VII. PHYSICS EXPERIMENTS AND METHODOLOGICAL INNOVATIONS

THREE STAGES OF THE STUDENTS' RESEARCH SKILLS DEVELOPMENT AT ECYGDA LABORATORY

N. Kazachkova[1], D. Kazachkova[2]
[1]Scientific Physics and Technology Centre (SPTC) Ministry of Education and Science in Ukraine at the Department of Physics and Technology in Karazin Kharkiv National University, Kharkiv, Ukraine, nataliyakazachkova@gmail.com
[2]Educational Centre of Youth Gifts Development (ECYGDA) at the Department of Physics and Technology in Karazin Kharkiv National University, Kharkiv, Ukraine, darya.sign@gmail.com

ABSTRACT

The work is dedicated to the good practice examples and some difficulties of extracurricular physics trainings for the secondary school students aged from 7 to 16. There are three stages how students' experimental skills are developed. To teach students how to make simple research, extracurricular courses have been organised at the Educational Centre of Youth Gifts Development (ECYGDA) which is situated at the Department of Physics and Technology at the premises of Karazin Kharkiv National University. During such training students gain special profound knowledge of physics and seriously improve their experimental skills by doing self-made experimental projects using recycled materials, simple household objects, ordinary toys by means of real tools.

INTRODUCTION

The problem of students' experimental skills developing during informal physics education has been mentioned in the works of some Ukrainian and European authors [1], [2], [3], [4]. It is well known that physics is an experimental science so the goal of the physics teaching does not refer only to remembering the main formulas, it means not only reciting and enumerating basic laws of physics but also stimulating interest in experimental work [4], [5]. However, during the last decade bringing up the use of modern computer technologies, an application of up-to-date computer programmes, modeling of physical processes by means of computer onone hand and the lack of financial support for Ukrainian education on the other hand resulted in the displacement of real physics experiments from the lessons at 80% of Ukrainian schools. Moreover, at ordinary secondary schools in Ukraine physics experiments during the lessons or beyond are usually carried out with pre-assembled equipment. Moreover, in most schools the experiments are run using pre-assembled instructions [6]. Those activities are definitely valuable and justified. But students who are interested in physics, technology or engineering as their future career should also have the opportunity to carry out projects they have planned, thought up and elaborated themselves. For that reason the Centre (ECYGDA) which offers special support for realising those projects has been created. Besides, the primary and secondary school students (from 7-16) are encouraged to take part in local and international annual Conferences, Competitions and Tournaments for secondary school children, their parents and university students with their experimental projects where they can "touch science" and find out about very serious topics in an entertaining way. ECYGDA's motto is "Teach to Research with Pleasure!"

ECYGDA LABORATORY

ECYGDA Laboratory was created in 2004 as an institute of additional physics education. There are different types of informal learning facilities like science museums and exhibitions, field trips, science centres and entertaining shows established throughout Ukraine [6]. In these institutes, school students usually participate in one-day excursion or lectures, which are still informal in comparison to school instruction.

Our Centre has agreements with 23 Kharkiv Secondary schools, where we regularly demonstrate Physics Theme Shows, which have the common name Paradox Show connected with a content of the Official School Physics Curriculum. During those shows the lecturers are able to select and choose the students who have capabilities for experimental work and invite them to join the regular trainings on Saturdays at ECYGDA. These selected primary and secondary school students have regular (once a week) short theoretical lectures (45 or 60 min), held by university teachers accompanied by practical training (90 min) under the leadership of university teachers or students. In addition, all our students have a special English course (two hours a week), where they learn physics and maths in English. It is a very important point of their preparation as future scientists. It is considered that there are three stages of experimental skills development.

The first stage is for primary school pupils aged 7-11. At our theoretical training we proposed them 13 interactive physics theme lectures which have been elaborated by the teachers of the Centre. All of them have been adopted to the primary school pupils to be understandable for children of that age range. Every Saturday at the premises of the Centre one of the lectures (dur. 45 min) is presented to our visitors. The topics are interesting for children: Physics in Toys, Wonderful Mechanic, Travelling in Sound Land, Physics in the Kitchen, Light and Colours, Paradoxes of Magnetic Field, Wonders of Electricity etc. At the beginning visitors become acquainted with simple principles and laws of physics and then they are able to do simple experiments themselves. After 5 months of training they choose the topic and prepare their own simple research projects. They usually report about their first "scientific results" at the annual University Conference "Junior Scientific Start-Up" in May. At the first stage they usually do simple experiments which are demonstrated and explained to the audience at the Conference. This new approach is a successful attempt to show that it is possible to change pupils' and secondary school students' views about physics with a relatively short but explicit methods (Fig.1.).

Fig.1. Simple research project Sound Waves at the first stage

The second stage is for students aged 11 to 14 who are selected by methods mentioned above from Kharkiv schools and lyceums. They are also involved in regular extracurricular (once a week on Saturdays) short theoretical lectures (45 min) and more serious practical training (90 min). During such experimental training students are taught to operate with simple tools like handsaw, boring mill, perforator, Vernier callipers, tester. They design and help to produce some exhibits for the Physics Exhibition [6] or for the events which are organised in their schools (Week of Physics, Science Picnic, Night of Science) under the leadership of university students and university research engineers from the Department of Physics and Technology. They gain a lot from such kind of practical trainings and their experimental skills are seriously improved by doing self-made experimental projects using recycled materials, simple household objects or ordinary toys (Fig.2.).

Fig.2. Working with real tools and the example of hands-on Heron Fountain from the plastic boxes as a second stage project

The third stage is research skills development (see Fig.3.). The prevailing lack of interest in physics matters among adolescents aged 13 to 17 is obvious and common not only for Ukraine but also for all developed countries [7]. It most notably manifests itself in the steady decline in the number of students at Physics Departments in all Ukrainian universities. ECYGDA with its location at Karazin University, combined with the possibilities associated to this fact – use of the machine laboratories and the electronics repair laboratories at the Department of Physics and Technology, subject-specific support by scientists, lease of equipment has got lots of advantages not only in Kharkiv Region, but also in Ukraine.

Every year the Centre staff works with 5-6 groups of students. There are 6-8 students in each group. They are divided according to their age range or secondary school forms. We also take into consideration their theoretical knowledge in physics and mathematics. Before they start, they have to pass specially prepared short tests in Physics and Math (for the students aged 13-16). It helps us to divide them into the appropriate and convenient teaching groups. There were 10 research projects in years 2014-2015. The best ones are the following:

– Simple experiments with sounds (first stage research project) reported in English by Daria Slobodina (11) and Aleksandra Barkova (10);

– Heron's Fountain (second stage research project) made of ordinary kitchen plastic containers, a non-typical pattern designed and produced by Anton Rusynnyk (12);

– Creation of the experimental set-up and demonstration of a "soap film liquid motor" which was done by students Maksym Peretyaha and Vitaliy Yurko aged 14. All those projects were done at ECYGDA Laboratory where students have the opportunity to obtain an insight into scientific method of investigation, to conduct their own research projects, to promote their activities and demonstrate some of their key competences in science and technology and communication in the foreign language at the different local and international conferences. Usually among them are ICYS (International Conference of Young Scientist), QUANTA Competition, IYPT (International Young Physics Tournament), annual Conferences of Junior Karazin University, Ukrainian Science Festivals, Science Picnics, Research Nights and some other events.

