PROFI CARTECH

Begleitheft • Accompanying Booklet • Manuel d'accompagnement
Begeleidend boekje • Cuaderno adjunto • Folheto

fischertechnik®

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1. Cartech: Total Automotive Technology!

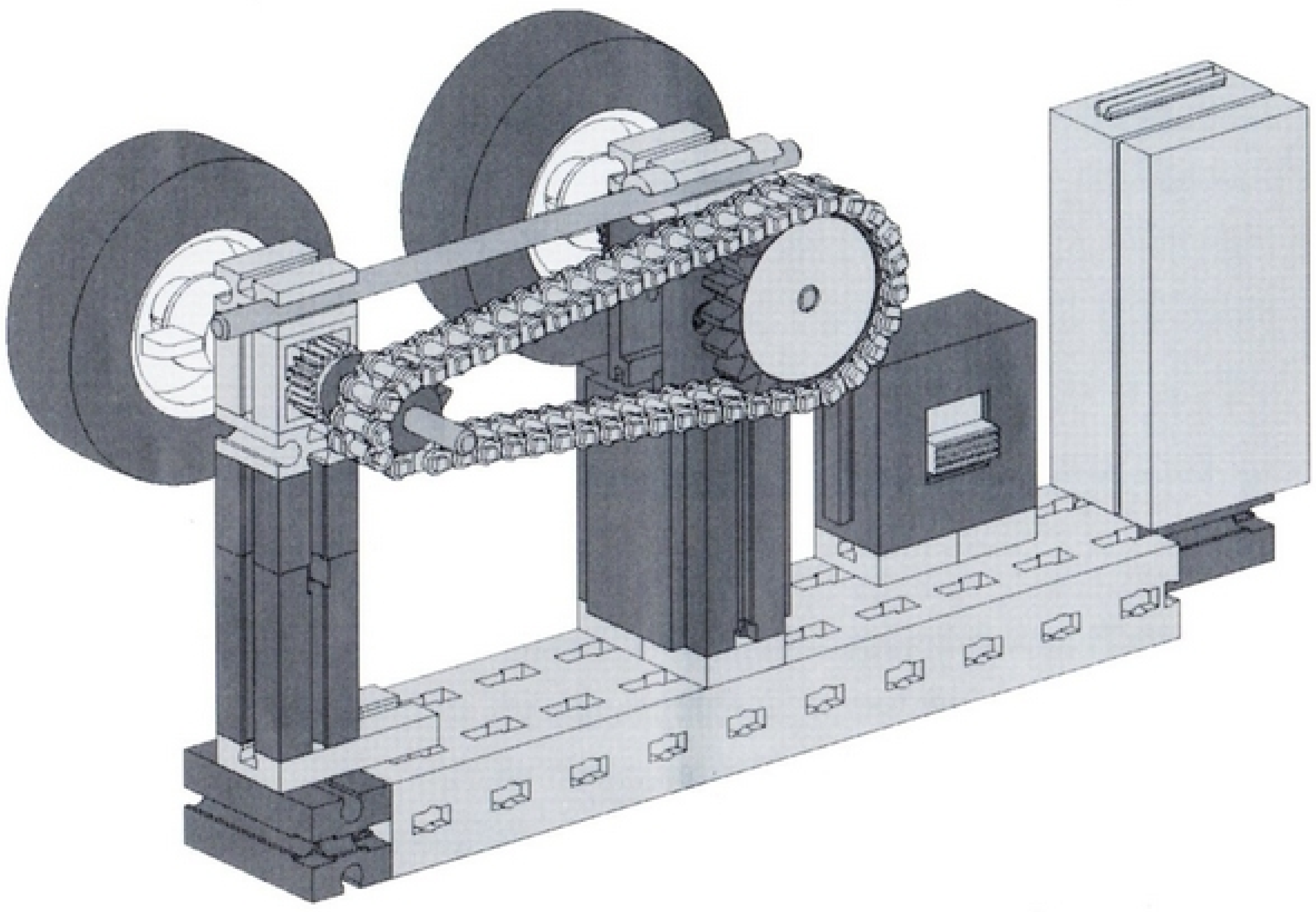
Jump up onto your bike, start pedaling and off you go. In the car, start the engine, shift to first and the trip begins. It's just the ways things are, isn't it? But what's behind all this? What happens between the foot pedals and the wheels, and how does the technology function when you drive in low gear slowly but relatively easily up a mountain or in a high gear racing down like mad? How do different steering and drive systems function? The Cartech assembly kit answers all these questions. And the best thing is, you can try out directly how it all functions using the models you assembly with the help of the instructions. Then you can read in the accompanying booklet what's behind all this. Okay then, time to get going!

2. Power Transmission via a Chain

Transmission of power from one axle to another can be done excellently using a chain. On a bicycle, for example, the power from the pedals (drive axle) can be transmitted to the back wheel (output axle). We can see during bicycle riding that the combination of different-sized chain sprockets (chain gears) results in the fact that you must pedal more quickly in 1st gear but only move forward slowly, while you only need to pedal slowly in the 21st gear to go quickly, but you need a lot more power.

Model: Chain Drive

(see the assembly instructions on page 6)



In our first model, the drive axle is not powered by pedals, but instead by an engine. We are going to build in different toothed gears and observe what happens:

Experiment 1:
Drive axle on engine (1) with toothed gear Z20 (= 20 teeth), output axle (2) with toothed gear Z10 (= 10 teeth), exactly as shown in the assembly instructions. Which of the wheels rotates more quickly?

Observation:
The wheel on the output axle rotates more quickly than the wheel on the drive axle.
If you detach the gears from the engine and rotate the drive axle by hand, you can observe that the output axle rotates exactly twice as fast as the drive axle.

Experiment 2:
Exchange the toothed gears on the two axles: drive axle with toothed gear Z10 and output axle with toothed gear Z20. Which wheel rotates faster now?

Observation:
The wheel on the output axle rotates more slowly than the wheel on the drive axle.
If you detach the gears from the engine and rotate the drive axle by hand, you can observe that the output axle rotates exactly half as fast as the drive axle.

Experiment 3:
Both axles with toothed gear Z20 (= 20 teeth)
Observation:
Both wheels rotate at the same speed.

Experiment 4:
Both axles with toothed gear Z10 (= 10 teeth)
Observation:
Both wheels rotate at the same speed again.

Consequently, it does not matter how large the toothed gears are. As long as they have the same size (have the same number of teeth), they rotate the axles at the same speed.

And what does this mean for us? Very simple. We see that the speed of the wheels depends solely on the size ratio of the gears. To put it more precisely, it is a question of the relation of the number of teeth of the two gears.

The two gears have the same number of teeth in experiments 3 and 4. The relation between

$$\frac{\textbf{Number of teeth on the driven gear}}{\textbf{Number of teeth on the drive gear}} \textbf{ is } \frac{20}{20} \textbf{ (Exp. 1) or } \frac{10}{10} = \frac{1}{1} \textbf{ (Exp. 2)}$$

The number of teeth of the driven gear is always in the numerator of the fraction and that of the drive gear in the denominator. The transmission relation is 1 to 1. The wheels rotate at the same speed.

In experiment 1, the transm. relation is: $\frac{20}{10} = \frac{2}{1}$ **(two to one).**

In experiment 2, the transm. relation is: $\frac{10}{20} = \frac{1}{2}$ **(one to two).**

If the transmission relation is greater than 1, it is a transmission into slower rotation, also called speed reduction. If it is smaller than 1, transmission is to faster rotation.

The transmission ratio is often written using a colon instead of a fraction:

Transmission ratio in:
Experiment 1 = 20:10 = 2:1 Experiment 3 = 20:20 = 1:1
Experiment 2 = 10:20 = 1:2 Experiment 4 = 10:10 = 1:1

If the number before the colon (toothed gear number of the driven gear) is greater than the number after the colon (toothed gear number of the drive gear), it is a transmission into slower rotation, called "speed reduction". If the number after the colon is greater than the number before, transmission is to faster rotation.

The way you write this down is up to you. We will use both ways in the experiments below.

Using this knowledge, you can build cars that move either fast or slowly. Take a look at the assembly instructions. You can find three vehicles there (a tractor, a racing car and an off-road vehicle), which use a chain as a drive.

Models: Tractor, Racing Car and Off-Road Vehicle Drives (see the assembly instructions on page 8)

The three models only differ in their combination and arrangement of toothed gears.

Task:
Write down the number of toothed gears of the drive and driven toothed gears for each model in the table and calculate the transmission.

Model	Drive gear	Driven gear	Transmission
Tractor			
Racing car			
Off-road vehicle (4-wheel drive)			

Solution:

Modell	Drive gear	Driven gaer	Transmission
Tractor	Z10	Z20	2:1
Racing car	Z20	Z10	1:2
Off-road vehicle (4-wheel drive)	Z20 and Z10	Z20 and Z10	1:1

Assembly the models one after another and make the following experiments with each model:

Experiment 1:
How fast is the model?
Set a distance, e.g., one meter long, and measure the time that the model requires for it using a stopwatch.

Experiment 2:
What incline can it ride up?
You can use a board for the incline, for example, which you lean on a pile of books or a chair.

What can you observe?

Observations:
The tractor is the slowest model, but is able to go up the highest incline. The racing car goes the fastest, but is only able to go up a slight incline. The off-road vehicle is between the other two.

Results:
You can see that the faster the car, the less power the wheels have. This power is called "torque" in engineering. The torque is in an inverse relation to the transmission, i.e., if the rotational speed is doubled between the drive and driven gears, the torque is halved (racing car). If the rotational speed is halved, the torque doubles.

Now you can imagine why although your bicycle is slower in 1st gear, you can ride up almost every mountain (slow speed, high torque).

3. Gear Shifting

You can change the rotational speed and torque not only with a chain, but also with gears in which the teeth grip one another directly. Of course, this saves space. Contrary to chain drive, the driven gear rotates in the opposite direction of the drive gear.

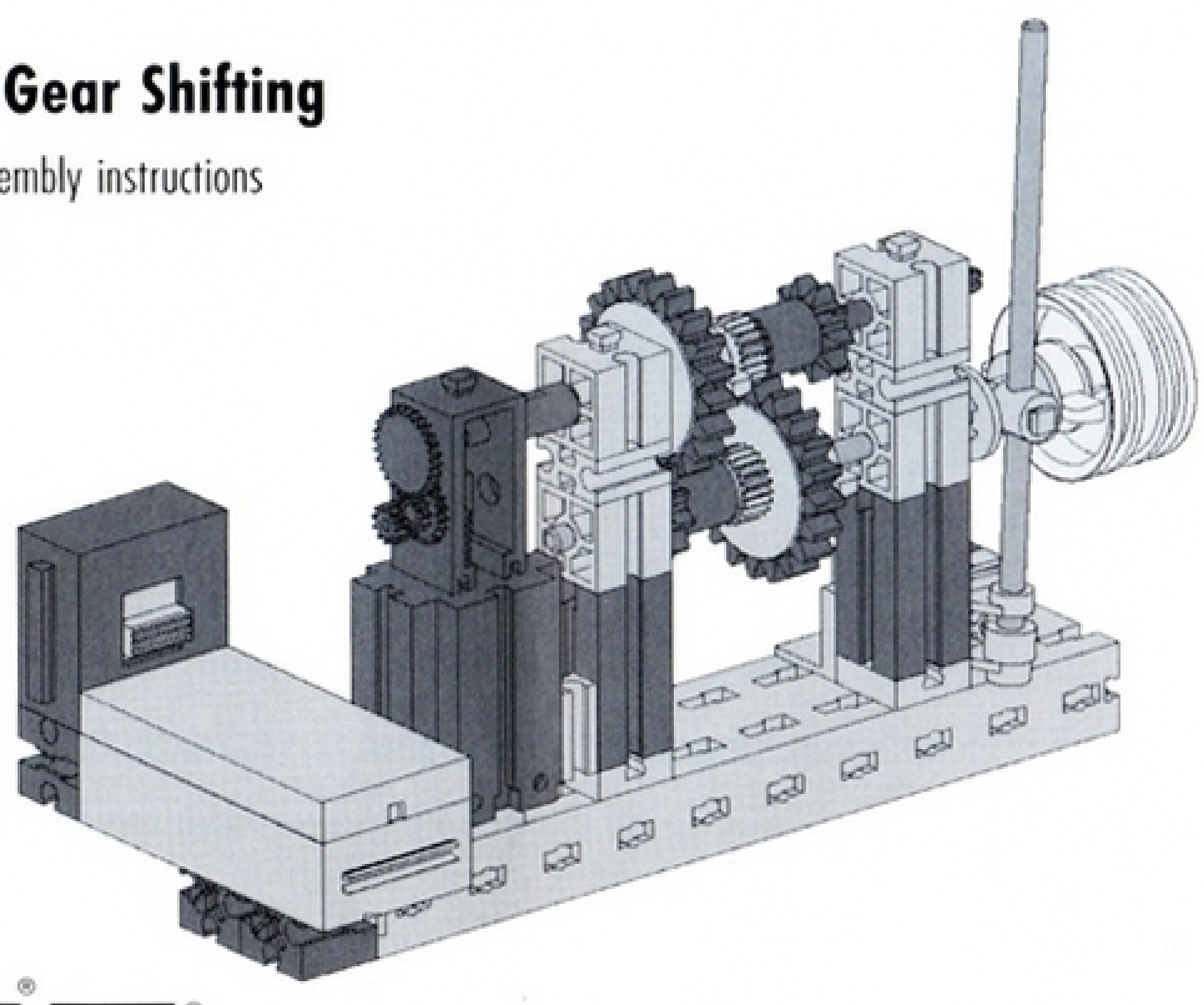
Why do we use gears? We could also regulate speed simply by using the gas pedal.

