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Complex Physics Competition Involving Future Teachers

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Abstract In this paper, we present the experience obtained with complex physics competitions which were organized every year of the last three decades for the students at catholic secondary schools in Hungary. The competition has consisted of various parts (problem-solving, experimental demonstration, group quiz, and a home project). We would like to present some examples highlight the focus of these activities and discussing the possibilities of bringing these activities to an average physics class. This complex system ensured that every student was able to find a part of the competition which attracts him. The organising team of the competition includes not only teachers from universities and high school but also pre-teachers who are given to opportunity to work with talented and enthusiastic students.

Key words: students' complex competition, physics, problem-solving, experiments, group quiz, high school

Súhrn: V príspevku predstavujeme skúsenosti s komplexnou fyzikálnou súťažou, ktorá sa v posledných troch desaťročiach organizuje každý rok pre žiakov stredných katolíckych škôl Maďarska. Súťaž pozostáva z rôznych častí (riešenie problémových úloh, predstavenie experimentov, skupinový kvíz, domáce projekty). Chceme bližšie predstaviť podstatu týchto aktivít, a rozobrať možnosti ich zaradenia do bežných aktivít žiakov v triede. Predstavený komplexný systém garantuje, že každý žiak vie nájsť tú časť súťaže, ktorá ju priťahuje. Organizačný tím pozostáva nie len z univerzitných a stredoškolských učiteľov, ale tiež z budúcich učiteľov fyziky, ktorí využívajú možnosť pracovať s talentovanými žiakmi.

Kľúčové slová: komplexná súťaž žiakov, fyzika, problémové úlohy, experimenty, skupinový kvíz, stredná škola

MESC: M50

1. The description of the competition

Physics competitions in high schools play a big role in developing students' skills in physics and increasing their interest in science. Both national and international competitions are targeting the most talented students with the intention of improving their problem-solving skills. Nevertheless, these competitions are only successful if they include a wide range of students not only just the best ones. However, the number of participants in traditional competitions has been declining for years. Furthermore, fewer students are interested in science both nationally and internationally too. For this reason, our goal was to create a competition where students could discover the beauty of physics and compete without stress – so it is likely that more students will take part in them. Producing the competition, we took four aspects into consideration: i. as far as it is possible, preserve the traditions of physics competitions, ii. to exploit the cooperative activities (group work) of students, iii. to rely on the students' enthusiasm for self-made experiments, iv to make the competition a public event with a larger audience.

In this paper, we are going to present our experience obtained through the decades of the competitions. We believe that *Károly Ireneusz Physics Competition,* besides that it has made young students love physics it has also motivated teachers too.

The competition is organized for three different age groups (for 13-14; 15-16; and 17-18 years old, respectively) and it has three different rounds. The diversity of the tasks varies from round to round. In the first-round students should make a home project, the second-round contains traditional problem-solving and the last-round is about performing and explaining a variety of experiments. The schools should apply at the beginning of the first semester. Then the contestants have 4 months to make a project in groups which is the first challenge of the competition. The next two rounds are hosted by one of the schools participating in the competition during the spring semester. Each group sends two students who represent their school in the competition. The delegated students are accompanied by their schoolteachers.

2. Goals

Informal learning is becoming increasingly important when students are not studying at school. One way to do this is to take part in competitions, as success often requires knowing much more than the curriculum or solving non-school tasks. They not only develop their professional knowledge, but also their attitudes towards science, especially physics, group research and their scientific approach. The success of the competition and the prize won can be an additional motivation for (further) learning and participation in other competitions. 0

Our purpose is not just to improve the students' knowledge of physics. In the first-round, students are required to work on a mini-research, they must learn how to cooperate with each other. To finish the report students also need to deal with different computer programs. With this competition we have more goals. Firstly, our aim is to motivate students by showing them the beauty of physics. Secondly, to help teachers improve their professional skills, and thirdly, to introduce the method of helping talented students to pre-teachers.

