# The cycling physicist 

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#### Abstract

Bicycle involves a lot of technical solutions. All of them are based on laws of physics, therefore bicycle is a suitable teaching aid at primary school. Riding techniques, pedalling, distribution of mass and aerodynamic shape are also important. Therefore, we can use bicycle as a connecting link between physics, technical education, informatics, physical and health education, and other subjects.


## Introduction

Bicycle is not only a vehicle, but also an exercise equipment, a tool for improving selfdiscipline and psychological state. Its user or owner should maintain his bicycle on a regular basis. In case of a trouble on the road, technical skills of the bicycle user will be checked by solving the problem. Another thing, which contributes to the aforementioned facts, is that the bicycle in its basic configuration is affordable to the majority of population.

## Bicycle

If we take a look at the bicycle from the point of view of physics and technology, we will see that a lot of technological solutions are combined in it, for example, distribution of material (location of the centre of gravity), riding techniques (in the saddle, out of saddle $=>$ rear wheel slipping on a gravel road), pedalling (how much does the foot rotate $=>$ tangent line to the pedal), aerodynamic shape and air resistance (shape of the cyclist at the Tour de France time trials), bicycle shift lever (gearing), inertia, friction [2].

All these techniques apply basic physics laws, therefore bicycle is a very good aid in primary school and not only for teaching physics. We can use bicycle as a connecting link to create a relation between subjects like physics, technical education, informatics and health education, and others [2].

## Bicycle in physics

As we have mentioned above, we can find lots of elements and situations related to bicycle, which could be appropriately used in teaching physics. For now we will restrict our attention to the problematics of the centre of gravity of the whole bicyclecyclist system, though.

## Location of the cyclist's centre of gravity

Nowadays, when more and more people think about their weight and healthy lifestyle, this trend surely has had some effect on cycling too. Actually, the opposite is true. Cyclists have already known for a long time the fact that it is easier and cheaper to reduce the mass of cyclist rather than the bicycle. Location of the centre of gravity is also related to this.

The following experiment was crucial for us. We have tried to simulate several situations. At first, we tried to find out the location of the centre of gravity of the cyclist without any additional load. In the next experiment we had been adding a load of the mass of 3 kg and 6 kg into the backpack, which was carried on the back or on the belly. The load was represented by one or two plastic vessels full of water. Measurement was performed in each of the configurations at three different elevations of the rear wheel. We have put up to three pieces of wood ca. 10 cm in height
under the wheel. We have measured the part of the mass of the bicycle-cyclist system, which falls on the front wheel, using the scale that was under it.

According to I. Krejsa [3], we will find the centre of gravity of a bicycle at following places:

- without cyclist - approximately above the middle of the assemblage and, depending on the bicycle type, height of the saddle and size of the wheels, from 0.33 m to 0.6 m above the road
- with cyclist - approximately above the saddle's level from 0.05 m to 0.25 m , depending on cyclist's weight and height

When measuring the location of the centre of gravity of the bicycle, we have had situations recorded in the pictures 1-3:


Pic. 1 - Measuring the location of the centre of gravity of the bicycle with cyclist without a load


Pic. 2 - Measuring the location of the centre of gravity of the bicycle with cyclist with the load on back


Pic. 3 - Measuring the location of the centre of gravity of the bicycle with cyclist with the load on belly

We will use the law of the lever, whose fulcrum in this case is the rotation axis of the front wheel. Change in projection of the distance between the centre of gravity and rotation axis can be decomposed into projection of the distance between centres of the wheels and projection of the height of the centre of gravity onto the horizontal line connecting centres of the wheels. Then, after adding the radius of the wheel $\boldsymbol{r}$, we will obtain the total height of centre of gravity $s$ from the ground.
We substituted the measured values into the relation (1) from [1]:

$$
\begin{equation*}
s=\frac{l\left(M_{1 a}-M_{1}\right)}{M \cdot \operatorname{tg} \alpha}+r \tag{1}
\end{equation*}
$$

Where we denoted:
$l$ - distance between centres of the wheels
$r$ - radius of the wheel
$M_{l}$ - mass detected by the scale under the front wheel of non-inclined bicycle
$M_{1 a}$ - mass detected by the scale under the front wheel of inclined bicycle
$M$ - mass of the bicycle-cyclist-load system
$\alpha$ - inclination of the wheel; $\operatorname{tg} \alpha$ can be determined, for example, as the ratio of the height of the rear wheel elevation and horizontal projection of the distance between axes of the wheels. The projection can be measured, for instance, by hanging plumb bobs on the axes.

Centres of gravity gotten from the measurements are shown in the pictures 4-8. Measurements were performed at four different elevations of the rear wheel, namely, $\mathrm{T}_{1 \mathrm{x}}=-8 \mathrm{~cm}, \mathrm{~T}_{2 \mathrm{x}}=2 \mathrm{~cm}, \mathrm{~T}_{3 \mathrm{x}}=12 \mathrm{~cm}, \mathrm{~T}_{4 \mathrm{x}}=22 \mathrm{~cm}$, where $\boldsymbol{x}$ corresponds to the particular situation.


Pic. 4 - a) Location of the centre of gravity of the bicycle with the cyclist - without any load b) Enlarged picture of the centre-of-gravity location $2: 1$


Pic. $5-\mathrm{a})$ Location of the centre of gravity of the bicycle with the cyclist - with 3 kg load on the back
b) Enlarged picture of the centre-of-gravity location 2:1


Pic. 6-a) Location of the centre of gravity of the bicycle with the cyclist - with 6 kg load on the back
b) Enlarged picture of the centre-of-gravity location 2:1


Pic. $7-$ a) Location of the centre of gravity of the bicycle with the cyclist - with 3 kg load on the belly
b) Enlarged picture of the centre-of-gravity location $2: 1$


Pic. $8-$ a) Location of the centre of gravity of the bicycle with the cyclist - with 6 kg load on the belly
b) Enlarged picture of the centre-of-gravity location 2:1

As we can see from the pictures $4-8$, the height of the centre of gravity $\boldsymbol{s}$ changes depending on the cyclist's load. Horizontal position $\boldsymbol{l}_{2}$ does not greatly change; we can determine its value using the law of the lever, whose fulcrum lies at the rotation axis of the front wheel (2):

$$
\begin{equation*}
l_{2}=\frac{M_{1}}{M} \cdot l \tag{2}
\end{equation*}
$$

Where we use: $l$ - distance between the rotation axes of the wheels; $M_{1}$ - mass detected by the scale under the front wheel of non-inclined bicycle; $M$ - mass of the bicycle-cyclist-load system.

## Conclusion

We have performed the first experiment practically with $9^{\text {th }}$ grade students as a part of preparation for entrance examination to secondary school. Students examined the experimental bases by themselves and they were greatly involved in the experiment realization. Theoretical preparation was assigned as a homework for students. Before the measurement we have done a revision of the whole task. The measurement itself was managed in about 45 minutes.

Many other aspects can be discussed with students, for example, influence of the material distribution on the ride, where is the centre of gravity of a car (passenger car, lorry, race car), when will be the front wheel blocked, so that the cyclist will fall over the handlebar, etc.

## References

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