Most engines have too high a rotational speed and too little power without gears, so that the wheels cannot be driven directly. That is why we reduce the rotational speed with a gear and increase the available power at the same time. Additionally, many engines do not provide the same power in each rotational speed range. By shifting gears, an engine can always run in a favorable rotational speed range, regardless of how fast you want to go.

Similar to in a car, we are now going to assemble a gearbox with which we can switch gears using a shift stick. So that it does not get too complicated, we will assemble a gearbox with only two gears.

Model: Gear Shifting

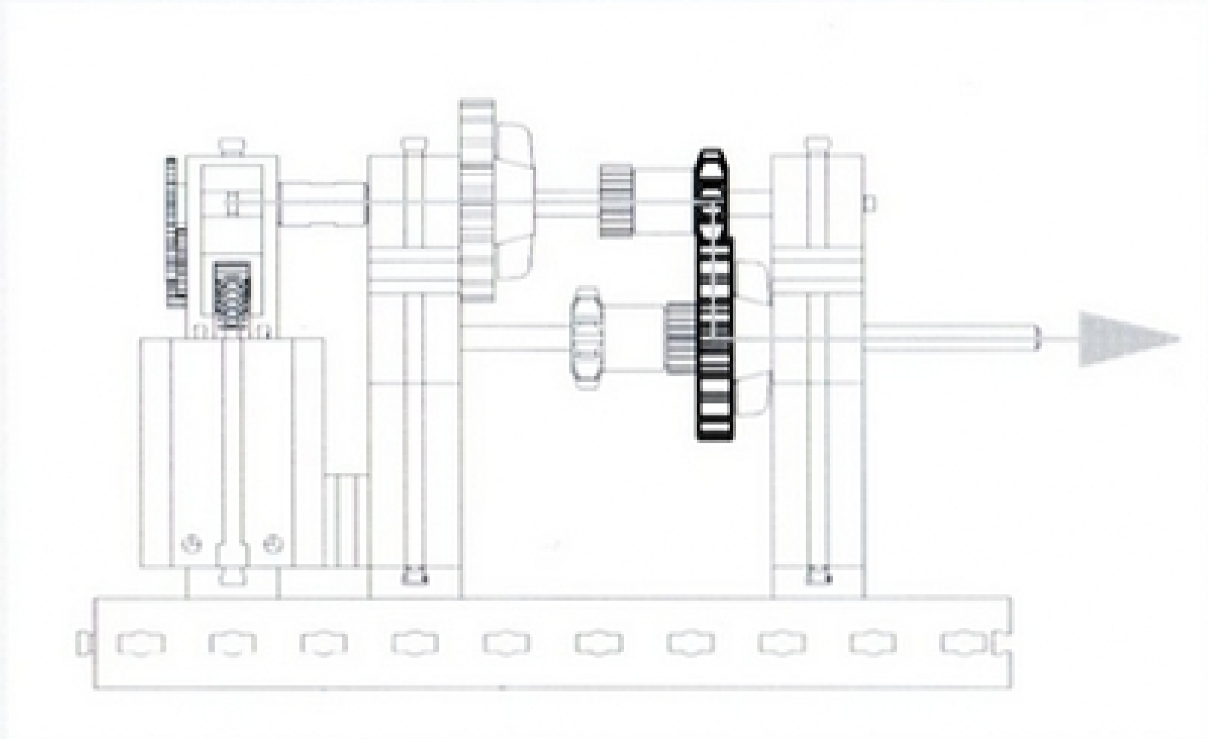
(see the assembly instructions on page 14)



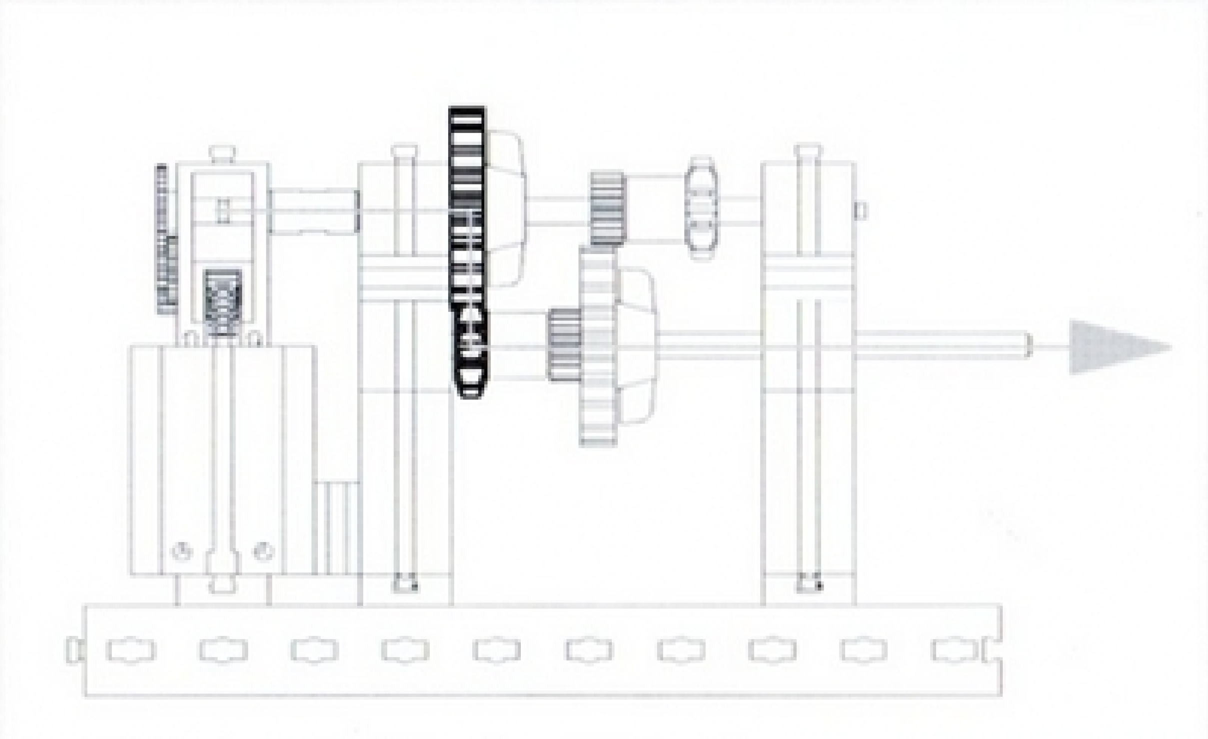
To see how shift gears work, you can build in stationary gear shifting in this demonstration model. You can do this quickly, and it demonstrates how it functions clearly. It is important to ensure that a narrow idling area is located between the first and second gear. Then the tooth can catch better when the gears are shifted.

Task:
Calculate the transmission relations in first and second gear.

Solution:



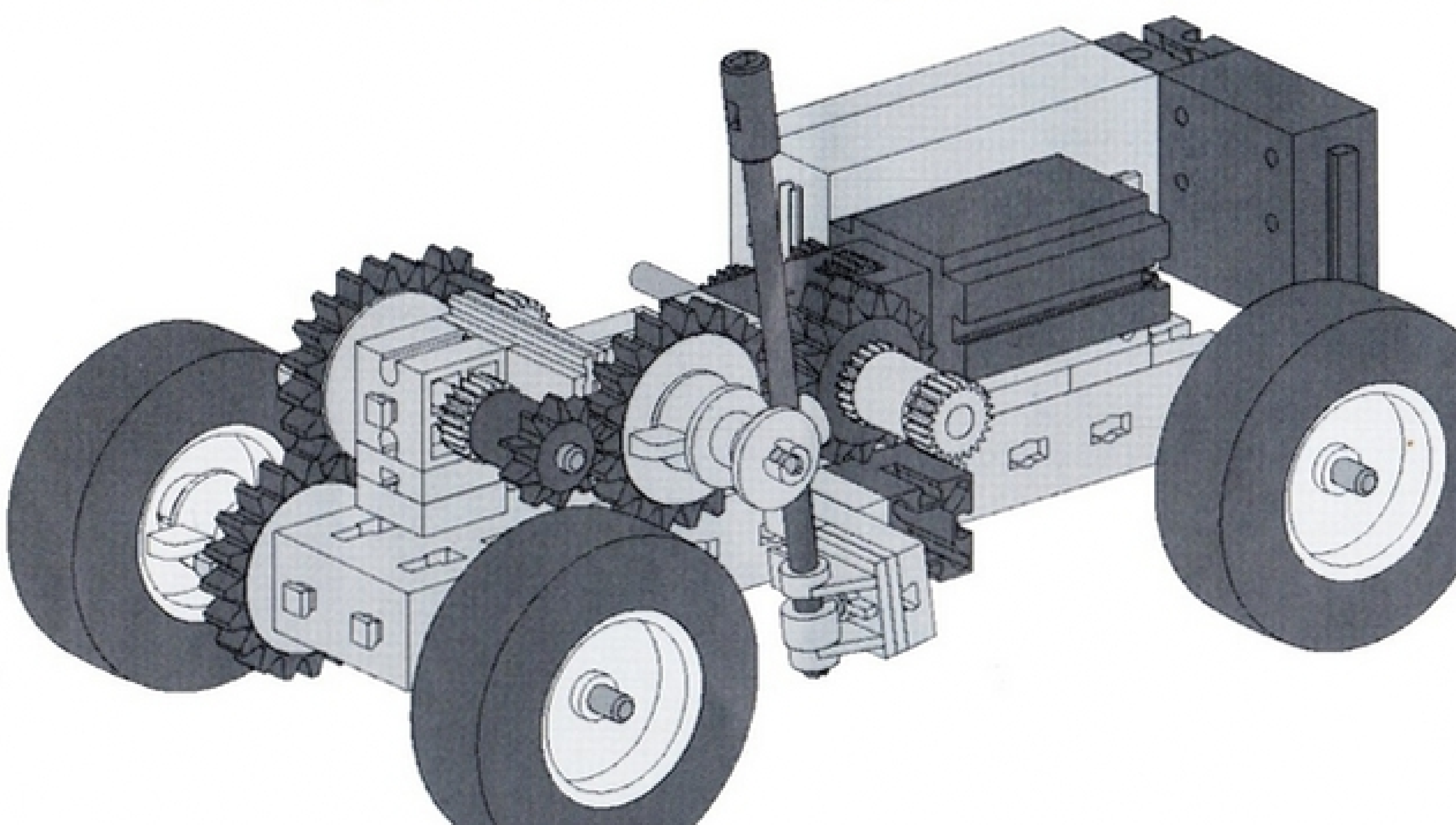
1st gear: (slow): 20:10 = 2:1,
i.e., the rim rotates at half the engine revolution



2nd gear: (fast): 10:20 = 1:2,
i.e., the rim rotates at double the engine revolution

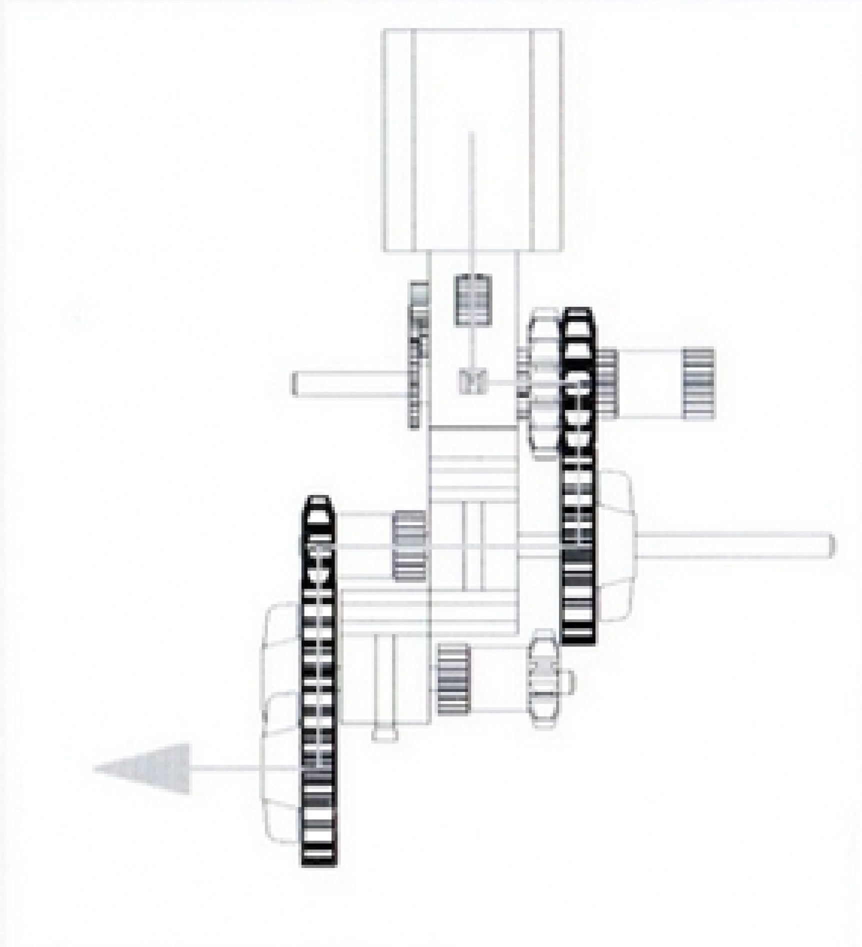
Model: Vehicle with Gear Shifting

(see the assembly instructions on page 16)