3. Home project

More and more modern teaching methods consider self-learning important, when students are not only passive recipients of knowledge, but also develop their talents independently with the help of experts. This is most easily accomplished through teamwork, which also develops the communication and collaboration skills of participants, which will become important later. [5]

The Competition Committee sets research topics from extracurricular material for each category. The students should do their projects in groups and their teachers are allowed to help them. The first round gives the opportunity to those students whose main interest maybe not physics but enjoy doing experiments.

In the first-round, students are asked to do a home-project. In the first decade of the competition the oldest students were given open-ended questions and activities which were chosen from the activities of the International Young Physicists' Tournament 0. As these tasks were much more challenging for the students and required more effort, the number of participants in the competition began to decline. In the years that followed, the judges tried to simplify the activities to stop the decline in the number of participants. Nevertheless, the goal of the competition remained the same which was to give students activities connected to real life situations.

Some examples: Experiments with paper airplanes (13-14 y.), Experiments with polarized light (15-16 y.), Experiments with musical instruments (13-14 y.), Smartphones in physics (15-16 y.), Experiments with colours (13-14 y.).

4. Problem-solving

Two representatives are sent by each group for problem-solving, which is the main activity of traditional physics competitions. Although the frames of the problem-solving part agree with those of the traditional ones the problems are unusual, many of them join to experiments shown at the scene. The tests are corrected by teachers and by university students who are in the teacher training program. We are presenting three examples from this part of the competition.

4.1 How much sugar contains a bottle of coke?

Problem: Find out the sugar content of the Coke with the help of Fig. 1. The bottle's height is 15 cm, the radius is 2.9 cm. Fig. 1 is very similar to what was given to the students.

Solution: While the Coke made with sugar totally immerses in the water, the other bottle is floating and one part of it is above water. This information is the key for students to calculate the mass of the sugar. The buoyancy acting on the difference of immersed volumes of bottles is the same as the weight of the sugar:

***Fig. 1**: Two bottle of coke in water.*

$$m_{\text{sugar}}\, g = \rho_{\text{water}}\, R^2 \pi h g.$$

Here h is the difference in the heights of the immersed parts of the bottles. Hence, the weight of the sugar $m_{\text{sugar}} \approx 26$ g.

4.2 Matchbox

Problem: I would like to introduce one of the experiments presented at the competition. First, one drops a box of matches (the box is half full) in vertical position on the table from approximately 10 cm high. After hitting the table, the closed box of matches bounces a little and falls over. Second, we repeat the entire experiment however, this time the box is half open. This time the box does not fall over but the half open box closes however, not entirely. The students should explain the phenomenon: Find out the friction force created by the box and the closing part of the box. (Fig. 2 can provide some guidance and help students solve the problem.) The mass of the box is 8 g. (In the competition, the center of gravity was not marked in the picture.)

Solution: When the closed box hits the table the position of the matches in the closed box changes and this change causes the fall of the closed box. If we repeat the experiment with the box half opened, the collision between the box and the table is inelastic, the open part of the box continues its motion after the box hits the table and the kinetic energy transforms into the work of the friction force. With the help of Fig. 2 we can estimate the displacement and the work of the friction force too.

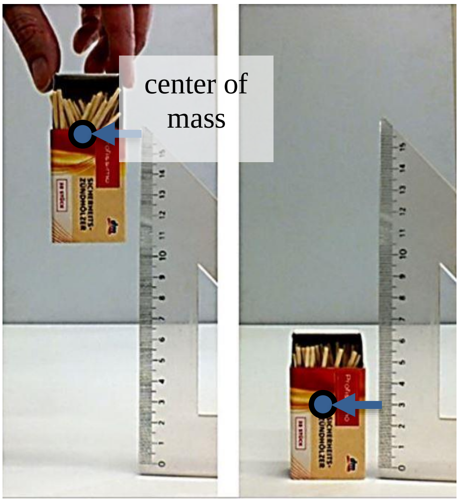

Fig. 2: *Matchbox before and after the fall*

The left side of Fig. 2 shows the box of matches before the fall and the right side of Fig. 2 demonstrates the box after the fall. After the box hits the ground and the main part stops moving, the open part continues its motion because of inertia. The friction force between the main part and the open part of the box slows down the motion of the open part of the box. To sum up, the box had potential energy which first transforms into kinetic energy and later it transforms into the work of the friction force. We can calculate the work done by friction from the product of the friction force F_f and the displacement Δs of the center of mass relative to the box