Fig.3. Experimental skills development at the third stage

The third stage projects are usually much more serious and can be compared with real Diplomas at University. The example is "Liquid film motor" [8]. In recent years scientists have become interested in the physics of liquid films. Study of those films is a part of the interesting physics section called "Physics of Surface". When the films are subjected to the action of various chemical, thermal, structural or electrical factors, they display interesting dynamical phenomena. Investigation of soap films and bubbles is very impressive topic in a lot of student research projects. A soap film should be formed on a flat frame. Place the film in an electric field parallel to the film surface and pass an electric current through the film. The film starts rotating in its plane (it can be seen in Fig.4. below). The phenomenon have been investigated and explained.

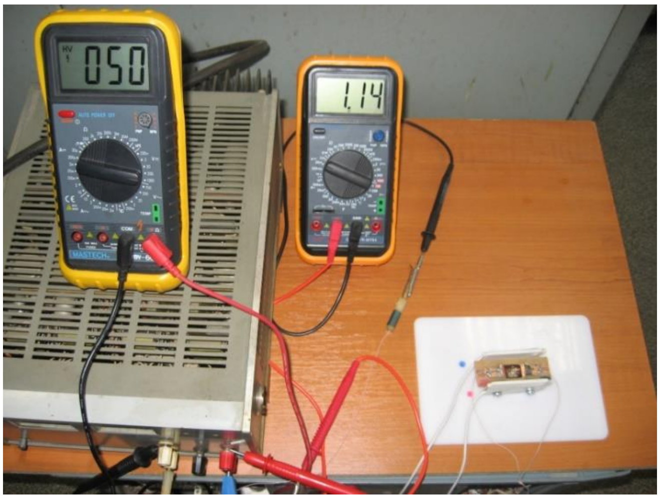

Fig.4. Elaborated liquid film motor measurements

CONCLUSIONS

Five self-made devices have been designed and created during 2014-2015 years in the Laboratory. During the extracurricular theoretical and experimental trainings mentioned above students have the opportunity to obtain an insight into the real research methods of investigation, to conduct their own research projects and demonstrate some of their KCs (for example basic competences in science and technology and communication in a foreign language) at the different local and international conferences (Bronze medal at International Conference of Young Scientists, April 2015, Izmir, Turkey). Teaching methods proposed by the authors are not contrary to the existing Ukrainian teaching techniques, they can be considered as an effective supplementation to traditional methods and forms of physics teaching. For more than 10 years of the Centre's existence 98% of the students entered in Kharkiv and some other Ukrainian Universities and became good students and successful scientists both in Ukraine and in some European countries. We are proud of our ex-students who are now working in Germany, Canada, the USA, the Netherlands and Poland.

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PENDULUM WAVE OR LOVE AT FIRST SIGHT

Dorottya Lendvai[1], Márton Czövek[2]
[1]Berzsenyi Dániel Gimnázium, Budapest, Hungary, dorcinomorci@gmail.com
Physics Education PhD Program, Eötvös University, Budapest,
[2]Budapest University of Technology and Economics, Budapest, Hungary

ABSTRACT

Pendulum wave is the motion of a chain of pendulums in which – if their length is chosen based on an appropriate mathematical relationship – remarkable shapes emerge. What should be the logic of composition? How long should the cords be in order for the pendulums to show nice shapes when they are initiated appropriately? We started to study this topic in more detail with high school students in a physics camp. Students had to develop their chosen project work in a team with the support of a teacher. After clarifying the physical and mathematical background, younger students prepared the tools, while the more senior ones worked on the related computer simulation that facilitated a more precise research.

INTRODUCTION

Few years ago we came across the beautiful phenomenon of pendulum wave, which was absolutely love at first sight. The students of our school dealt with this phenomenon in more detail for the first time in the 2014 physics school camp.

Let's see what the pendulum wave is. Pendulum wave is a series of pendulums in an optional number. If the length of each pendulum and the initial conditions are chosen by an appropriate mathematical relation, the pendulums can shape special formations. Our most important question is what the logic of composition should be. In other words, how long should each cord be in order to show a beautiful formation after releasing them? (It should be noted that the pendulum wave is not considered a wave in physical terms, what we see is rather a joint view of independent pendulums.) You can see in the first color picture (Fig.1.) a snapshot of our pendulum wave. This phenomenon has many nice moments, perhaps the most beautiful is this front view.

Fig.1. Snapshot of a pendulum wave (front view)

Relatively little detailed literature related to the phenomenon can be found [1-3]. You can see videos of our [4] or other's [5] pendulum wave on the Internet. It is recommended to look at them before proceeding with the reading of this article. Two additional snapshots of our pendulum wave are shown in Fig.2. in top-side view. The parameters of the device are the same as the data in the later Table 1.

Its beauty and “obscurity” were the reasons why we would like to share our experiences with others. We hope that this beauty excites you, too.

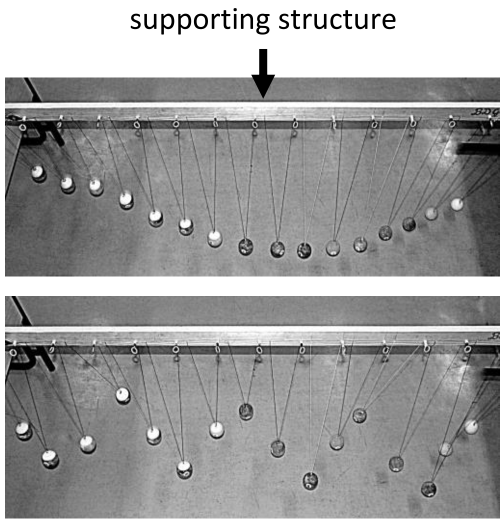

Fig.2. Snapshots of pendulum wave (top-side view)

THE PHYSICAL BACKGROUND

The physical background of the phenomenon is not difficult, but not obvious either. The “trick” is that the pendulums are adjusted in a way that the whole pendulum wave shall return to its starting position after certain time. Then all balls should be at the same position as their starting point again. During this time each pendulum swings with different frequency. For example, during the whole period of the pendulum wave the longest swings 52 times in total, the second swings 53, the next one 54 and so on. If we recognize this regularity, the problem isn’t that difficult mathematically anymore.

We enumerate the pendulums: $i = 0,1,2,\ldots n$. The pendulum wave consists of (n+1) balls. Pendulum No. 0 is the longest. We have additional symbols:

- $\boldsymbol{\tau}$ is the whole period of the pendulum wave (so the shortest time within which all pendulums in the pendulum wave return to the starting position).

- $\boldsymbol{T_i}$ is the period of the pendulum No. i (with the assumption of small amplitude swings).

- $\boldsymbol{N}$ is the number of swings made by the longest ($i = 0$) pendulum during the time τ.