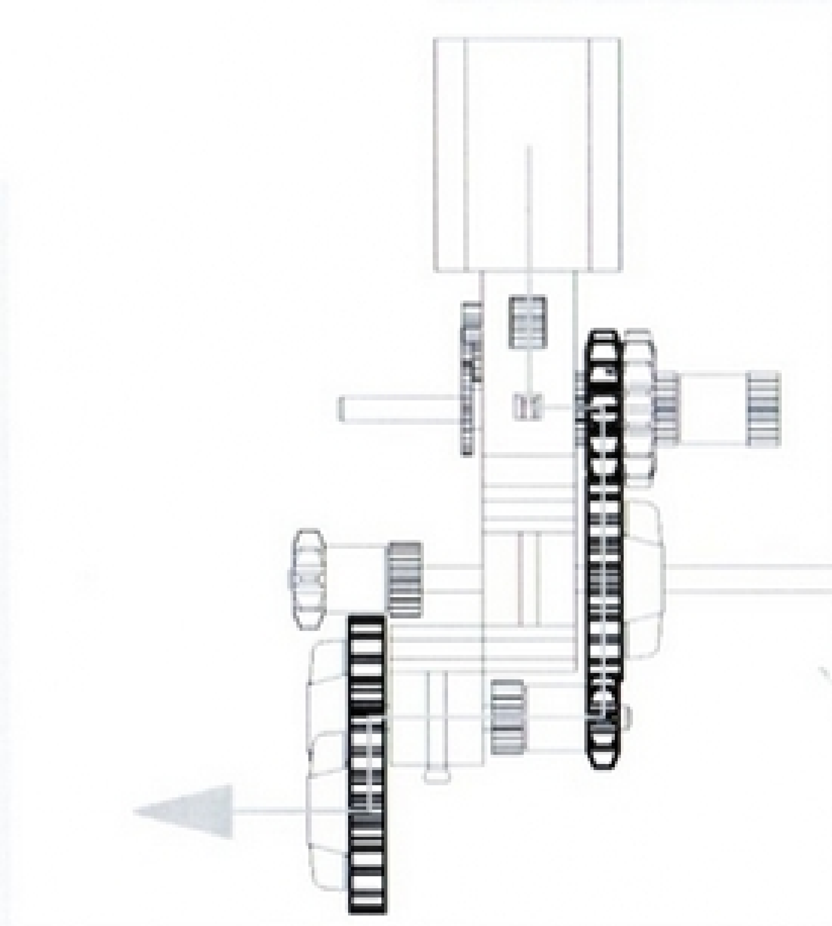
Now you can assembly this vehicle with gear shifting. In the design of every vehicle, you must ensure that the gears take as little space as possible. The vehicle has two gears.

Task:
How big are the transmission relations in first and second gear?
Solution:



In the first (slow) gear, the transmission relation is

$$\frac{20}{10} = \frac{2}{1} = 2$$



In the second (fast) gear, the transmission relation is

$$\frac{10}{20} = \frac{1}{2} = 0,5$$

.

Consequently, the vehicle goes four times faster in the second gear than in the first.
If we base our calculations on the output shaft of the engine gearbox, another transmission level is added, specifically that from the two gears next to each other with 15 teeth to the gear with 20 teeth.

This level has a transmission of $\frac{20}{15} = \frac{4}{3}$

The total transmission is calculated by multiplying the two transmission levels.

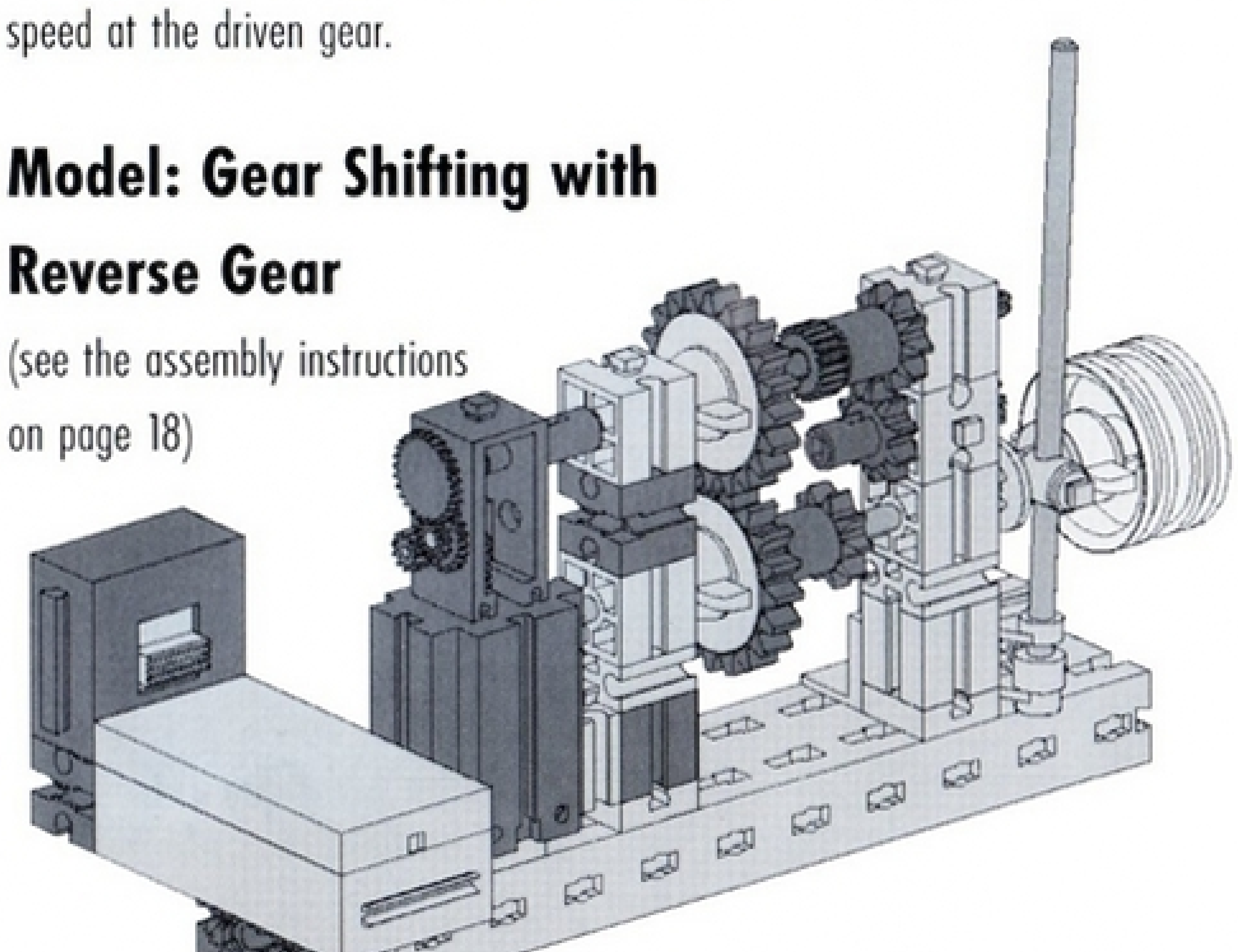
First gear: $\frac{2}{1} * \frac{4}{3} = \frac{8}{3}$ or 2.66:1 Second gear: $\frac{1}{2} * \frac{4}{3} = \frac{2}{3}$ or 0,66 : 1

Consequently, the wheels rotate somewhat more slowly than in the stationary gears (2:1 in first gear; 1:2 or 0.5:1 in second gear).

The following applies: the larger the transmission relation, the smaller the speed at the driven gear.

Model: Gear Shifting with Reverse Gear

(see the assembly instructions on page 18)



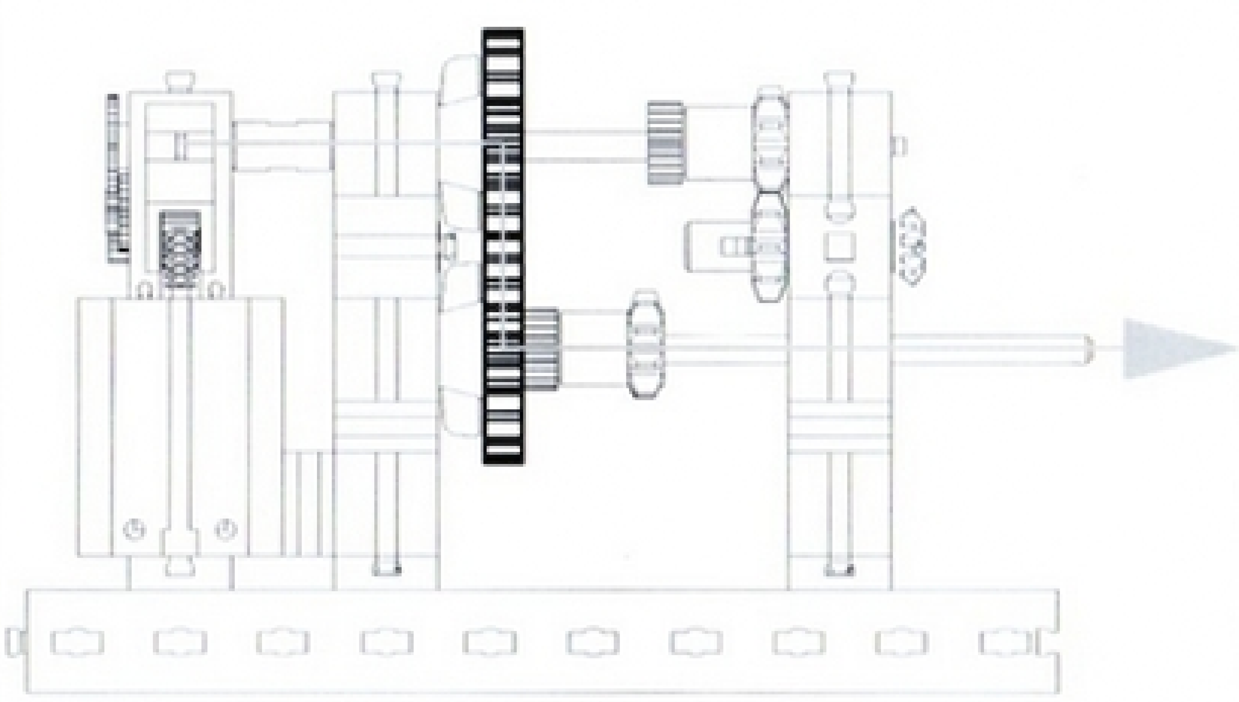
In the fischertechnik electric engine, you can reverse the rotational direction easily by reversing the poles of the power supply. This is not possible with a combustion engine; it always runs in the same direction. The rotational direction is reversed there via a gearbox with a reverse gear. This model demonstrates how this functions using the example of a simple, stationary gearbox.

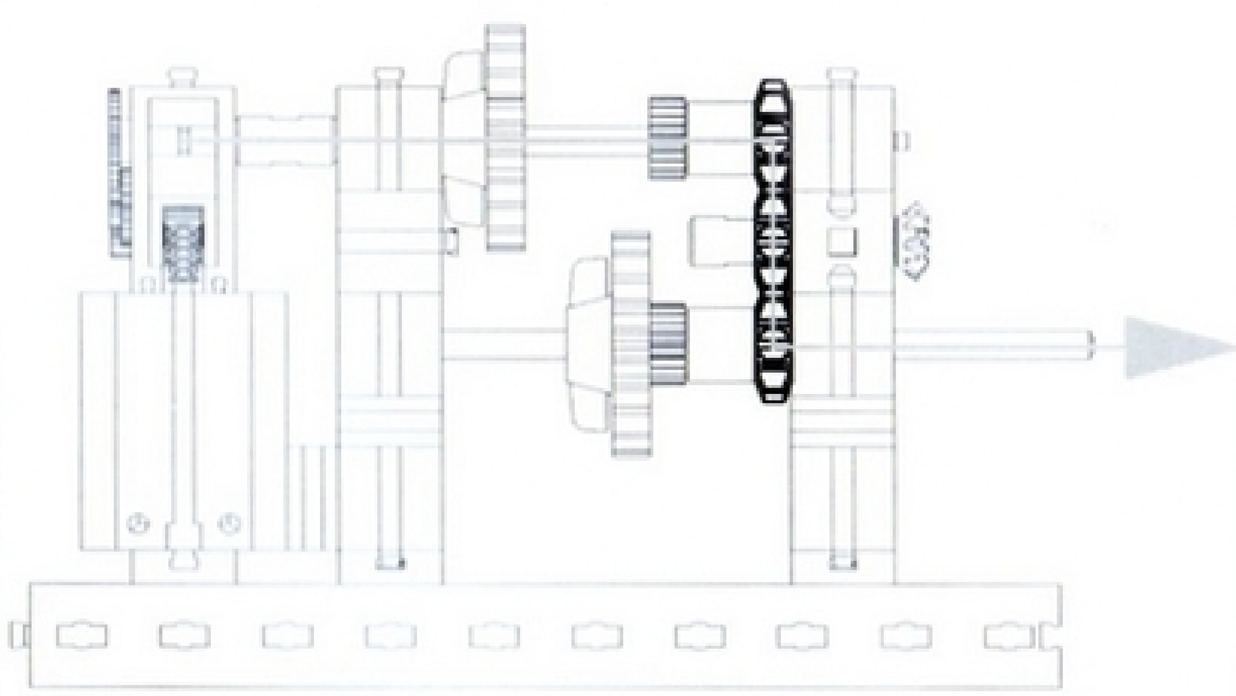
Task:

1. How can you achieve the different rotational directions in a gearbox with forward and reverse gears?
2. Calculate the transmission relation in the forward and reverse gears.