$$W_f = F_f \, \Delta \, s.$$

The change of the potential energy (ΔE) is defined by the mass (M) and the change of the height (Δh) of the centre of the mass of the box relative to the table

$$\Delta E_p = Mg\Delta h.$$

Fig. 2 can help identifying the change of heights of the centre of the mass and the displacement of the open part of the box. The change of height of the mass of the centre marked on the photo is $\Delta \, h \approx 13$ cm. The displacement of the open part of the box after it hits the ground is $\Delta \, s \approx 1{,}5$ cm. The magnitude of the friction force

$$F_f = \frac{Mg\Delta h}{\Delta \, s} \approx 0{,}68 \text{ N}.$$

Notes: As a teacher, we can present this experiment as a trick to our students and encourage them to try it on their own because the tools needed for the experiment are very simple. It also provides an opportunity to discuss how the number of match-sticks can affect the experiment and why. (For example, we can do the experiment first with an empty box and later with a box full of matchsticks. We can also change the size of the box.)

4.3 Turning airplane

Problem: Can you calculate the angle of the airplane's turn with the help of the picture if you know that its speed is 100 m/s, and its height does not change during the turn? What is the connection between the radius and the mass of the airplane?

Fig 3: *Airplane.*

Solution: The aerodynamic force acting on the airplane is always perpendicular to the wings of the airplane. If the airplane does not have a horizontal position, it automatically changes

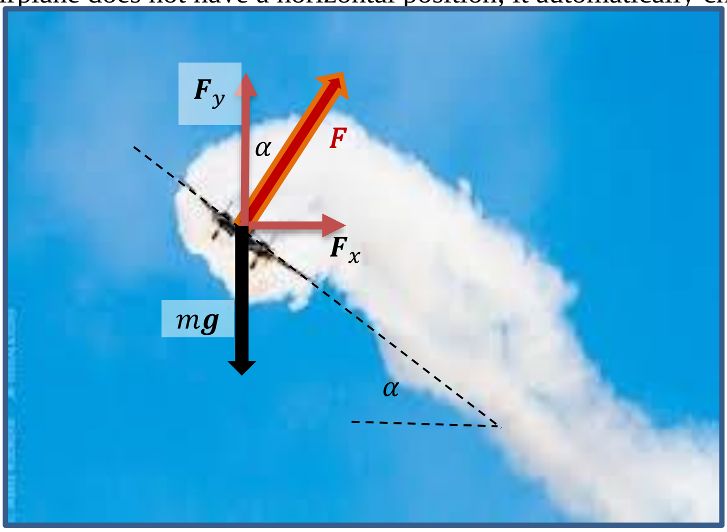

Fig. 4: *Free-body diagram of the forces.*

the direction of flights and turns. The radius of the turn's circle (the aircraft's trajectory) can be determined by the forces acting on the plane (see Fig. 4). The two main forces are the gravitational force ($m\boldsymbol{g}$), which acts vertically on the aircraft, and the aerodynamic force ($\boldsymbol{F}$), which acts perpendicular to the plane of the wings. Since the altitude of the aircraft does not change, the magnitude of the vertical component of the force $\boldsymbol{F}$ is equal to the force of gravity

$$F_y = F\cos\alpha = mg.$$

The horizontal component $\boldsymbol{F}_x$ of the aerodynamic force $\boldsymbol{F}$ is perpendicular to the velocity of the aircraft and results the aircraft to turn.

$$F_x = F\sin\alpha = \frac{mv^2}{R}.$$

Dividing the first equation by the second we obtain

$$\frac{F_x}{F_y} = \tan\alpha = \frac{v^2}{gR}.$$

The radius of the circle trajectory

$$R = \frac{v^2}{g\tan\alpha}.$$

We can calculate the value of $\tan\alpha$ by measuring the two components of the aero-dynamic force. The ratio of these components will give the value of $\tan\alpha$

$$\tan\alpha = \frac{F_x}{F_y} \approx \frac{2}{3}.$$

The radius of the turn's circle will be approximately 1.7 kilometers.