So the period of each pendulum is calculated according to this formula:

$$T_i = \frac{\tau}{N+i}\,. \tag{1}$$

According to the well-known connection: $T = 2\pi \cdot \sqrt{\frac{l}{g}} \;\rightarrow\; l_i = \frac{g}{4\pi^2} \cdot {T_i}^2$, and from formula (1), with a given $\boldsymbol{\tau}$, $\boldsymbol{i}$ and $\boldsymbol{N}$, the length of each pendulum is found as:

$$l_i = \frac{g}{4\pi^2} \cdot \left(\frac{\tau}{N+i}\right)^2, \tag{2}$$

where, of course, **g** is the gravitational acceleration. Thus, we have to choose the length of the rope No. $\boldsymbol{i}$ to be $\boldsymbol{l_i}$. This is the most important formula for us now.

Table 1. Our demo data

$\tau = 90\ s$	the whole period of the pendulum wave
$n = 15$	$(n + 1) = 16$ pendulums
$N = 52$	no. of swings made by the longest pendulum

CONSTRUCTION OF THE SET-UP

The following points are worth paying attention to during the building and the preparation of the set-up:

- a stable supporting structure (lath supported at both ends, for example by a table)
- the procurement of the balls (or other hanging objects)

- the selection of ropes (it shouldn't be breakable, or spinning), it's really hard to find good rope (the fishing line breaks, the embroidery yarn tears), we can find specialized shops on the Internet with the "twine, rope, cord, yarn" search words, then we must try them out with the swinging of only one ball
- an accurate suspension
- fine tuning and synchronization, this is the most important and the most difficult

To ensure this, set the lengths manually as accurately as possible, let the pendulum swing, and fine-tune the length of each pendulum by eye-measurement (extend or shorten). Small screws at the suspension of the pendulums are applied for this purpose. The tuning can be done with a computer method (for example: Webcam Laboratory Program), with that we are able to measure exact periods, but based on our experience, it isn't much better or easier. You should try it out, we don't have an exact recipe.

THE USE OF THE EQUIPMENT – THE INITIAL CONDITION

Figure 3. shows how we initiated our experimental runs. Initially, we displace the pendulums with a long, straight lath. However, based on our earlier calculations, the swings shouldn't be done with the same amplitude, but with the same starting angle for each. This does not make a large difference with the parameters we've used in practice, a line is a good approximation of the extremes' envelope. This we may not notice by just looking at videos, but can be found easily by watching a simulation based on exact mathematical formulae (as shown in the next paragraph). This means, that the lath should be long enough, to be able to start the system, but there is no real need of special equipment for this purpose.

Fig.3. The experiment at start (front view, data as in Table 1.)

COMPUTER SIMULATION

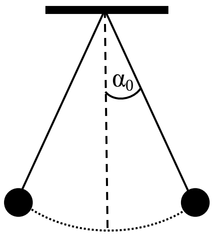

Fig.4. The initial angle

As a further analysis of the pendulum wave, we implemented a simulation of it. To create an animation, we simply redraw the whole picture very frequently. To be able to draw it, we need to know every pendulum's length and its current angle at any moment. We already know the lengths (2). Assuming that the pendulums start without any initial velocity at time $t = 0$, the angle vs. time function is given as:

$$\alpha_i(\mathrm{t}) = \alpha_0 \cos\left(\sqrt{\frac{g}{l_i}}\,\mathrm{t}\right). \tag{3}$$

Here, α_0 stands for the initial angle for all the pendulums (Fig.4). This formula (3) is an approximation, which uses the assumption that the value of $\alpha(t)$ is always small; this applies for all these pendulums. With these, we can calculate the coordinates of the whole system, so we can draw it.

Note that these approximations are considered to be really good with $\alpha_0 \leq 5°$, but that would not be spectacular enough. In practice (in the case of the experimental equipment and the simulation, too) we use angles more or less 10°, which is still good as an approximation, but there is a lot more movement, making it look better. The simulation allows more than 10° for the sake of spectacle, the program will continue to use the approximation.

Our program shows the front and top views of the model set-up (Fig.5. – it's a typical moment, which shows a similar shape for a prolonged period). The program has a feature which makes it possible to export data (rope lengths, etc.) with the current parameters, so that we don't have to make the calculations ourselves. The program is free-to-download as well [4] – directly download and run –, with the pre-requirement of having the Java Runtime Environment 7 installed [6].

The simulation can be stopped at any moment, or even put to an exact timestamp, as it is way more precise than the real experiment. By using the program, the formations are much easier to analyse. Of course, it can't substitute a real experiment.

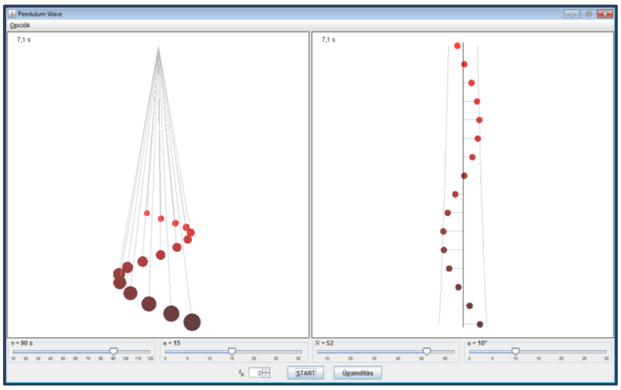

Fig.5. Simulation of a pendulum wave. Left: front view, right: top view ($t = 7.1\ s$, $\alpha_0 = 10°$), with the parameters of Table 1.

ANALYSIS

The moments we will analyse are the half and the one-third of the full period, in our case 45 s and 30 s (Table 2). The first column shows the pendulum's index, the second is the number of swings through the full period. The third and the fourth columns contain the number of swings done during these selected time intervals.

Table 2. Comparison of the number of swings within different time intervals: full (90 sec), half (45 sec) and one-third (30 sec) of period τ

Pendulum no.	**No. of swings ($\tau = 90\ s$)**	**No. of swings during 45 sec**	**No. of swings during 30 sec**
0	52	26	17 **1/3**
1	53	26 **1/2**	17 **2/3**
2	54	27	18
3	55	27 **1/2**	18 **1/3**
4	56	28	18 **2/3**
5	57	28 **1/2**	19
6	58	29	19 **1/3**
7	59	29 **1/2**	19 **2/3**
8	60	30	20
9	61	30 **1/2**	20 **1/3**
10	62	31	20 **2/3**
11	63	31 **1/2**	21
12	64	32	21 **1/3**
13	65	32 **1/2**	21 **2/3**
14	66	33	22
15	67	33 **1/2**	22 **1/3**

If we are at half time (45 s), the first pendulum did an integer number of swings, the next one did an integer and a half, then again an integer number, and so on. In perspective of positions, the number of fully completed swings does not matter, only the fractional part does. This means that every second pendulum is at the same position: the even ones are in their starting position, the odd ones are on the other side.

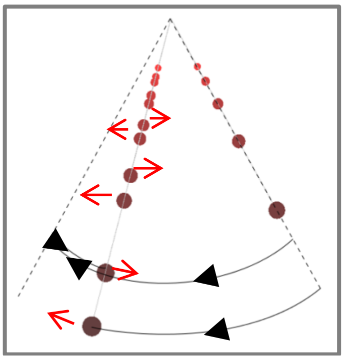

Fig.6. Pendulum positions (front view) at one-third of the full period (t = 30 s) in computer simulation with the parameter data as in Table 1.