Solution:

We already saw in our first experiment with gear shifting that the driven gear rotates in the opposite direction to the drive gear. We reverse the rotational direction once again for the reverse gear and require a third gear to do this. Consequently, gear shifting with forward and reverse gears involves two gears working together one time and three gears working together another time.

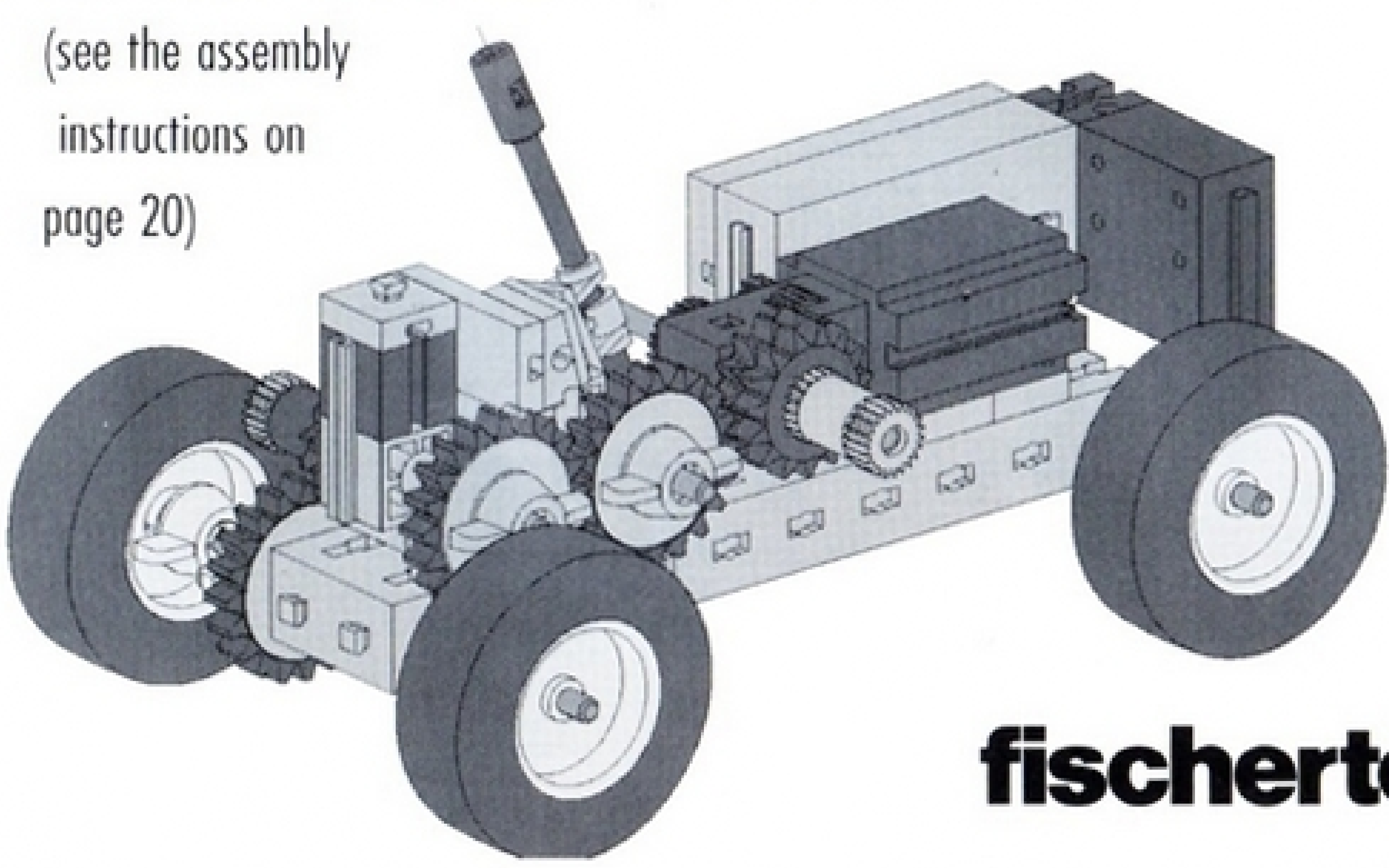




The transmission relation is the same in the forward and reverse fears, i.e., 10:10 = 20:20 = 1

Model: Vehicle with Reverse Gear

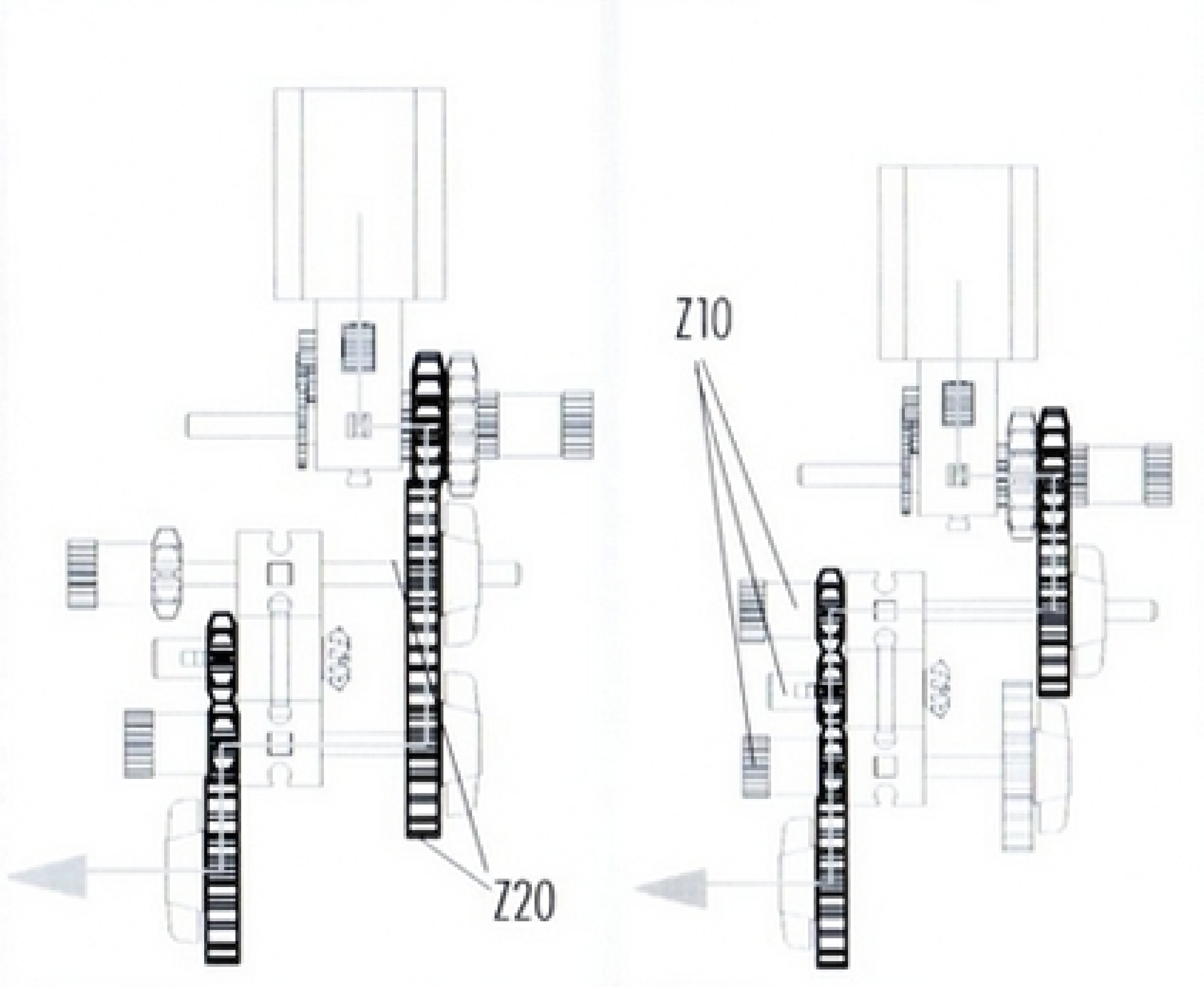
(see the assembly instructions on page 20)



A gearbox with reverse gear is built into the vehicle in this model.

Task:

What are the transmission relations in the forward and reverse gears?



Solution:

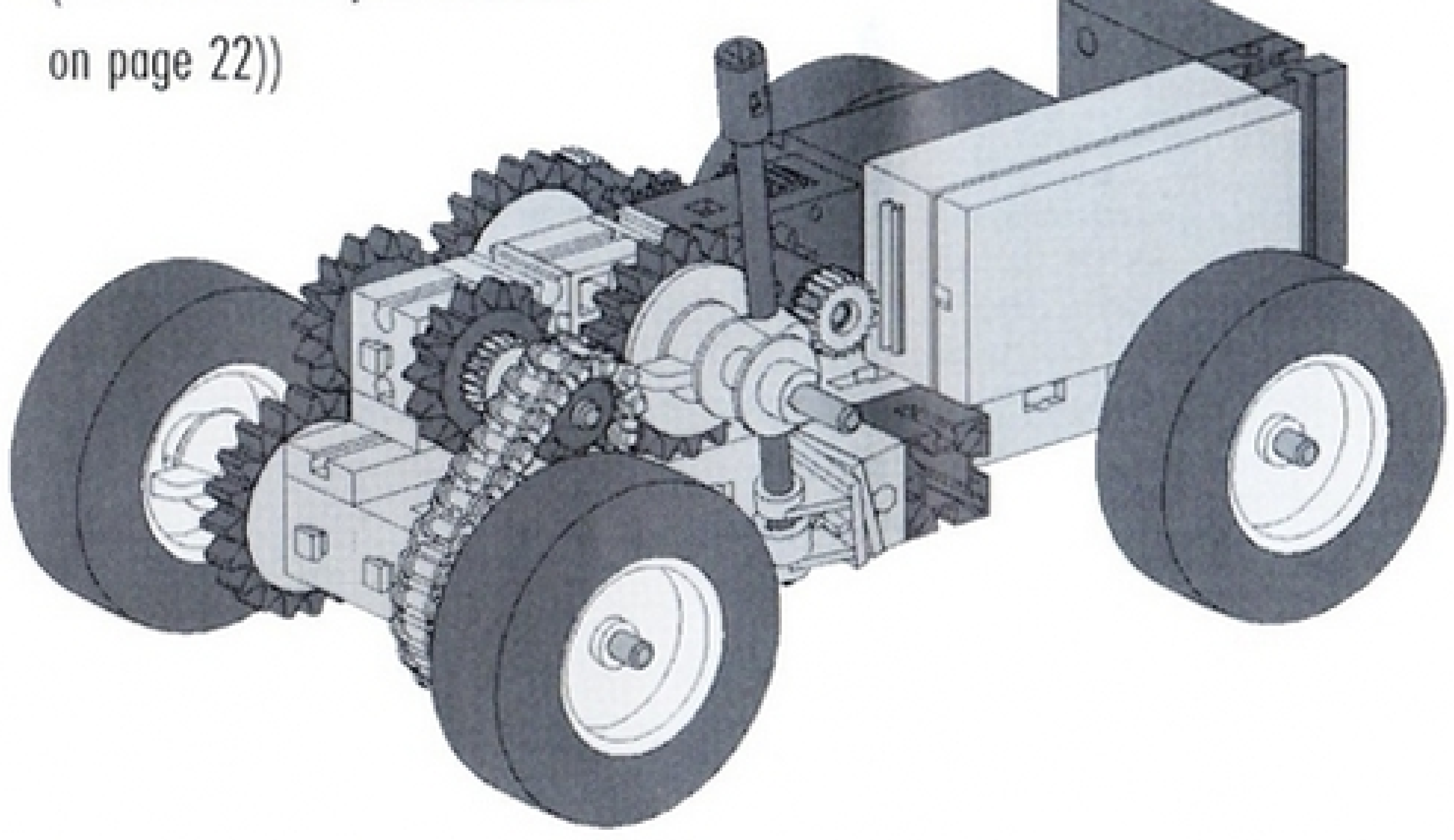
The transmission relation is 1:1 each time between the gears, which are responsible for the change of direction (2 toothed gears Z20 in the forward gear and 3 toothed gears Z10 in the reverse gear). This means that we do not need to consider them in the calculation. Consequently, we restrict our calculation to the transmission between the geared engine shaft (toothed gear Z15) and the first toothed gear Z20 as well as to the last two toothed gears Z10 and Z20 on the rear axle of the vehicle.

We again calculate the total transmission by multiplying the individual transmissions: $\frac{20}{15}*\frac{20}{10}=\frac{4}{3}*\frac{2}{1}=\frac{8}{3}$

The transmission relation is the same in the forward and reverse gears.

