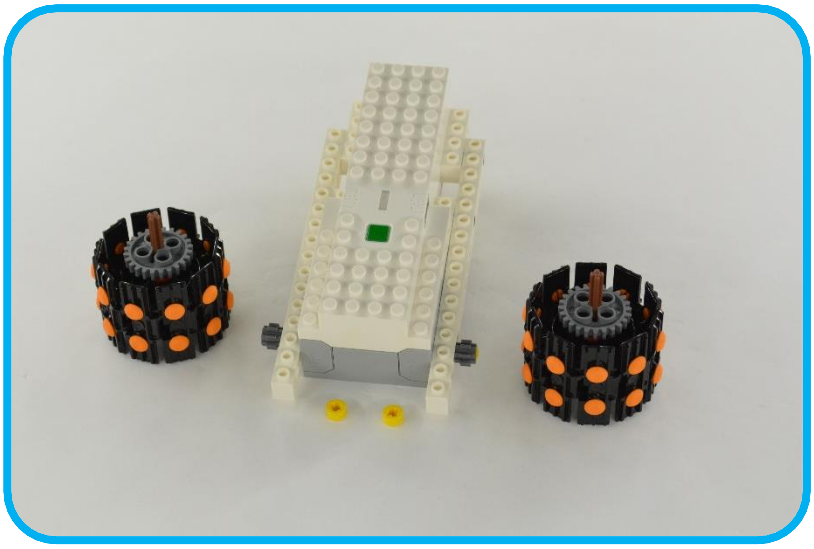
The construction of the rear wheel from the 2nd Section, Suggested designs, Rear wheel