At one-third of the full period (30s), we can see in Table 2. that there are 3 different positions the pendulums can be in, with fractional parts of 1/3, 2/3 and 0. However, only two distinct positions are visible in Fig.6. (for convenience, the path of the two longest pendulums are also drawn be continuous arcs). This is because the 1/3 and 2/3 positions are the same, but the balls are moving in different directions. The 1/3's are still on the way to the opposite side, the 2/3's are coming back towards the starting position.

Any moment can be analysed like these; we recommend considering the one-quarter (Fig.7.), one-sixth or two-fifths (Fig.8.) of the full period, as the constellations which occur in these moments are quite remarkable.

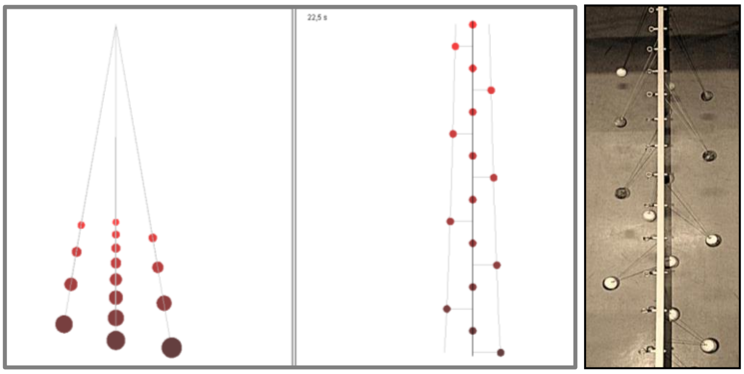

Fig.7. Positions at one-quarter of the full period
Left and middle panel: simulation, front and top views.
Right panel: photo of our set-up, top view, data as in Table 1.

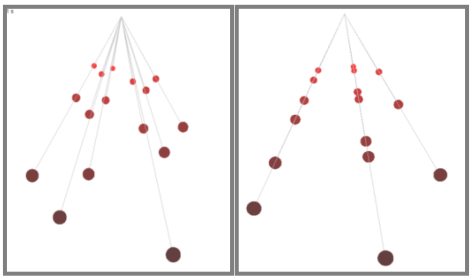

Fig.8. Nice shapes, left panel: 1/6 period, right panel: 2/5 period, simulation, front views, data as in Table 1.

CURIOSITIES

The simulation software did not learn physics: it does not know anything about Newton's laws, or gravitation, it only knows the formula, which is an approximation. Thanks to the missing knowledge of the program, we are able to see what this formula would give for angle values too large, where the small angle approximation does not hold. If we use $\alpha_0 = 120°$, the simulation is very spectacular, it makes shapes like butterflies. This sight can be observed really well on the move (for example in Fig.9. around half period). Even more beautiful, when the n-value is large. (You can see this in our simulation – "Enable great angles" button.)

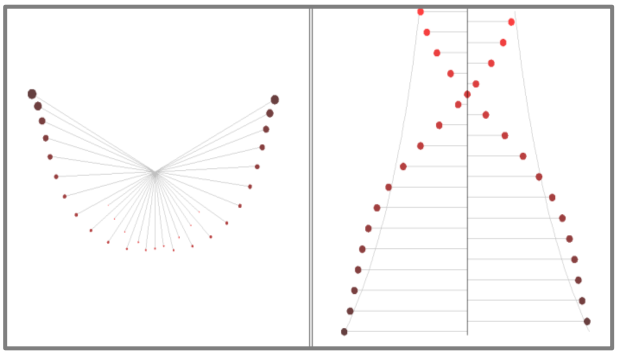

Fig.9. „Butterfly" → $\alpha_0 = 120°$,
Left: front view. Right: top view
$(n = 31; t = 44.1\ s; N = 52; \tau = 90\ s)$

We asked ourselves what would happen if the pendulum wave could "sing". Although building this in real life would be complicated, in the simulation we implemented this feature easily. The pendulums make sound in their leftmost and rightmost positions, and the longest pendulum gives the sound of a small „A", the next pendulum one semitone higher, and so on. The result was a beautiful, or – at least – quite interesting music. (You can hear this when running our program – "Enable sounds" button.)

We raised another question: what if we used a much simpler formula for the lengths, for example an arithmetic sequence. The beginning is very similar to the original one, it starts waving, but later, it turns into a system with no beautiful shapes at all. (You can see this in our program, too. – “Linear lengths” button.)

PHYSICS SCHOOL CAMP

Finally we would like to mention the physics school camp in our high school. Fig.10 shows two selected pictures of the camp. My school organizes a four-day physics camp each year, which forty-fifty students are attending from the school. In 2014, our pendulum wave-project was a great success.

The students have to work in smaller groups on a jointly chosen topic under the supervision of teachers. They present the projects to each other during the camp. The project’s framework might contain one or more experiments, measurements, evaluations, building of experimental equipment, preparation of computer simulation, theories or calculations. In the camp, the teachers also hold small group lessons. The programs are completed with invited speakers, team competitions, experiments and constant thought-provoking tasks. The location is usually an open-air school.

Fig.10. Top panel: observing of spectroscope, bottom panel: small group lesson with a physics program

OUTLOOK

You can find other versions of pendulum waves on the Internet [7]. For example a more spectacular version with fireballs, or one which is painted with fluorescent material, so it glows in the dark. We hope that some of you get a feel for preparing the equipment.

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   Directly to the simulation: http://www.berzsenyi.hu/Lendvai/PendulumWave_eng.jar
5. Simple pendulum wave: https://www.youtube.com/watch?v=yVkdfJ9PkRQ
6. http://java.com/en/
7. Additional videos about other versions of pendulum waves:
   Pendulum wave with fireballs: https://www.youtube.com/watch?v=u00OF3ilNUs
   Pendulum wave in the dark: https://www.youtube.com/watch?v=7_AiV12XBbI
   Symmetrical pendulum wave: https://www.youtube.com/watch?v=vDtfWxL-AJg
   Spiral version with sound: https://www.youtube.com/watch?v=JMzB7sLeSbs

VIDEO INSTRUCTIONS FOR UNDERGRADUATE LAB EXPERIMENTS: A STUDENT-TO-STUDENT APPROACH

D. Dvorzhitskaia, L.Wemmers, L. Kryvoruchko, A.Geck, H. Derksen, G. Bastian, A. Struck
Rhein-Waal University of Applied Sciences, Kleve, Germany,
a.struck@hochschule-rhein-waal.de

ABSTRACT

Lab experiments are an important part in teaching undergraduate physics at universities, in particular in subsidiary courses for engineering students. A lack of preparation time and/or motivation of students affect the ability to successfully perform a given experiment. Our attempt of improvement is providing video tutorials that explain the lab experiments in addition to usual text instructions while giving experimental details to large groups. This adds an interdisciplinary aspect, and the advanced students serve as role models for other students.

INTRODUCTION

Physics remains the fundament of all modern sciences and engineering disciplines. In universities, it is nowadays often absorbed in special courses designed to meet the purposes of the actual major subject; nevertheless, most non-physics science and engineering programs include a first-year module concerned with teaching the fundamentals of physics.