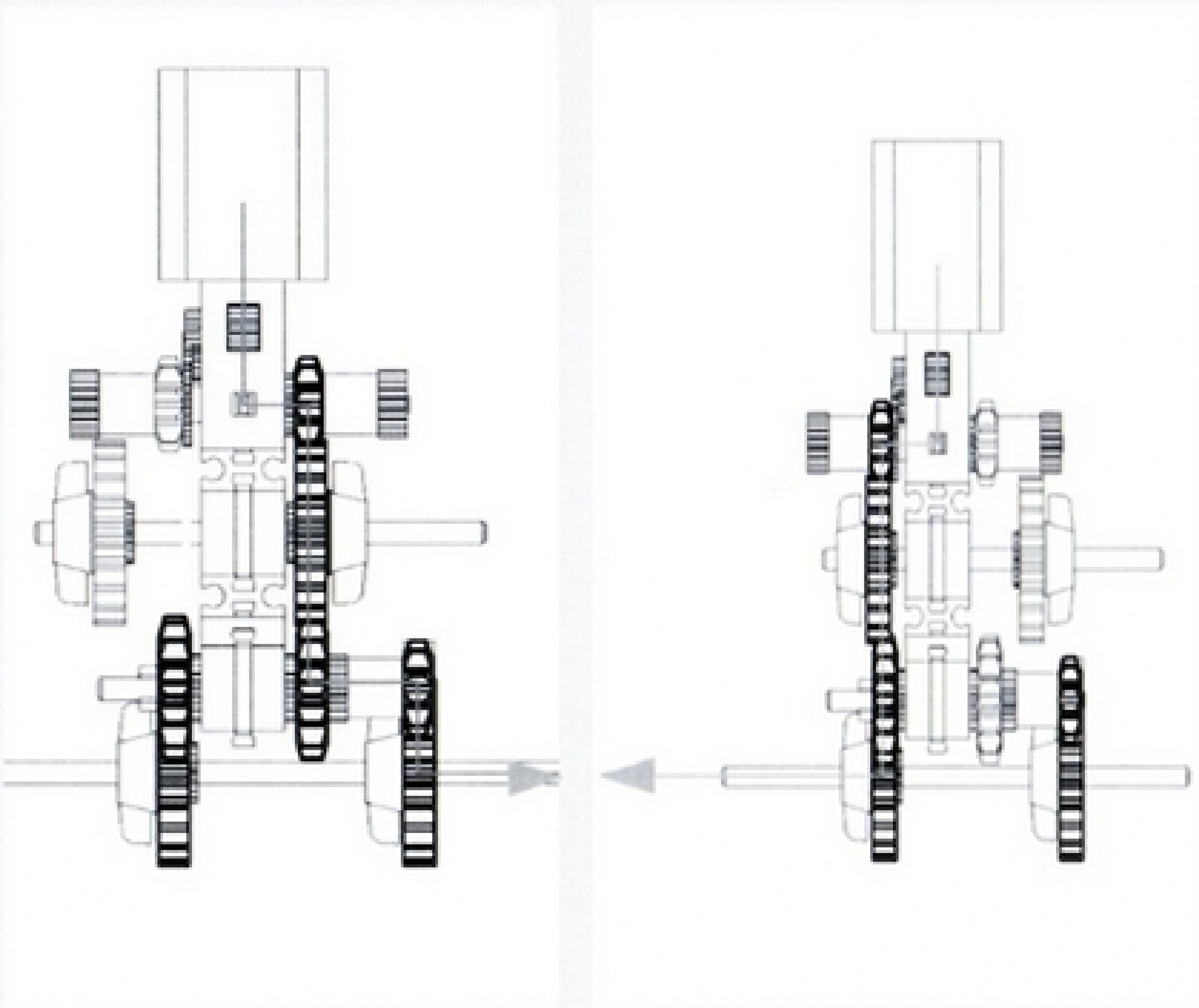
Model: Vehicle with Reverse Gear and Chain Drive

(see the assembly instructions on page 22))



Because a real vehicle goes faster in forward gear than in reverse gear, this model has different transmissions in both gears.

Task:
What are the transmission relations in the forward and reverse gears calculated from the output shaft of the engine?
Solution:



Forward gear (faster):
$$\frac{20}{10} * \frac{15}{20} * \frac{20}{15} = \frac{6000}{3000} = \frac{2}{1}$$

Reverse gear (slower):
$$\frac{20}{10} * \frac{15}{20} * \frac{20}{10} = \frac{6000}{2000} = \frac{3}{1}$$

Task 1:
Which wheel moves the greater distance in a curve: the outside wheel or the inside one?
Which wheel rotates faster?
Try it out on the model!

Solution:
The outer wheel travels the greater distance, because it moves over a greater circle. Because it travels the greater distance, it also rotates more quickly.

Task 2:
Which disadvantages did you notice in trying out the pivot-support steering on the model?

Solution:
The wheels need a lot of space when they incline during turning.
The vehicle can tip easily in sharp curves, especially when it is going fast.

Task 3:
Which vehicles use pivot-support steering today?

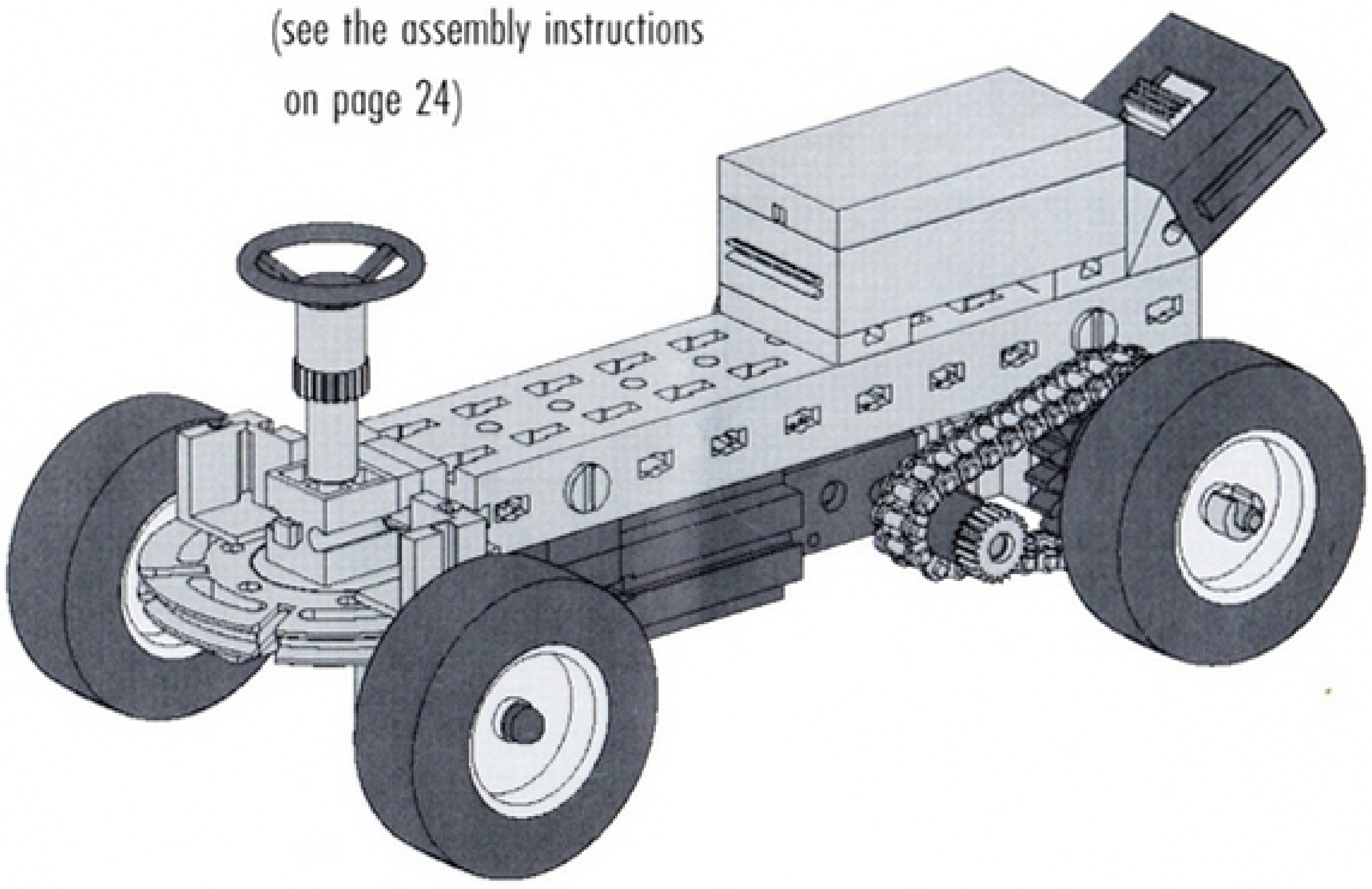
Solution:
Trailers and handcarts, for example.

4. Vehicle Steering

Something has been missing in the models up to now, which is absolutely necessary for a vehicle: the steering. Is there any vehicle that just goes straight? Even before cars existed, carriages and wagons were already equipped with steering. This steering was of a very simple design as in the following model.

Model: Pivot-Support Steering

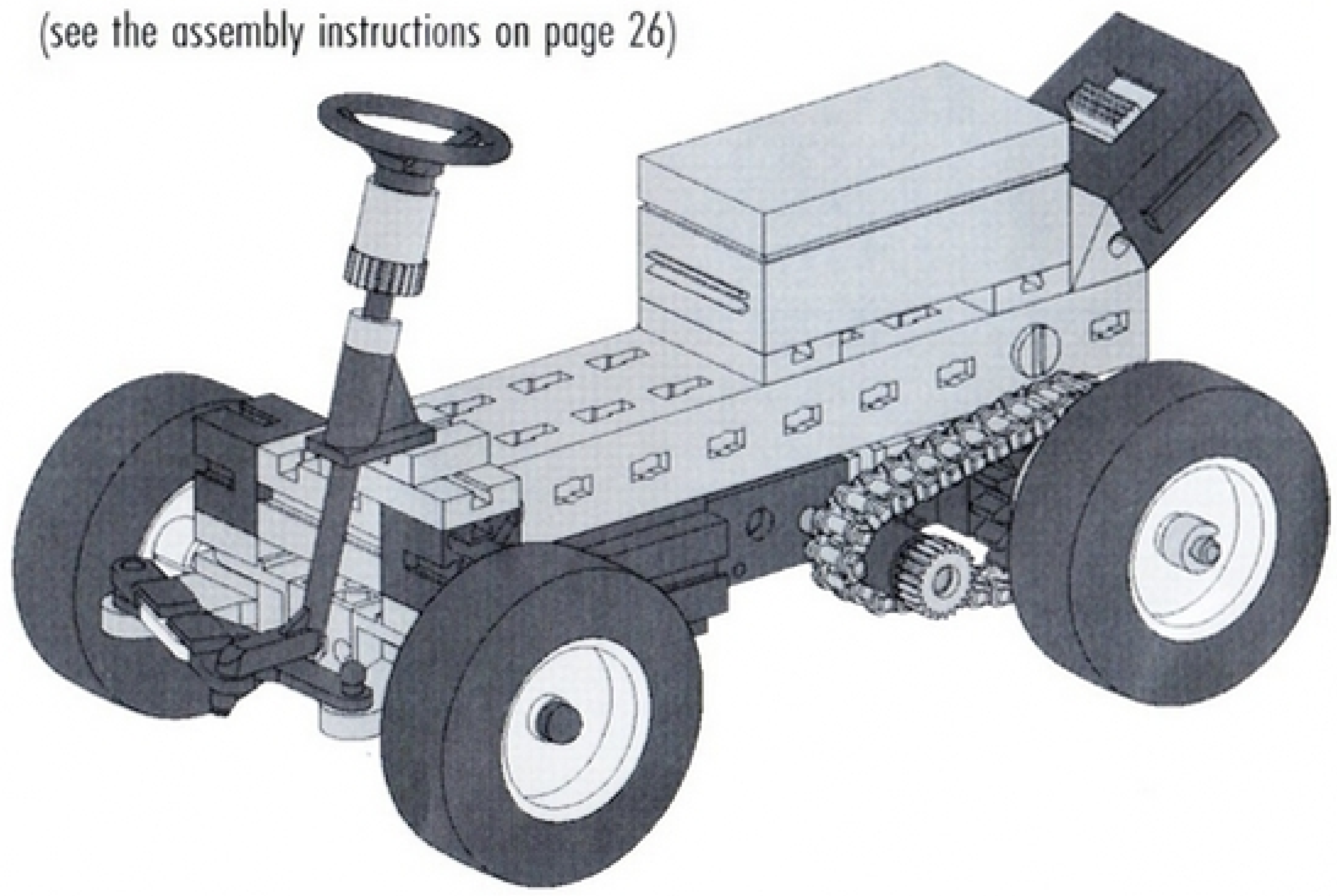
(see the assembly instructions on page 24)



In pivot-support steering, the complete front axle is mounted on a board or a round plate and attached to the vehicle so that it can be turned. Consequently, the complete front axle can be moved around the pivotal center, and the vehicle can be steered in this way. Because both wheels travel different distances in curves, the wheels must be mounted so that they can rotate freely on the axle. This allows them to rotate at different speeds.