Note: This activity can improve certain skills of the students such as analysing and interpreting a picture. If they can measure the needed information the task becomes very easy.

4.4 Balance of a chain

Problem: One end of the thin chain is fixed to the wall; the other end is pulled horizontally with a force of 0.1 N. Fig. 5 shows the motionless chain in front of a square paper. Calculate the weight of the chain with the help of the picture.

Solution: As we can see in the figure the chain's shape shows a characteristic curve.

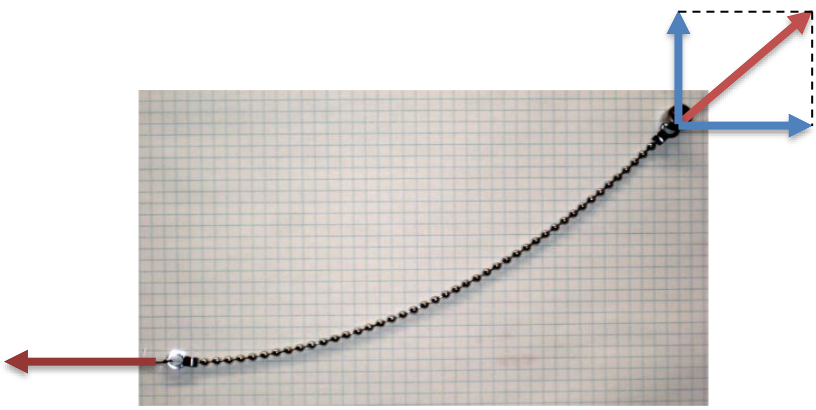

Fig. 4*: Forces acting on the chain.*

At the fixed end, the curve is steep, but as we move to the other side, the curve becomes less and less steep. The chain is at rest that means that the vector sum of the forces on the body must be zero. The three forces acting on the chain are the following: the two forces acting at the ends of the chain, and the gravitation. The background behind the chain can help students recognize that the fixed end of the chain is at a 45° angle, which is also the direction of the force acting on the fixed end of the chain. The direction of the gravitation acting on the chain links is vertical and the force acting on the end of the chain with the thread is horizontal, so, we can say that in a rest position the vertical component of the force acting on the fixed end of the chain is the same as the gravitation acting on the chain. (The magnitude is the same, but the direction is the opposite.) The magnitude of the horizontal component of the force acting on the fixed end of the chain is the same as the magnitude of the force acting on the other end of the chain, but its direction is also the opposite. The vertical and horizontal components of the force acting on the fixed end are of the same magnitude which is 0.1 N. Hence, the weight of the chain is 0.1 N.

4.5 Coins

<u>Problem</u>: Put two different coins next to a magnifying glass, the bigger coin should be closer to the magnifying glass. In the first photo we can see the virtual image of the bigger coin and we cannot see the smaller one. By shifting the smaller coin further away from the lens, its virtual image will appear.

Fig 6: *Only the virtual image of the bigger coin is visible.*

Fig. 7: *The virtual image of the smaller coin appears.*

The task here was to give an explanation to this phenomenon. In their explanation the students had to draw their solutions, and the older contestants also had to calculate the criteria of the appearance of the second image.