Since the advent of affordable video equipment, attempts were made to implement this new tool for teaching physics [1]. With the rapid development of internet availability and video-sharing platforms during the last years, educational footage has become a widely used source of information. Mobile information technology enables users to quickly find answers to questions of different levels of detail.

In this paper, benefits and difficulties in first year physics courses at universities are discussed and analysed. As a possible attempt to overcome the difficulties, we present our experiences with student-made introductory videos to lab experiments. Instead of presenting the whole experiment in a recorded video, only the introduction to conducting the real experiment is shown [2]. We discuss the additional learning outcome and motivation boost associated with the preparation of such videos and suggest strategies for a proper integration into existing courses.

PHYSICS LABS: BENEFITS AND DIFFICULTIES

All science and engineering courses at Rhein-Waal University include at least a one-semester course on elementary physics. The degrees include mechanical engineering, electrical engineering, materials science and science communication among others. Students enrolling in these courses have often a very different expectation and also a varying skill set with respect to physics.

A typical physics course taught as a minor subject consists of a lecture with e.g. two hours per week presence time, accompanied by a one-hour problem solving unit and a two hour lab course. The latter usually requires students to understand the theory of the experiments, conduct the actual experiment in the lab and present the results in the form of a written lab report.

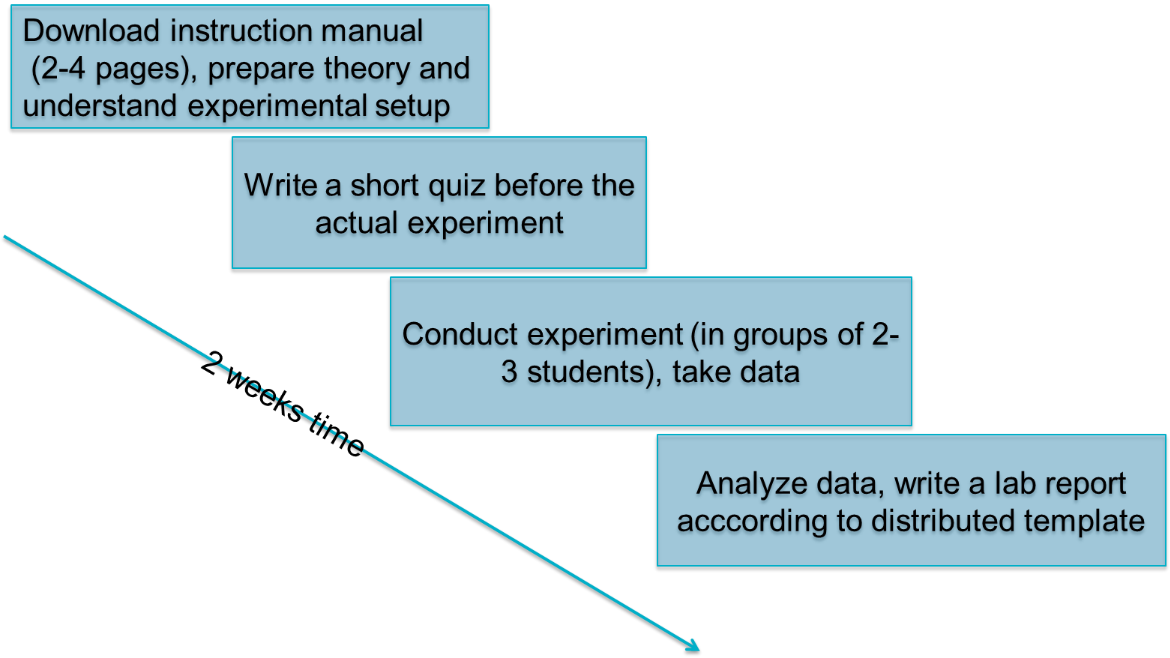

Fig.1. Workload cycle for first-year students in the physics lab courses. Engineering students have to complete five experiments in the first semester.

The physics labs (Fig.1.) play an important role in transferring methodical competence. Students are not only introduced to scientific methods, the art of measurement, data analysis and error treatment, but are also confronted with teamwork, often for the first time.

In many reported cases, the exact sciences like mathematics and physics turn out to be very difficult for students who have to take these subjects only as minors as illustrated in Fig.2. The reason for this is often a lack of motivation, because the students cannot see yet how these subjects are related to their majors. Moreover, even introductory courses often need to rely on the fundamental ability to think scientifically. In fact, even simple approximations require a certain level in mathematical education that cannot always be met by first-year students; important concepts like error propagation and other statistical tools for quantitative measurement analysis are even more out of reach for scientific beginners.

VIDEO TUTORIALS AS SUPPORT FOR LAB INSTRUCTION DOCUMENTS

The expected benefits of video tutorial can be grouped into a technical, a sociological and a pedagogical aspect.

1. Technical aspect

Even simple experiments can have a complex setup that is sometimes hard to describe by a written introduction. In a typical arrangement, various devices are connected in different ways that are visually perceived easily while evading a short description in words. A technical drawing can perhaps visualize the setup but often fails to illustrate the dynamics of the measurement. Very fast or slow events can be presented in different replay modes. Additionally, a video can transport real acoustical features of the experiment, e.g. in collisions of object, friction sounds or humming of transformers. This makes students feel more familiar with the experiment when actually being in the lab. Moreover, artificial sounds can be included to emphasize certain details, e.g. the sound of accelerating cars. This is intended to help students relate to the subject by making connection to everyday experiences. Small details of instruments, fittings and other parts can be filmed in close-up mode and thus can be shared with a large audience. It is also assured that different groups performing the same experiment get identical instructions. Especially in international classes taught in English, the visual outreach of the video can help overcome language difficulties by directly linking pictures of objects with technical terms. Difficult experimental situations can be scrutinized by the audience by individually pausing or rewinding the film. Sharing the footage well before the experiment enables the students to get familiar with the actual equipment even before entering the lab. This saves time for students and instructors and allows for more time to actually do the experiment. The video can be maintained over different courses, improvement and reaction to student feedback can be consistently offered over a long period of time.

2. Sociological aspect

Video instructions designed and filmed by students who have already taken the labs help to establish them as role models for the next generation. Unlike more senior lecturers, they can better relate to new students facing the experiments for the first time. Furthermore, a certain enthusiasm can be stimulated easier from student to student.

Since video clips are part of the students' everyday life, the students can easily be addressed by this communication channel.

3. Pedagogical aspect

Our science communication students have to complete the same physics labs in the first semester as all the other, mostly engineering students. While producing the clips, they can directly apply their recently acquired proficiencies in film making. In addition, they intensify their knowledge about physics and their experimental skills.

There is also a fruitful feedback from students to the lecturers; by actively accompanying the production process, they obtain incentives for improving physics teaching.