Model: Steering Knuckle

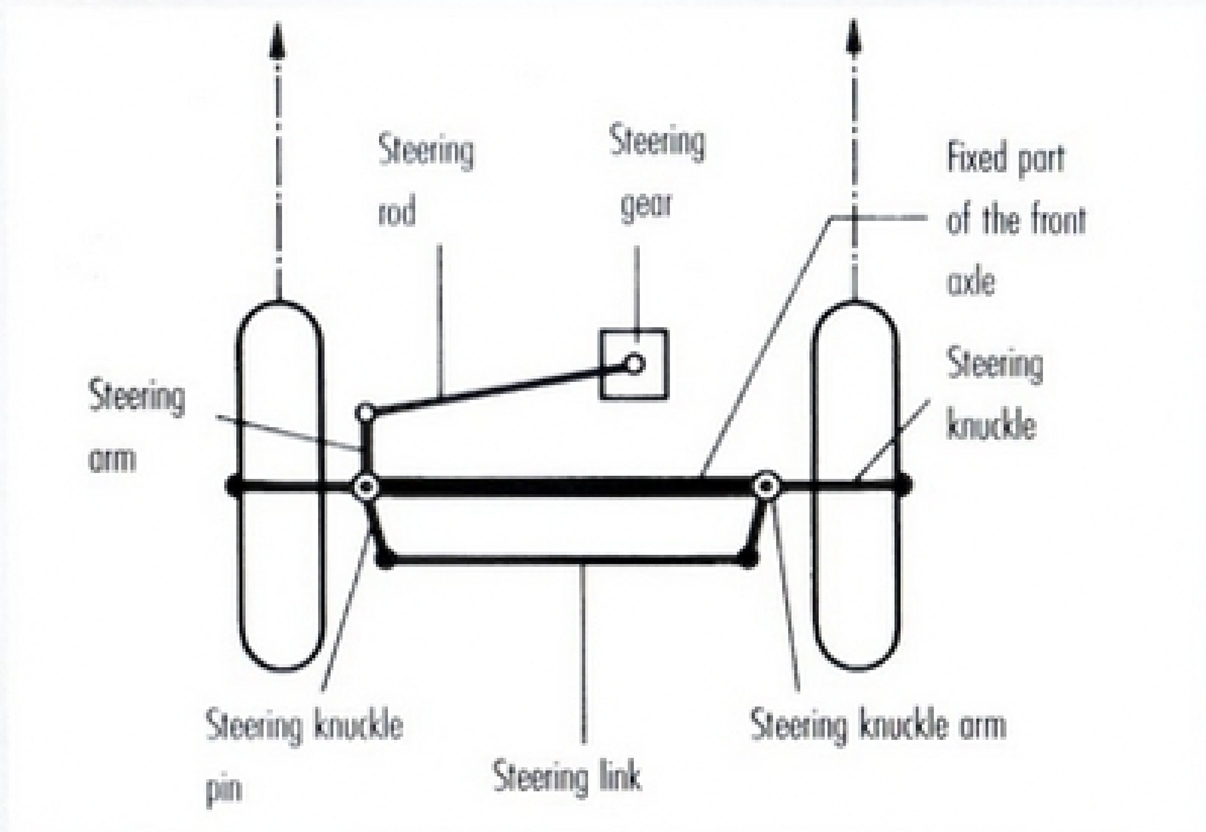
(see the assembly instructions on page 26)

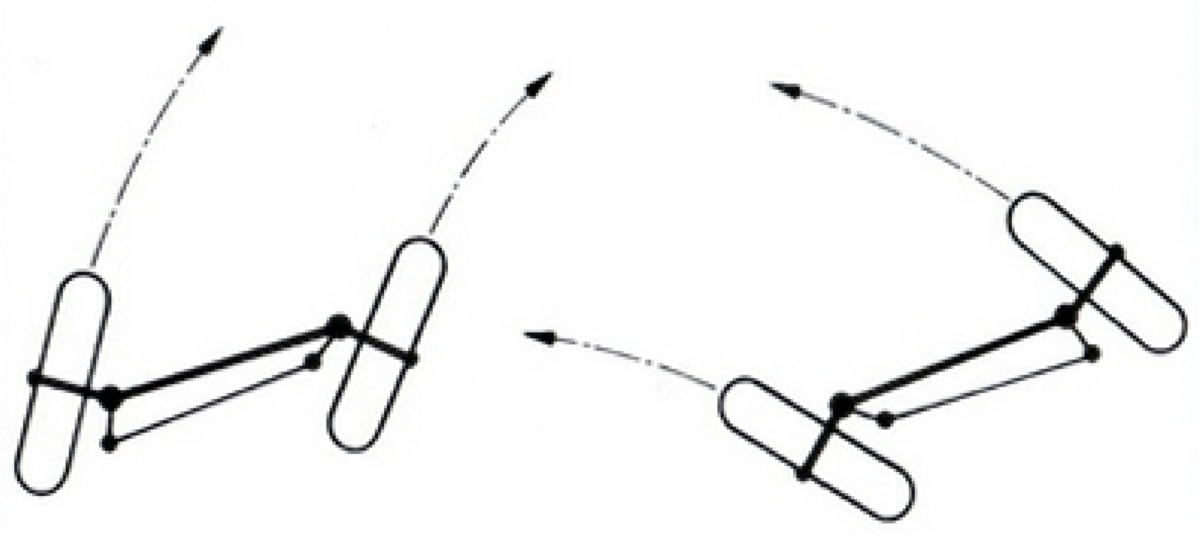


As engines became increasingly powerful and consequently cars faster, automotive engineers had to come up with improved steering too. The result was a steering knuckle, as it is found in our model.

In this type of steering, each wheel is mounted on a very short axle, called a steering knuckle. This steering knuckle is mounted on a steering knuckle pin in such a way that it can be turned.

The steering link connects the two steering knuckles to the steering knuckle arm. This ingenious design of the link and arm is called a steering trapezoid. It ensures that the inner wheel inclines more in a curve than the outer wheel. You can observe this in the fischertechnik model too. The steering knuckles are turned to the left or the right using the steering rod.



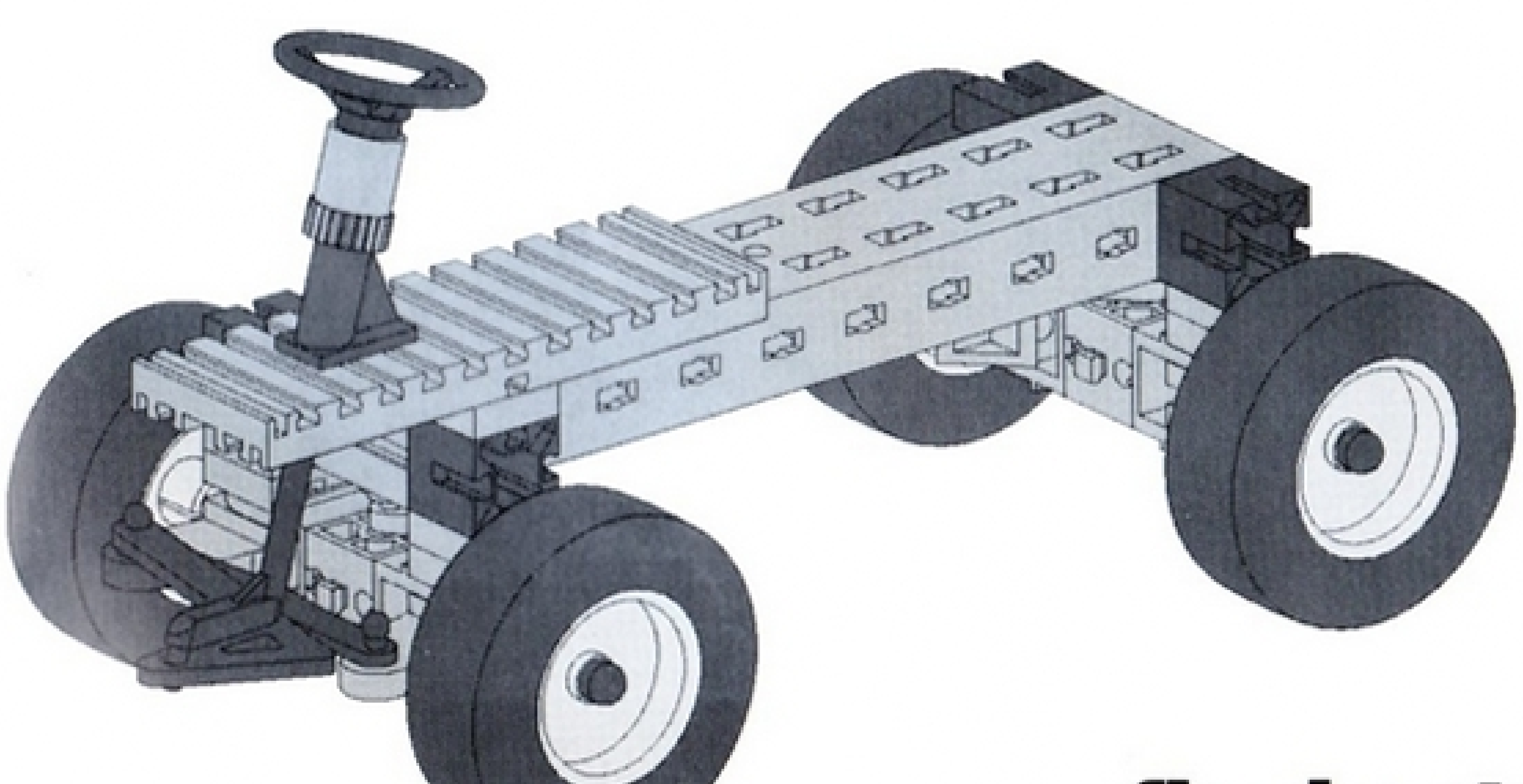


Task:
Which advantages does steering with a steering knuckle have compared to pivot-support steering?

Solution:
It requires less space, because the wheels rotate on a very short axle.
High degree of stability in curves, because the position of the wheels hardly changes at all.
Less wear on the tires, because the wheels rotate precisely in the correct arc due to the different inclines of the outer and inner wheels.

Model: Vehicle with Four-Wheel Drive

(see the assembly instructions on page 28)



Both the front and back axles have steering knuckles in four-wheel drive vehicles. Both steering systems are connected and controlled using a steering wheel.

Task:
What advantages does four-wheel drive have, and where is it used?

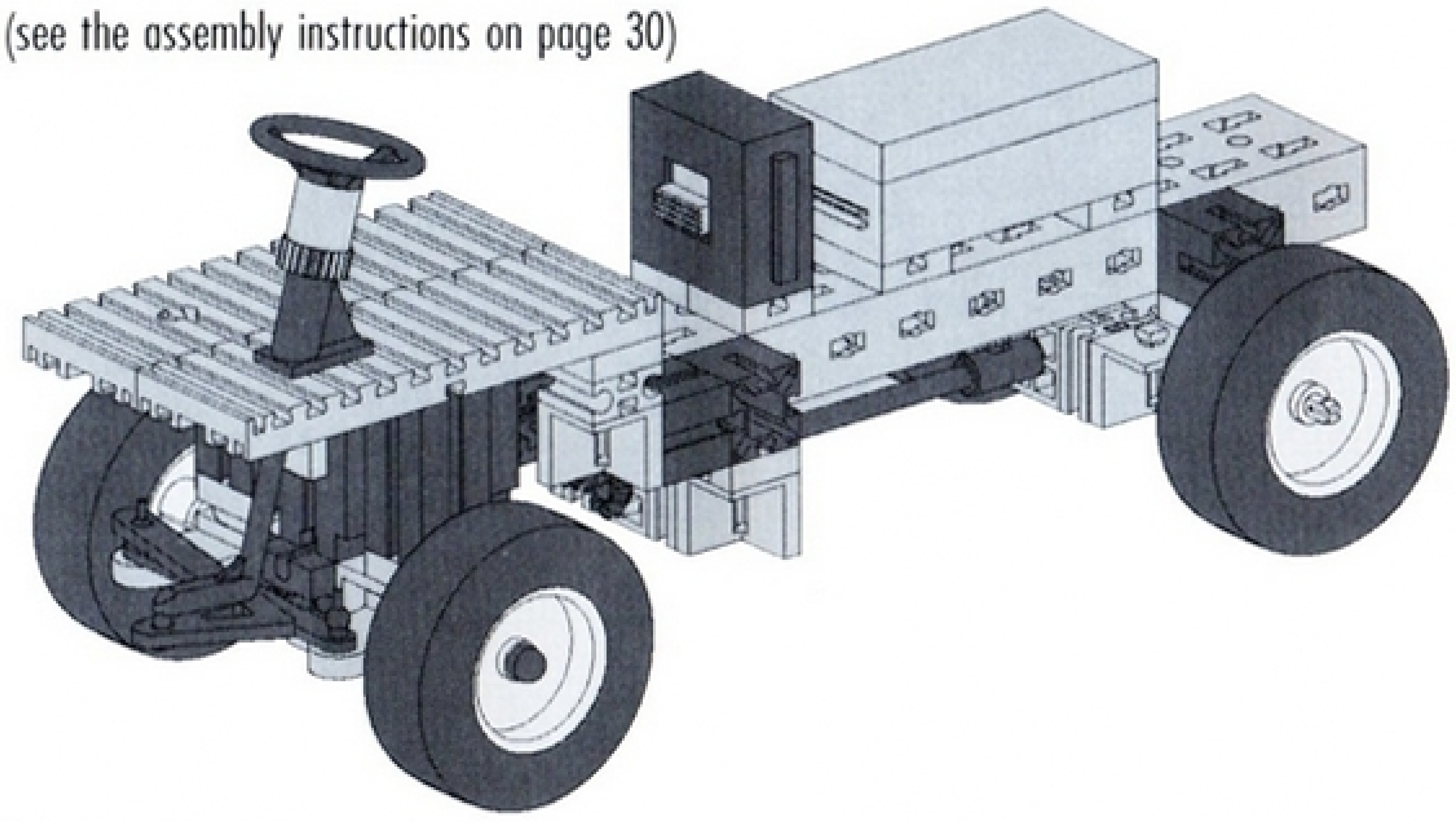
Solution:
Four-wheel drive steering makes it possible to turn within a small radius. It is used when vehicles have to be especially maneuverable, e.g., in cramped construction sites for earthmoving. In especially long vehicles such as trailer trucks, the rear axle is also steered, because otherwise there would be problems in normal curves.

