Efficiency in action

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Abstract: At home in preparation for a physics laboratory students make a handcart that is driven by weights. Afterwards they measure the potential energy, kinetic energy and efficiency of this handcart in the lessons. This paper summarizes present experiences and reasoning involving such experiments in a physics laboratory.

Handcart-making

We recommend to give to students the task of handcart-making 14 days before the date of performing the experiment. At this time they should learn about power and efficiency. It is good to show students at least one homemade handcart, for instance one made from a Merkur construction set. Firstly, students can estimate how demanding the making is. Secondly, they can see how the construction affects the parameters of the handcart.

Moreover, showing a few photos of handcarts made by students in previous years could be beneficial as you can emphasize that there is no restriction in the choice of construction methods. It has proved true that a handcart made from paper, skewers and CDs can have excellent parameters. The only restriction is that the handcart has to be powered by the potential energy of solid weights.

It is also true that handcarts made with an effort to achieve maximal trajectory (range) do not have high velocity and vica versa. Students have to decide in which aspects they want to achieve better results.

Finally, it is important to note that the technical parameters of the homemade handcart will have no influence on marks given for the experiment (although there should also be an effort for as good a result as possible). The grading only includes the understanding of the problem and the right application of knowledge of the measured characteristics. There should be one handcart per pair of students.

Effective range

Efficiency η as is usually taught at high schools is derived as the ratio of output power to input power. In our case the output power is the kinetic energy of the handcart divided by time and the input power is the potential energy of the weights divided by time. Therefore the efficiency is given by the ratio of the kinetic energy of the handcart and the potential energy of the weights.

$$\eta = \frac{P}{P_0} = \frac{\frac{E_k}{t}}{\frac{E_p}{t}} = \frac{E_k}{E_p}.$$

If there is no change in the other parameters, the maximum velocity of the handcart is needed to achieve maximum efficiency. It is interesting that handcarts with high velocity have a low range and vice versa. Therefore for the purposes of our experiment the characteristic effective range was established as the ratio of the trajectory of the handcart and the potential energy of the weights:

$$d_e = \frac{s}{E_p}$$

Students measure the values of both characteristics.

The course of the experiment

The experiment is assigned very briefly - tell students as little information as possible, for instance: "Measure the necessary values and then calculate both the efficiency and the effective range." How to do this is their own business. The aim of this experiment is to understand the problem on their own as much as possible. Therefore answer their questions at first in a brief way such as: "Find it in your notebook, try to think about it ... "etc. Only if there is no other way, tell them only a small amount.

Our experience is that two lesson periods are sufficient, at the end more capable pairs have nothing to do and therefore they advise other pairs. It is good, if students calculate both characteristics in the lessons. They can check and compare the calculated efficiency of their handcarts with other students. Furthermore, they can discuss the reasons for differences between them.

Our experiences or why to do this experiment

Connections between theory and reality

Even clever students have problems with matching the characteristics from "books" to real systems as seen with their handcarts. This I regard as the biggest contribution to learning of the whole experiment.

1. For instance, most students know very well the relation for kinetic energy $E_k = \frac{1}{2}mv^2$, however they hesitate where to find *m*, especially if there is a second *m* in the relation for potential energy $E_p = mgh$ where the *m* naturally belongs to the mass of the weights.

2. More problematic is the measurement of the velocity of the handcart. In the lessons the velocity is always discussed and calculated in details. However it took students a few minutes to realize, that they have to measure the trajectory range and time and from these measurements compute the average velocity.

3. Furthermore – and this can be surprising for a teacher – they are satisfied with average velocity for the whole time of movement. Only a few students try to measure a short displacement in a short time in the situation where the handcart is the fastest. Here, it is necessary to point this out to students; otherwise the resulting efficiency would be very low.

4. The problem is also only with term efficiency. Most students are very surprised, that the handcart with the lower velocity had a higher efficiency of energy transfer from potential to kinetic energy as a result of the lighter weights.

5. The effective range is a good example of the fact that our physical characteristics do not fall from the sky, but are introduced as needed. The unit of effective range is also an example of how to create a derived unit.