MAKING VIDEO INSTRUCTIONS

The videos of five physics lab experiments (Kinematics, Pendulum, Energy and Momentum, Moment of Inertia, and Resonance) and a tutorial on data analysis software were produced by four students studying in the Rhein-Waal bachelor degree course "Science Communication and Bionics", from April to May 2015. The production of the video was completed by June 2015. The aim of the videos was to instruct students how to work with the equipment and what exactly they were supposed to do as part of the experiment. Each video took approximately 2 hours to prepare a script, 2-3 hours to film, and 7-9 hours to cut clips and produce the whole video. The script was based on the written lab guidance to the experiment, on the lab reports written earlier by the team, and on the test-videos developed by the instructors preliminary to the more detailed production completed by the students. Professional equipment, such as TV cameras and video post-processing software, were used for filming and cutting. The length of the videos depended on the content and the amount of tasks which had been completed in the experiment:

- Kinematics (4:50 minutes);
- Pendulum (5:09 minutes); this clip can be seen at [3]

- Energy and Momentum (5:37 minutes);
- Moment of Inertia (4:42 minutes);
- Resonance (6:08 minutes);
- Tutorial on data analysis software (10:49 minutes).

Each video ends with a small, somewhat ironic or funny scene involving presenters and part of the equipment. This entertaining part was created as a 10-30 second closing, in order to encourage students to work hard and to show them that physics can be fun and, more importantly, is closely related to everyday life.

Fig.2. Video production of the experiment on moment of inertia.

CONCLUSIONS

With the help of students from our science communication course a set of video tutorials for physics lab experiments have been created. This tool offers several benefits in teaching first semester students innovatively, although further statistical and pedagogical investigations are required to quantitatively judge the impact of this teaching method. We have already received an overwhelming positive qualitative feedback from a number of students who were using the video tutorials in September 2015. In particular those students, who did not pass the labs during the previous year without video tutorials, were able to judge the new teaching using videos in comparison. We are aware of possible drawbacks of our approach, like a reduced imagination of real setups and processes based on written descriptions. The development of such skills have to be addressed within the curriculum, but not necessarily during the physics labs, so that introduction videos can become a helpful tool for teaching.

ACKNOWLEDGMENTS

The technical support of Campus TV Kleve is highly acknowledged.

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FROM HEAT PUMPS TO HURRICANES: APPLICATION OF THERMODYNAMICS IN SECONDARY EDUCATION

A. M. Tasnádi
Karinthy Frigyes Gimnázium, Budapest, Hungary, tasnadi.aniko@gmail.com
Physics Education PhD program, Eötvös University, Budapest

ABSTRACT

A short teaching unit was devoted to explore and understand the physics behind some natural phenomena and devices the operation of which are connected to thermodynamics. Besides to deepen the students' knowledge of thermodynamics, the aims were to raise their interest, to enhance collaborative work, and to emphasize the importance of environmental mindedness. In the present paper the main discussion points of the teaching unit and the experiences gained during the lessons and afterwards are presented.

INTRODUCTION

The students' decreasing interest for physics is a major problem of physics teaching, and physics teachers worldwide seek the possibility for the change of this tendency [1, 2]. In our opinion the investigation of the physics of the devices used in everyday life might be a good tool for this. Thermodynamics gives a lot of opportunities to raise the interest of students. The basis of the operation of many appliances and machines, (e.g.: refrigerator, air conditioner, heating systems of houses, engines of cars, jets etc.) and even a natural phenomenon, the hurricane can be discussed by some kind of thermodynamic cycles.

With one of my groups of students I spent 8 extra lessons to teach the thermodynamic background of some technical devices and the tropical cyclones. The aim on one hand was to raise the interest of the students. On the other hand, it gave the possibility to address the environmental issues as well. The students had to work in groups, they had to do some research on how the chosen device worked, and they also had to give an oral presentation to their classmates about what they learnt. Finally a questionnaire was given to them, in order to find out how much they learnt.

BACKGROUND AND TASK

In the academic year of 2014-15 I taught the first year of a 2-year preparatory physics course for the University. (The time allocation of the course was four 45-minute lessons per week.) Part of the course was to introduce the students the basics of thermodynamics: gas laws, kinetic gas model, processes (isothermal, isobaric, isochoric and adiabatic) and cyclical processes (including the terms efficiency and COP), and the laws of thermodynamics.

Two 45-minute lessons were spent on the thorough discussion of the idealised cyclic processes of the two most common car engines, the Otto and the Diesel engines.

The Otto cycle is easier, after introducing the equation of the adiabat the efficiency ($\eta = 1 - \left(\frac{V_2}{V_1}\right)^{\kappa-1}$, where V_1 and V_2 are the bigger and smaller volumes of the working substance, respectively, and κ is the ratio of specific heats) of the idealised cycle was derived.

Although the derivation needs some mathematical skills, (maybe in the case of a less able group it can be omitted) but the result is quite simple and it enables us to explain the terms compression ratio ($\frac{V_2}{V_1}$), octane number and the role of the spark plug. The calculation of the efficiency of the ideal Diesel cycle is a bit more demanding, so its formula was just stated, in order to show that (among other factors as well) it also depends on the compression ratio of the working substance [3]. Students can easily understand it, since in the case of Diesel engines air is compressed instead of the air–gasoline mixture, it is more compressible, therefore Diesel engines have greater efficiency. Students can also realise that these engines are heavier because for the greater compression stronger piston walls are needed.

Besides the discussion of the operation of these engines it is also substantial to explain the environmental impact of these engines. Students could be explained to that although Diesel engines have greater efficiency than Otto-engines, their exhaust fumes are more dangerous, because they contain more Nitrogen-oxides and particulate matter, which are both harmful pollutants [4]. After this introduction, students were given the task to research different devices which are operated either as a heat engine or a heat pump. They were given two weeks to work in groups and prepare for their presentations (as homework). Four 45-minute lessons were spent on discussion of these devices, and where it was relevant the environmental issues were addressed as well.

OTHER TWO HEAT ENGINES (EXPLAINED BY STUDENTS)

Two groups of students researched and made presentations about heat engines, one was the Wankel engine, and the other was the Stirling engine. Both groups found interesting details on the operations of the engines, and showed videos (found on the internet) to illustrate their operation.

Wankel engine is a spark ignited engine but it works differently from the usual four-stroke engines. Its common name is rotary engine, since the piston is rotating in an eccentric shaft. Its advantages are that it is small and simple, it has high power to weight ratio. Its disadvantages are that it needs frequent service, it has higher fuel consumption and its exhaust is harmful. The Japanese factory Mazda manufactures cars with this type of engine [5].

Stirling engine is a well-known engine among physics teachers, but not for the ordinary people. It is important because it is an external combustion engine, so it can be operated with any heat source, thus it can be more environmental friendly if the burning process of the fuel is complete. It has high efficiency, but less than the Carnot efficiency [6, 7], (this is stated wrongly in many cases) since the cyclical process consists of two isotherms and two isochors (and not two adiabats). Some disadvantages of this engine are for example that it is big and slow to ignite.

HEAT PUMPS

Before the discussion of heat pumps, it was recalled that heat pumps are reversed heat engines. The schematic figure of heat pumps is shown in Fig.1, where Q_C is the heat released by the cold heat reservoir, Q_H is the heat absorbed by the hot reservoir and W is the external work done.