5. Vehicle Drive

The engine is in the front in many vehicles, but it drives the rear wheels. This section explains how the drive power from an engine is transmitted to the wheels. This usually happens differently in reality from how it was done in the Cartech models assembled until now.

Model: Vehicle with Drive Shaft and Bevel Gear Drive

(see the assembly instructions on page 30)



This model contains a typical truck drive. The engine is in the front under the driver's cab (not present) in our model. The power is transmitted via a drive shaft to the rear wheel. We use a bevel gear to transmit the power at a right angle. They are called this because their teeth are shaped like cones..

Task:
In this model as in the previous ones with steering, only one rear wheel is driven. Why?

Solution:
The rear wheels travel different distances in curves and rotate at different speeds. If both wheels were connected rigidly to each other and driven, they would both rotate at the same speed and push the vehicle straight forward. On the other hand, if only one wheel is driven, the other wheel can run freely and rotate at any speed.

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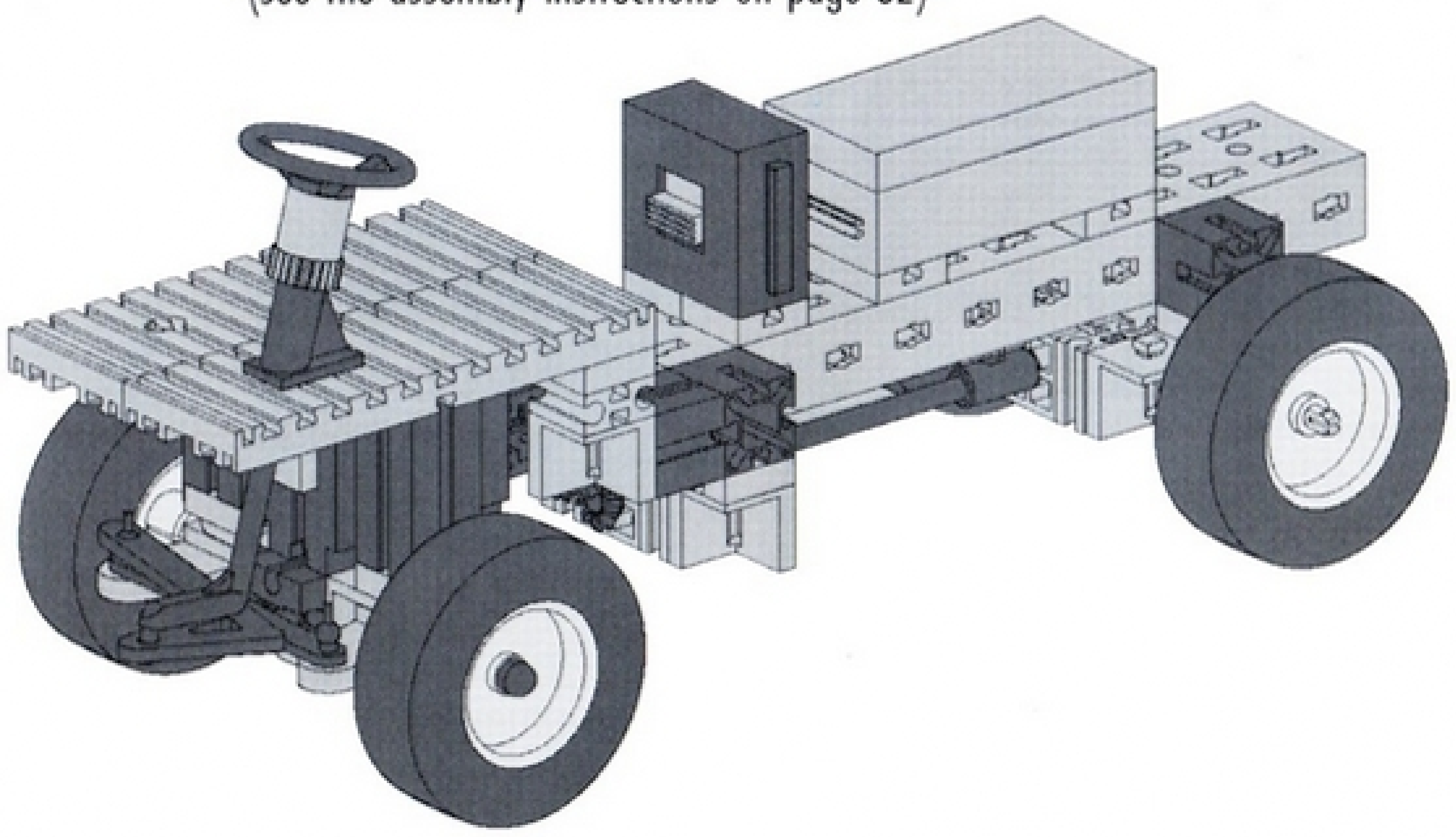
Model: Vehicle with Differential

(see the assembly instructions on page 32)



Of course, only driving one wheel of the rear axle is not ideal, because then the vehicle has less drive power. An ingenious invention, which allows drive of both wheels without them having to be connected rigidly to one another, is represented by differential gears. First assemble the model, and then we will take a closer look at the technology.

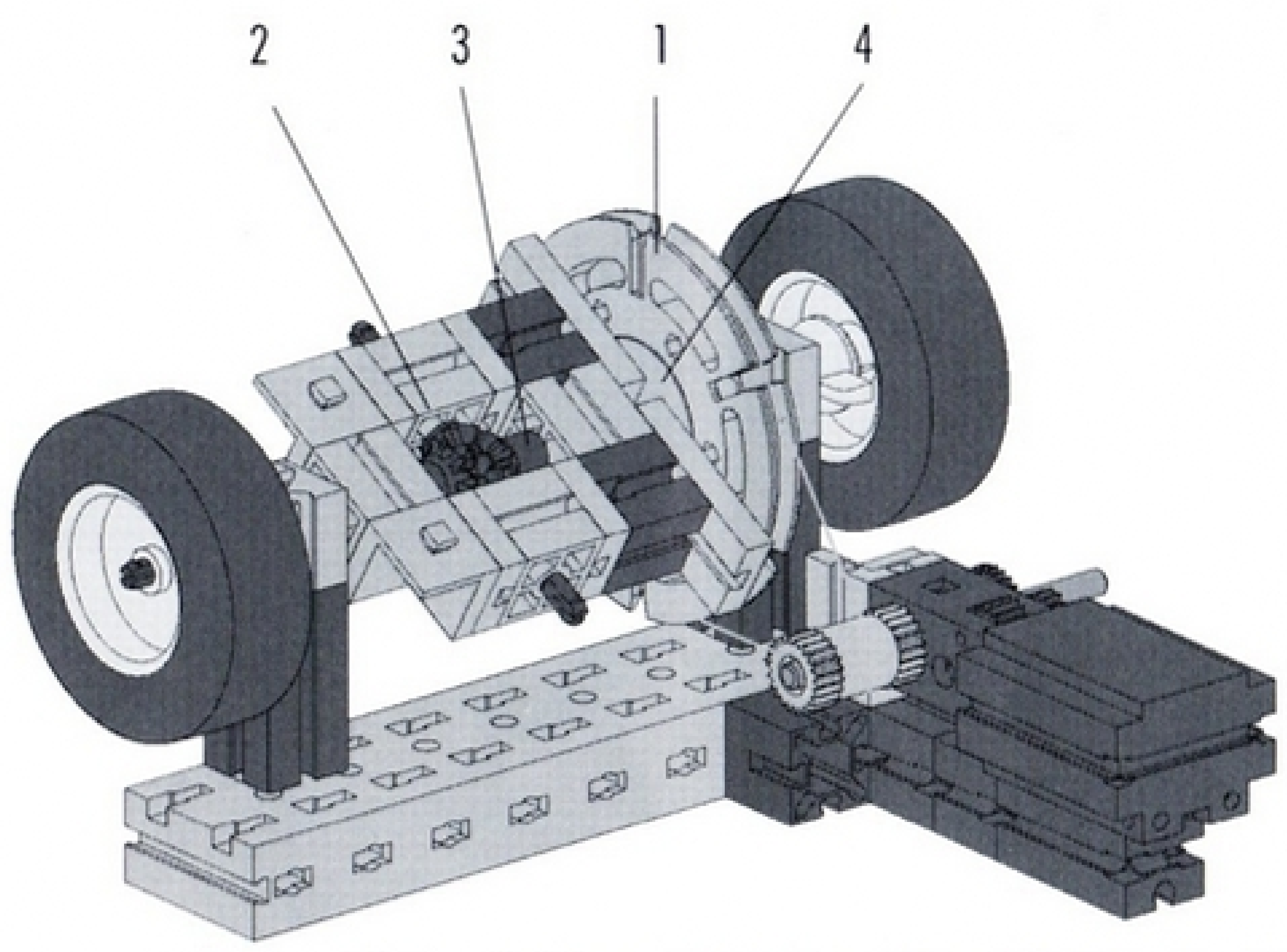
Experiment:
First have the car go straight, then around a curve and observe whether all wheels always rotate and whether the model takes the curve cleanly without pushing forward.

Observation:
If the model has been assembled correctly, both wheels on the rear axle rotate when the car goes straight and when it goes around a curve too. The model takes curves cleanly.

Result:
Without knowing how the gearbox functions exactly, we can see that it is obviously able to drive both rear wheels simultaneously.

Model: Functional Model of Differential Gears

(see the assembly instructions on page 34)



To make it easier for you to see how differential gears are constructed on the inside, assemble it as a large function model from fischertechnik construction components. It is important that you do not tighten the hub nut (4) on the hub (1), so that it can rotate freely on the axle.

Experiment 1:
Rotate each wheel individually. What happens to the other wheel?

Observation:
It turns in the opposite direction.

Experiment 2:
Switch on the engine. Both wheels must rotate at the same speed. What happens if you hold one wheel?

Observation:
The other wheel rotates faster.

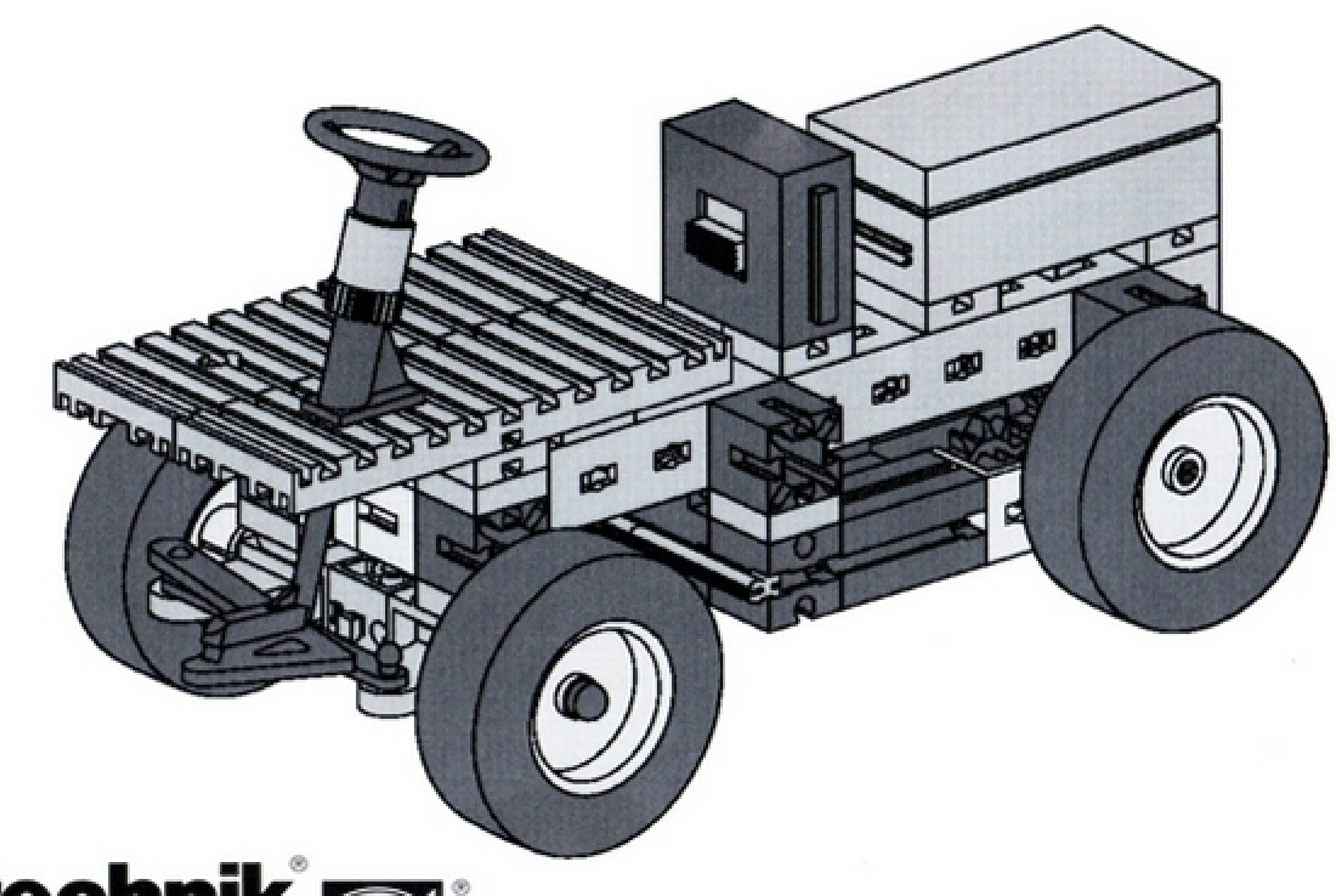
Task:
Can you explain from the observation in Experiment 2 why you cannot go forward with a car in winter if only one of the driven wheels spins on ice?