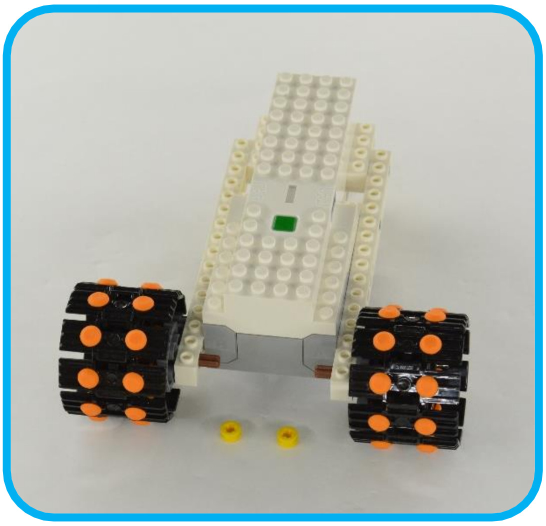


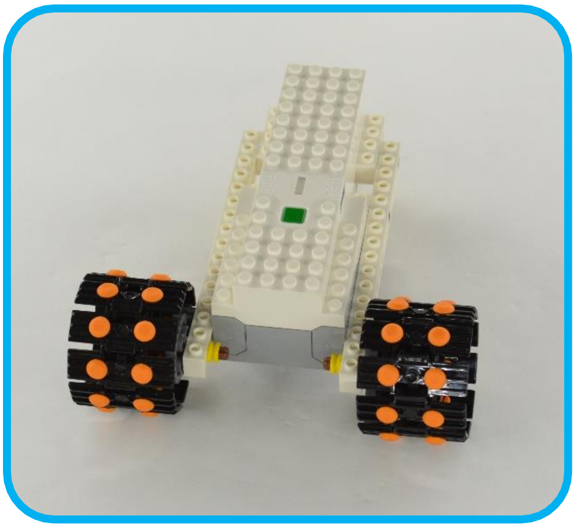




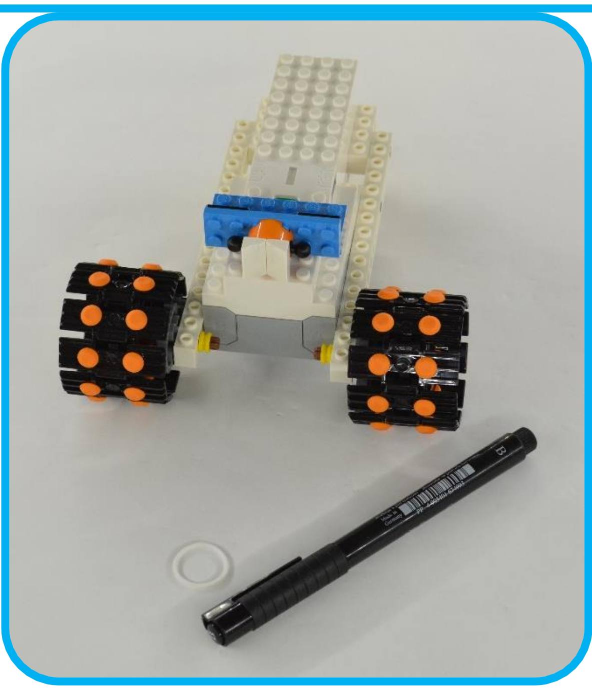
The construction of the non-slip wheel from the 2nd Section, Suggested designs

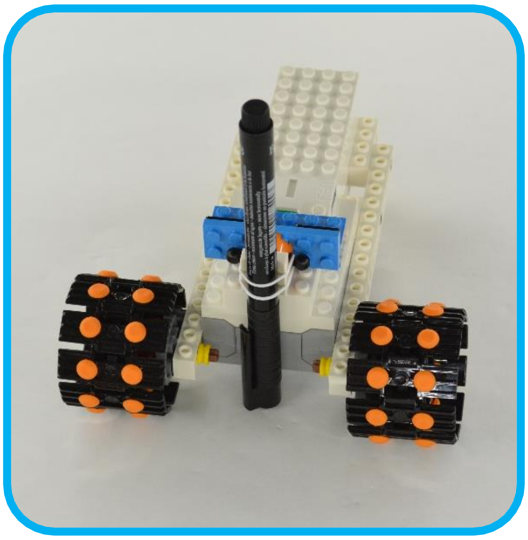






The construction of the support for the pen from the 2nd Module, Suggested designs





Teaching Scenario "Changing the speed and torque of the vehicle using gears"

1 Build the robotic vehicle according to the assembly instructions in module 4. Place the small gears on the motors and the large gears on the wheels as shown in the pictures.

2 Using the tape, measure the perimeter of the anti-slip wheel Perimeter of the anti-slip wheel

____

3 Program the motor of each wheel of the robot to move forward 360°.

A. How far did the vehicle travel?

____

B. Did the wheels move 360°? Can you describe why this happened?

____

4 Program the robot to move forward for one second.

A. How far did the vehicle travel in one second?

____

B. What is the speed of the robotic vehicle?

____

5 Reverse the gear placement. Place the large gears on the motors and the small ones on the wheels.

6 Program the motors of each wheel of the robot to move forward 360°.

A. How far did the vehicle travel?

____

B. Did the wheels move 360°? Can you describe why this happened?

____

7 Program the robot to move forward for one second.

A. How far did the vehicle travel in one second?

____

B. What is the speed of the robotic vehicle?

____

8 Describe what you observed. Which combination of gears makes the robotic vehicle move faster and why?

____

____

9 Try making the robotic vehicle move while pulling a weight. Observe and note which gear combination is the most effective in this situation.

____

____

Teaching Scenario "Game with two robotic vehicles"

Part 1

Working as couples, we tie two robotic vehicles together so that they pull each other in the opposite direction.

We assemble the first robotic vehicle using the small gears on the motors and the large ones on the wheels. In the second vehicle we place them the other way round, i.e. the large gears in the motors and the small ones in the wheels. The goal is to see which vehicle has the greatest force and will eventually pull the other towards it.

Be careful: Vehicles must execute exactly the same program, except for the direction of motion. Also, the batteries need to be fully charged in both vehicles.

Which vehicle will "win" and for what reason?

Part 2

Each team can configure their vehicle as they like. The team can also change the configuration in the motion command. The aim is to repeat the match between all the teams.