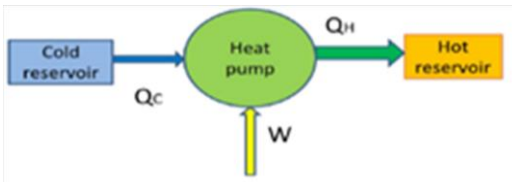

Fig.1. Schematic figure of a heat pump

Their "efficiency" is characterised by the so called coefficient of performance (abbreviated as COP). It was also pointed out that this COP is defined differently if the heat pump is used for heating or if it is used for cooling, depending on what is useful for us.

$$COP_{Heating} = \frac{Q_H}{W} = \frac{Q_H}{Q_H - Q_C} > 1 \tag{1}$$

$$COP_{Cooling} = \frac{Q_C}{W} = \frac{Q_C}{Q_H - Q_C} \tag{2}$$

Taking away (2) from (1) it can be seen that if the same heat pump is used for heating and for cooling, the difference between its COP values is one. In this sense heating is more efficient than cooling [8].

REFRIGERATORS AND HVAC (HEATING, VENTILLATING AND AIR CONDITIONING) DEVICES (STUDENT'S EXPLANATIONS)

For the technical application of heat pumps students found many different devices like refrigerators, the phase-change cooling system of computers, air conditioners, tumble dryers, and the different source heat-pump systems to heat buildings. In this paper only the refrigerators and the heating of buildings are presented.

The most widely used heat pump, which was developed first (more than a century before the first heat pump was used for heating) is the refrigerator. Students introduced the main ideas of both the vapour compression and the gas absorption type refrigeration systems. Although the cyclic process of the refrigerant is too difficult (in both cases), the essence that the refrigerant periodically evaporates and condenses in order to absorb heat from the evaporator and then to release heat in the condenser can be understood well. In the case of the compression type refrigeration system the evaporated refrigerant is compressed by an electrically powered compressor, so the cooling cycle can be repeated. In the case of the absorption type system the evaporated refrigerant is absorbed by some salt solution. This refrigerant-saturated absorber must be heated, in order that the refrigerant evaporates out, and in the heat exchanger it can condense again. Since the vapour compression refrigeration system has greater COP, it is more widely used, but the other is quieter, and can be operated with any type of heat like waste heat or solar power, and not just electrical energy.

The first practical heat pump system which was used for heating was proposed by Lord Kelvin in the 19th century, but heat pumps used for the heating of buildings were only introduced in the 20th century [8]. The operation of heat pumps that are used for domestic heating and air conditioning is similar to the operation of refrigerators. The great majority of these devices are vapour-compression systems. HVAC devices are usually classified according to their heat source: there are air, ground (sometimes called geothermal) and water source heat pumps.

Air source heat pumps are the cheapest, and most commonly used as air conditioners. They can also be used for heating, but since the temperature of air in winter can be very cold, the COP of these heat pumps decreases in the coldest days of the winter. Another disadvantage is that it may be noisy.

Ground source systems are stable, but far more expensive. Fig. 2 left panel shows the sketch of two types of ground source heat pumps. Either long horizontal trenches are dug (the total area where the collector pipes are laid is approximately 2-3 times of the area which is to be heated), or vertical boreholes are drilled (60-100 m deep). Both have COP approx. 4-5.

Fig.2. Left panel: Ground source heat pumps. Right panel: Water source heat pumps

Fig.2. right panel shows the two types of water source pumps. The first extracts the heat of the ground-water. (Two wells must be drilled, one is the source from which water is pumped up, and the other is the sink, into which the cooled water flows back.) This is the most efficient of all with a COP value of 5-7, but not the cheapest, the open-loop circuits need maintenance;

ground-water must be filtered. (In Hungary the Hotel Stáció near Vecsés is equipped with this type of HVAC system.) The last figure shows a system in which heat is extracted from a river or a lake, it is less disruptive than ground source, but the open-loop type may be cut-out in winter.

A simple estimation can be made for the COP of these systems. As an example consider the shallow vertical ground source system. It extracts heat from the ground at a temperature of 10°C and it releases it to the room at a temperature of 20°C. If the Carnot cycle's COP is used for the estimation we gain $COP_{Carnot} = \frac{293}{293-283} = 29.3$. In reality the heat pump is operated not between the heat reservoirs of temperatures 10°C and 20°C, but between colder and warmer ones. If the ground is at a temperature of 10°C the trench temperature is approximately 4 °C, the temperature of glycol which is flowing in the collector pipes may be at -1°C. The refrigerant temperature in this case might be only -10°C. Similarly in order that the radiators release heat to the room at a temperature of 20°C, the radiators must be warmer, let us estimate with 50°C, and the condensing temperature of the refrigerant must be even higher, approximately 60 °C. Again approximating the cyclic process of the heat pump with the Carnot COP, but using the -10°C and 60°C temperature values, we gain a much smaller coefficient of performance: $COP = \frac{333}{333-263} = 4.75$. (These estimations were not calculated by the students, but not too difficult to understand.) [9] What is important to realise, is that heat pumps perform better if the difference between the temperatures of the hot and cold reservoirs is smaller. It means that in the case of domestic heating large heat exchangers are better, therefore wall or underfloor heating should be used rather than radiators.

ENVIRONMENTAL ISSUES TO DISCUSS

Heating with heat pumps is regarded as an environmental friendly way of heating, since it is considered a low carbon technology, but we should be careful. To operate the heat pump we (usually) need electricity, so the carbon emission of the heat pump also depends on how electricity was generated. The installation of the heat pump should be carefully planned, otherwise it may happen that the heat source gets exhausted of heat, its temperature decreases, thus the COP of the heat pump decreases as well, and it uses more energy.

Another important factor that scientists and engineers must consider is the question of refrigerants. In the beginning of the last century chlorofluorocarbons (CFC) later hydro-chlorofluorocarbons (HCFC) were used, but they caused the depletion of the ozone layer of the Earth. Now the most common refrigerants are hydrofluorocarbons (HFC), which do not ruin the ozone layer, but have very big global warming potential. (Approximately 1550 times as much as that of carbon dioxide.) Hydrocarbons (HC), ammonia (NH_3) or carbon dioxide (CO_2) can also be used as refrigerants, but unfortunately HCs are flammable, NH_3 is toxic, and CO_2 is not as efficient as the others [9].

NATURE'S HEAT ENGINE

Finally during two lessons the physical background of tropical cyclones were explained to the students. For the explanation of the formation of hurricanes, the Coriolis force was introduced to the students, and then the necessary conditions for Tropical cyclone genesis were explained [10]. (These are the following: at least 27˚C sea-surface temperature; instability of the air; high relative humidity, it should be at least 500 km away from the equator; surface vorticity; weak vertical wind shear.)

Fig.3. left panel shows the tracks and intensities of tropical storms observed between 1851 and 2006. It can be seen in the figure that there are no hurricanes close to the equator, because the Coriolis force is not big enough to make the air rotate. Also the already formed hurricanes never cross the equator.