Solution:
The rotating wheel revolves quickly, and the wheel on solid ground remains stationary (it is "held").

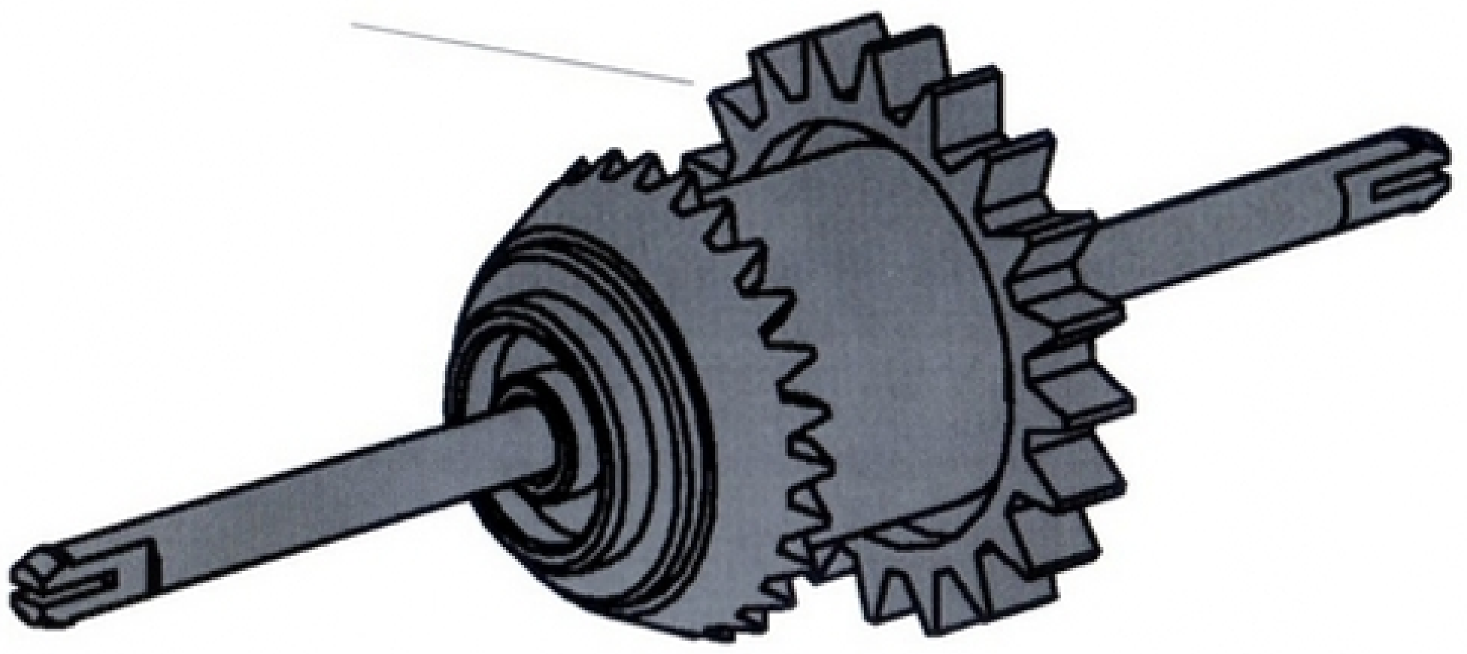
Mode of Operation of Differential Gears:
The differential is driven via a belt pulley (1) (see the diagram above). The power is transmitted to the two wheels via the differential bevel gears (2). They are capable of compensating for the rotational differences between the wheel on the inner and outer positions of a curve by rotating around their own axle and hobbing on the axle shaft wheels (3) at the same time.
When the car drives straight forward, the differential wheels do not rotate. Then they act like a fixed connection between the two driven axles on which the wheels are mounted. The inner wheel is slightly braked in a curve, and the differential wheels start to rotate and make the outer wheel faster. The outer wheel is always faster at the exactly the same rate as the inner wheel is slower.
Too complicated? No problem. The main thing is that you have seen how differential gears function and now know an elegant way of driving both wheels on the rear axle of a vehicle.

Model: Rear Engine and Differential Gears

(see the assembly instructions on page 36)



The differential was driven by a bevel gear or a belt in the previous models. Now we are going to drive the differential via a cylindrical gear pair.



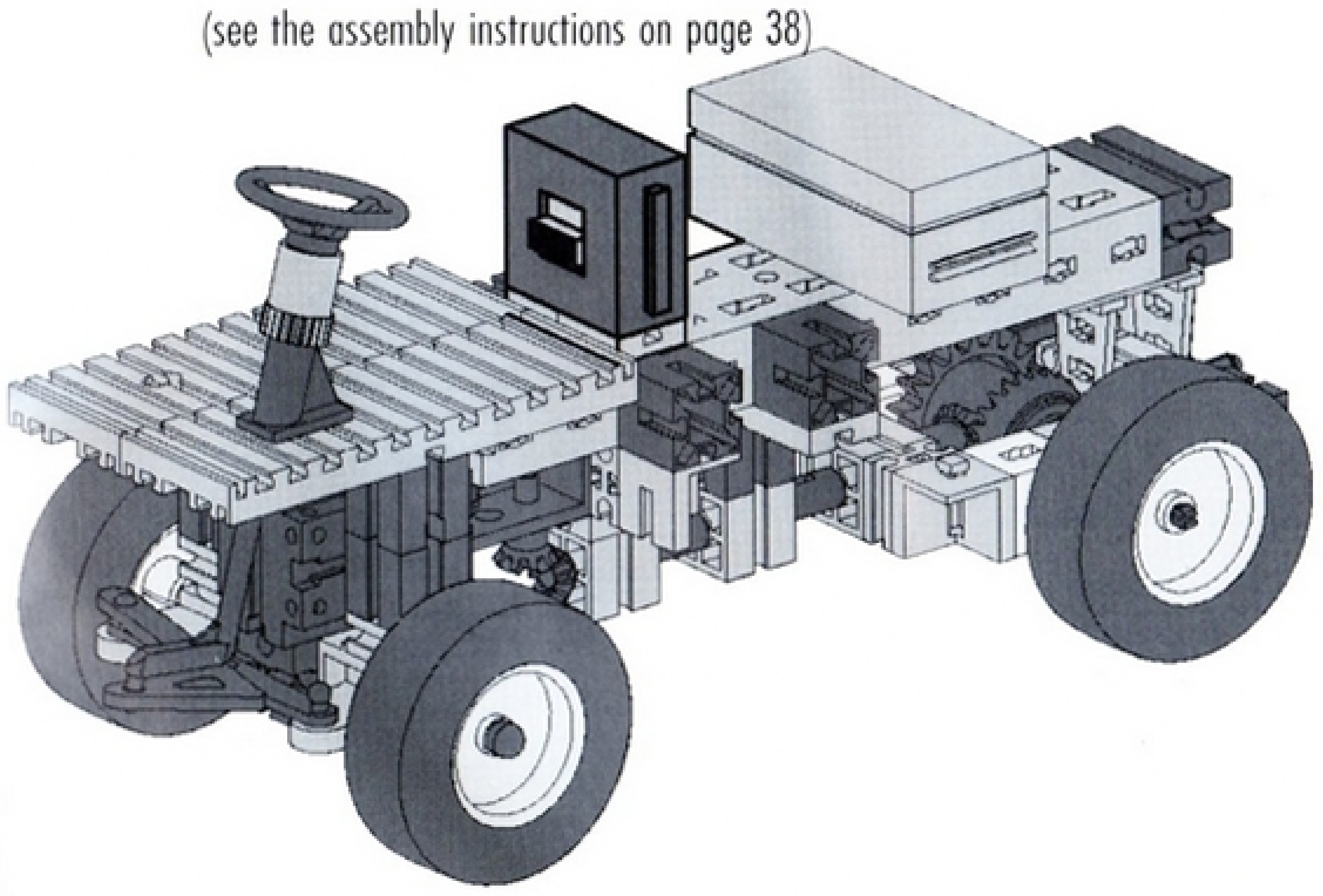
This makes it possible to position the engine directly next to the differential, which is the case in a vehicle with an engine in the rear.

Task:
What was the most famous vehicle equipped with a rear engine?

Solution:
The VW Beetle. The engine and the drive axle were in the rear. The weight of the engine on the axle helped the Beetle to make good progress through snow in winter.

Model: Pendulum Axle and Differential Gears

(see the assembly instructions on page 38)



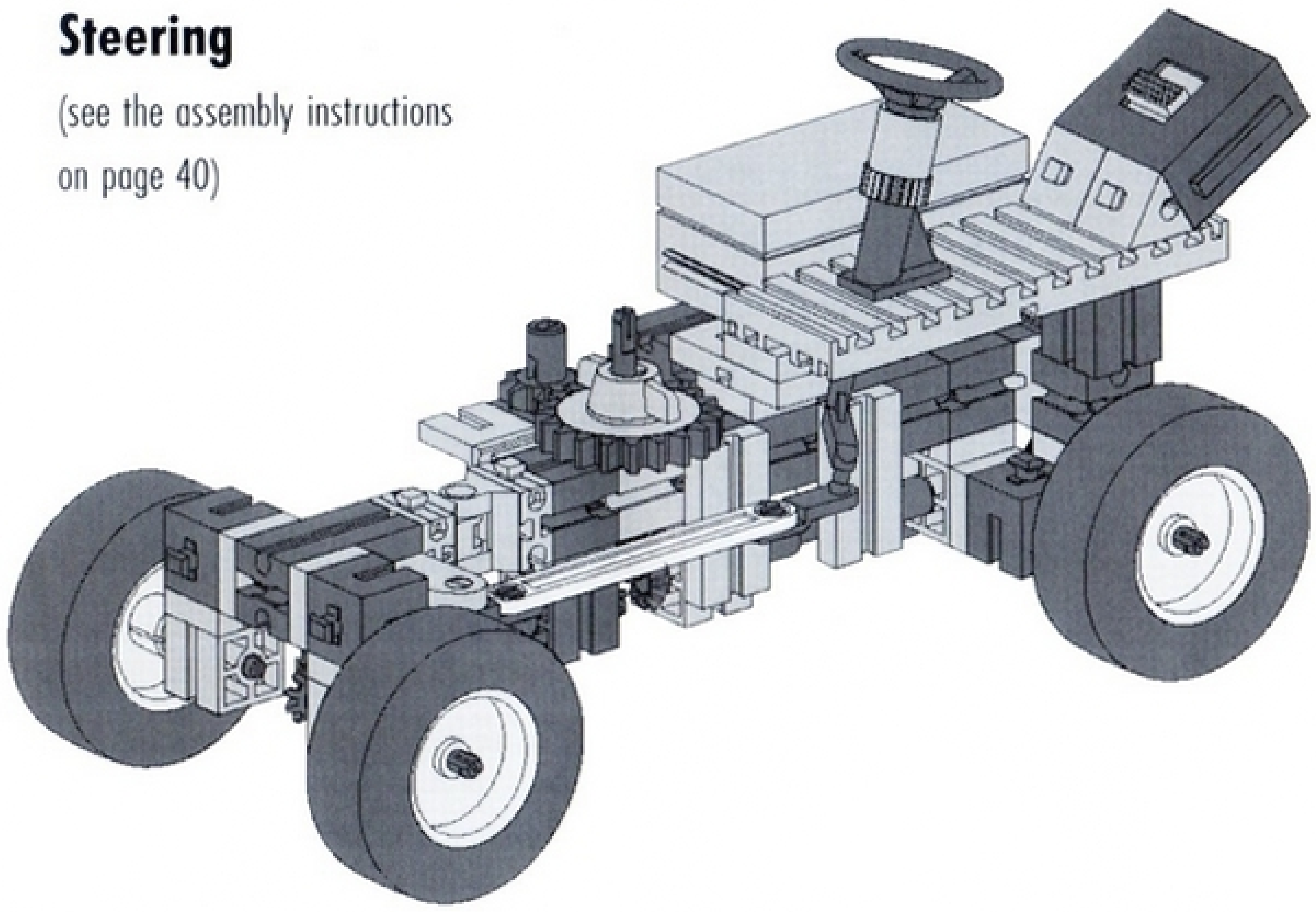
The axle is not connected rigidly with the vehicle with a pendulum axle, but instead it can rotate around the drive shaft.

Task:
What is the advantage of a pendulum axle compared to a rigid axle? Which vehicles is it used in?

Solution:
Both wheels stay on the ground with a pendulum axle when the ground is uneven and provide the necessary drive. It is used for earthmovers, unimogs and off-road vehicles.

Model: Four-Wheel Drive and Artic-Frame Steering

(see the assembly instructions on page 40)



Both axles and all four wheels are driven in some vehicles. In our last model, we drive both axles but cheat a little and drive only one axle per wheel, so that the vehicle can turn corners even without differential. Artic-frame steering is used in this model.

Task:
Which vehicles do you know with four-wheel drive?
What are the advantages of four-wheel drive?
Which vehicles use artic-frame steering?

Solution:
Four-wheel drive is found in all common off-road vehicles, but also in normal passenger cars. The advantage is that you can make much better progress on slippery surfaces (e.g., icy roads). Artic-frame steering is used especially at construction sites, e.g., for front-end loaders or dumpers. They can be maneuvered easily around their own turning radius.

That's all about vehicle technology. Now, you most certainly see details on vehicles differently than before and can easily hold your own in a conversation about simple technical details of vehicles.
People will be surprised about how much you know!

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