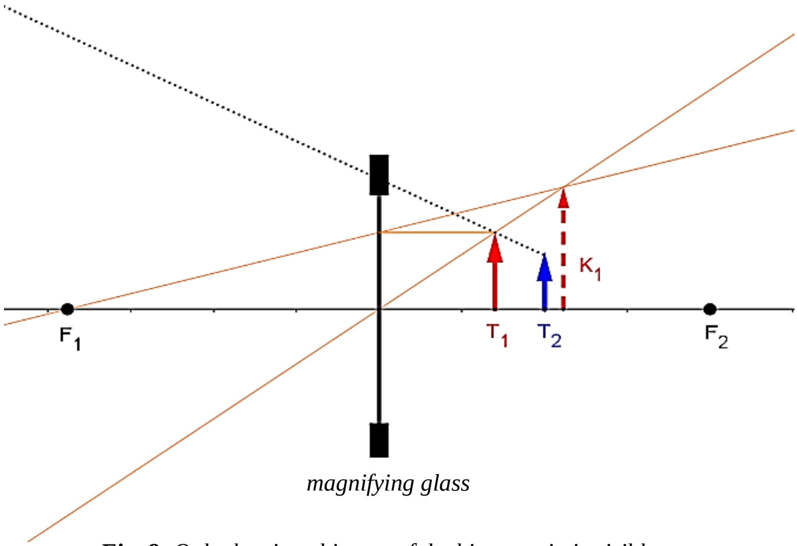

Fig. 8: *Only the virtual image of the bigger coin is visible.*

Solution: Since both photos show an enlarged version of the coins, this means that the coins are behind each other, within the focal length. This is true in both cases; in the first case only the virtual image of the larger coin is shown, in the second case the virtual image of the smaller coin is also displayed. We cannot see the smaller coin in the first case because the rays (blue line in Fig. 8) coming from the object T_2 (smaller coin) do not reach the lens because of the object T_1 (larger coin).

Fig. 7 gives information about a small change, how we slowly pulled further the smaller coin from the lens. The black dashed line connecting the end of the arrows of the objects T_1 and T_2 reaches the lens hence the virtual image K_2 appears. (We use the well-known radius to draw the image K_2. These radiuses do not have to take part in the process of constructing the image.)

We need that one part of the rays from the second object must go through the lens in order of the appearance of magnified image of the two coins behind each other. We can explain this phenomenon with a mathematical inequality using the marking system of Fig. 10