Other experiences

1. Students that do not like lessons of physics and theory or are not good at physics can improve their marks and relationship to physics by this experiment.

2. We cannot recommend additional marking for those who achieve the highest values of both characteristics. In our case the highest value of effective range was obtained by a handcart made from cardboard. However, in efficiency the best handcart was made in a workshop with the help of the student's father. As other students could not compete even with their best effort, they were glum and upset about it.

3. The results are very different for different handcarts. The best handcarts have an effective range above 10 $m.J^{-1}$ and efficiency above 50 %. Still, most handcarts achieve an effective range of about 1 – 4 $m.J^{-1}$ and an efficiency of about 5 – 20 %. Sometimes the values can be even lower.

Competition

Students from the first grade took part in a competition for the best video recording of a physics experiment that was arranged by the British council within the World year of physics.

These students were inspired by our experiment. They used the handcart made in the workshop from one student. The results were 50 m in trajectory and 11 $m.J^{-1}$ of effective range.

The prepared recording was chosen as one of the 10 best (from 36 entered) and our team took part in the final that was held in Prague at the British council.

Conclusions

This experiment is much-favoured by students, especially thanks to the chance to play with handcarts. In this way students can connect the relationships that are used for solving problems with the real things. This all can be summarized with the idea "I hear and forget, I see and remember, I do and understand."

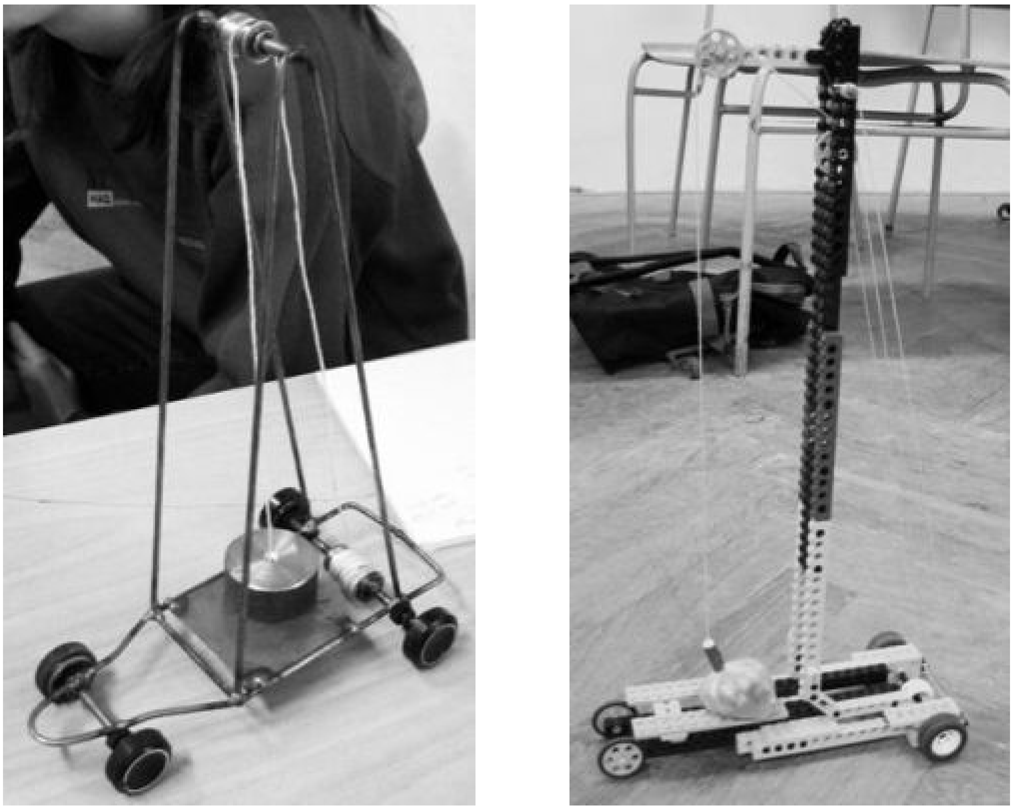

Figure 1: Images of handcarts prepared by students.