$$\frac{\frac{D}{2} - T_2}{t_2} \geq \frac{T_1 - T_2}{t_2 - t_1}.$$

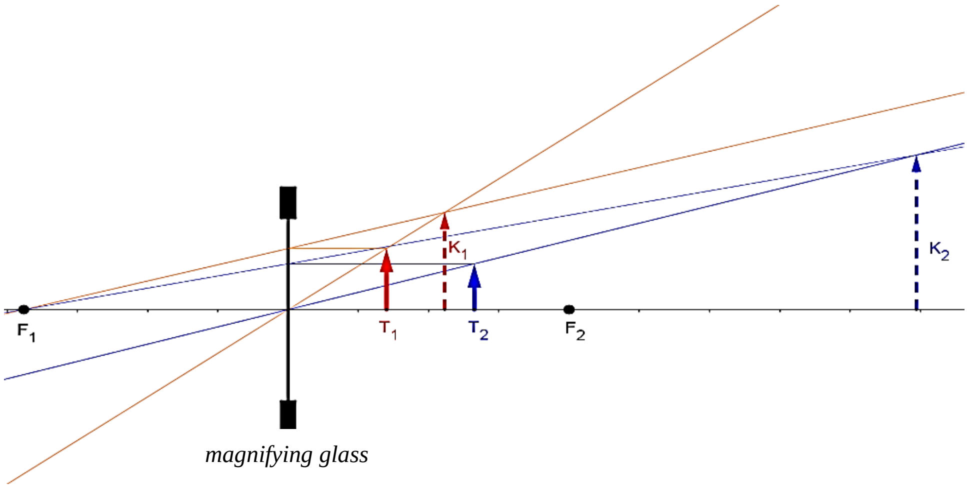

Fig. 9: *Both virtual images are visible.*

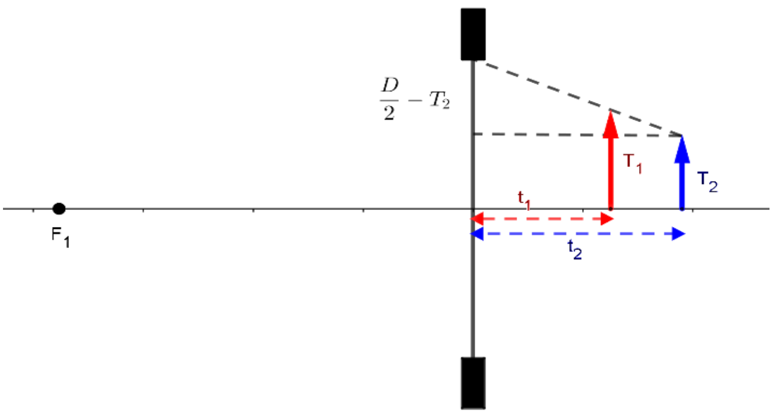

Fig. 10: *Explanation of the size-effect of the lens.*

Notes: The activity is based on a simple examination of the magnifying glass and this task is just based on the knowledge of 8th grade students. However, to solve this problem, children need to understand the whole situation and take into account factors (e.g., lens size that provide extra criteria) that can usually be neglected in an average physics class.

5. Experiments

Students of the first two categories are given the opportunity to bring and present experiments chosen by their interest. This part of the competition is open for the public and prizes are awarded by public vote. Recent years have shown that this is the longest and most popular part of the competition because of the interesting and creative experiments brought by students.

Students between the ages of 13-16 prepare experiments chosen by their interest. Their task was to present, explain and answer the questions by the judges connected to their experiment. The groups put their experiment together at the scene of the competition and they give a real physics show to the judges, to their peers, to the teachers and to everyone else who is interested. Our experiences of the decades show that this part of the competition plays a huge role of the motivation of the students. (The good atmosphere, the interesting presentations and the community keeps the students to come back the next year.) The photos of this part of the competition are proof how much the students enjoy experiments.

This is not just the most enjoyable part of the competition but also a place where the students learn a lot from each other by presenting their experiments. For pre-teachers it also gives an opportunity to collect new ideas for their physics class.

6. Quiz

The oldest age group compete in a public quiz show where the schools are represented by a pair of students. The quiz contains a wide variety of activities connected to videos, computer programs and experiments presented at the scene of the quiz. The points given by the judges are based on the professionalism of the groups. The awards are given to the first three groups with the highest scores.

7. The role of pre-teachers in the competition

In the last two decades, university students of ELTE (Eötvös Loránd University) who take part in the teacher training program could volunteer to help organize the competition. They have assisted in the preparation of the competition, have taken part in correcting the tests and they have also presented different experiments in the last two rounds.

Fig. 11: *Some picture of the show.*

Fig. 12: *More picture of the show.*

The teachers, pre-teachers and the judges share their experiences about the competition. (All the mini-research papers are public so everyone who is interested is allowed to read them.) They discuss the correction of problem-solving activities. The teachers are suggested by the judges to have a discourse with their students after the competition. They are also encouraged to highlight their students' best works and to inspire the children to continue their participation in the field of physics.

Pre-teachers are given the opportunity to gain experience and get some help when they start working in schools. They can practise correcting tests, evaluation; they connect with other physics teachers and can join the community of physics teachers. Moreover, they can work with talented and enthusiastic students and can practise preforming in front of students.

8. Conclusion

In this article we introduced a complex competition in Hungary. This competition, which has been running for almost three decades, is popular among students and professional teachers, and its success is proved by the fact that many of the participants in the former competitions graduated from engineering and science or became physics teachers. For future teachers, participation in the organization of the competition and in the pilot-demonstrations provides a good opportunity to prepare for teaching and gain experience in practical pedagogical work. Simplified versions of the tasks of the competitions can enrich high school teaching.

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