The structure of a hurricane is shown in Fig. 3 right panel. If somewhere above the sea there is a depression, then air begins to flow there and then it rises. While the hot humid air rises, it expands and should cool down, but also the water precipitates and rains out, which warms back the air in the eye of the hurricane. The air which flows in above the sea, is rotated by the Coriolis force, in the Northern hemisphere in counter-clockwise direction, while at the top of the hurricane the air spreads out and is rotated in the opposite direction. In the figure it can also be seen that in the eye of the hurricane air is descending whilst in the eyewall it ascends. The heaviest storms occur in the eyewall, while in the eye there is neither wind nor rain. The regions in which air ascends and descends vary almost periodically in space.

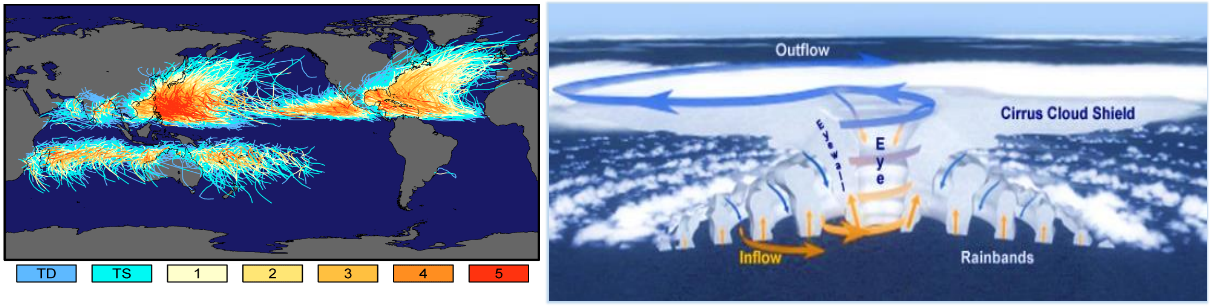

Fig.3. Left panel: Tracks and intensities of tropical storms (TD: tropical depression; TS: tropical storm; tropical cyclones are numbered from 1 to 5 in the order of increasing strength.) (source [11]), Right panel: Structure of a hurricane (source [11])

Meteorologists approximate the cyclic process of the hurricane as a Carnot cycle. The left panel of Fig.4. shows the ideal Carnot cycle of hurricanes, whilst on the right panel the p-V diagram of the cycle is indicated.

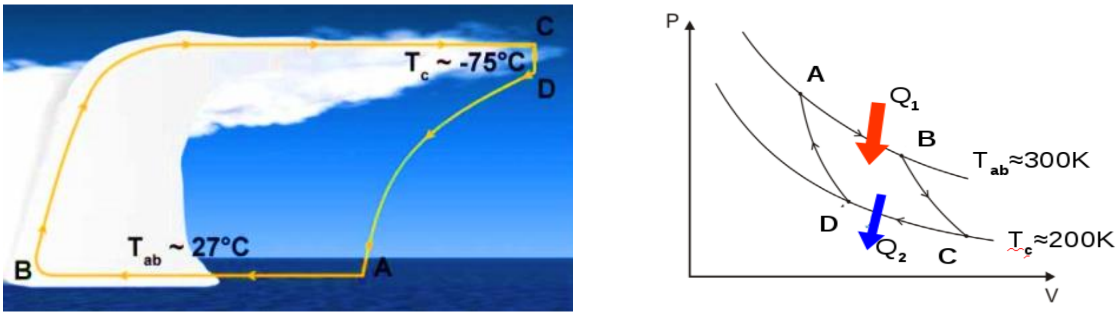

Fig.4. Left panel: the Carnot cycle of hurricanes (in space). (source [11]), Right panel: the p-V diagram of the Carnot cycle

The processes can be described as follows: A→B (isothermal process): the warm surface of the ocean keeps the air at approximately constant temperature, which begins to flow towards the centre of the hurricane. B→C (adiabatic process): the saturated air begins to rise. During the adiabatic ascent, the air cools down and the water precipitates and rains out. When water changes from the gaseous to the liquid state heat is released, thus the centre of the cyclone remains hot. The ascent of air slows down and the air spreads out and gets far from the core of the cyclone. C→D (isothermal process): the temperature of the air is approximately constant in this zone; the air descends and gives off heat. D→A: adiabatic descent of air. After the explanation my students could easily calculate that the efficiency of the Carnot cycle of tropical storms is 1/3.

ASSESSMENT

At the end of the 8-hour teaching unit the students were given a questionnaire. In the first part the students were asked true-or-false questions based on the covered topics. (There were eight

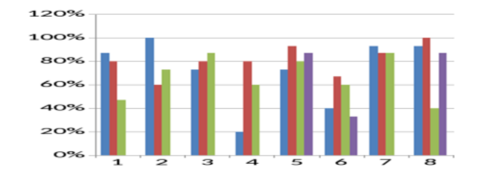

Fig.5. Percentage values of correct answers for the questions

groups of questions, each containing 3 or 4 questions.) The percentage value of the number of students who answered correctly to each question is shown in Fig.5.

As examples here are some of the questions: (the percentage values after them indicate the ratio of students who answered the question correctly)

2. c) In Diesel engines the pure air is compressed. (True) 73%
5. d) If the same heat pump can be operated in order to cool down and to heat up the room, then its COP is greater when it is used for cooling. (False) 87%
5. c) In the case of the gas-compression type refrigerators the condensing refrigerant absorbs heat from the environment. (False) 80%
6. d) In a hurricane the ascending wet air condenses and heats up the ambient air. (True) 33%

The second part of the questionnaire aimed to find out the students' opinion about the project. They had to give marks from 1 to 5 for the following questions: (1 meant disapproval, and 5 approval; each number after the question indicates the average of the given marks.)

Did you find it useful to prepare for your oral presentation? 4.46
Did you find the presentations useful? 4.15
Did you find the presentations interesting? 4.31
Did you learn from the presentations? 3.69
Would you like to learn this way in the future? 3.42

CONCLUSIONS

A new short teaching unit was elaborated for teaching the basis of thermodynamics with particular regard to its technical applications, and the environmental impact of the applications. The main purpose was to raise the student's enthusiasm to learn physics. The students worked in groups and researched different devices, and finally gave short presentations on their results. Most of the students were enthusiastic, inquiring, and enjoyed the lessons. The topics were worth discussing. Quite understandably the students found their own presentations the most useful, and probably they learnt the most from these. They also found the presentations interesting, but found a bit more difficult to learn from their classmate's ones. It can be seen that the idea of efficiency and COP, (particularly that of the Carnot cycle) has a central part in understanding the operation of the household technical units. However, in numerical calculations students need a bit more feedback and guidance to be able to apply these ideas independently.

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APPLICATIONS IN THE FOCUS: PHYSICS TEACHING FROM A NOVEL TEXTBOOK

Sándor Egri[1], Péter Ádám[2], Gyula Honyek[3], Péter Simon[4], Gábor Horányi[5], Ferenc Elblinger[6]

[1]University of Debrecen, Department of Physics, Debrecen, Hungary, egris@science.unideb.hu

[2]Institute for Solid State Physics and Optics, Wigner Research Centre for Physics, Hungarian Academy of Sciences, Budapest, Hungary, adam.peter@wigner.mta.hu

[3]Eötvös Loránd University, Radnóti Miklós Practicing School, Budapest

[4]High School Leőwey Klára, Pécs, Hungary

[5]Lauder Javne School, Budapest

[6]High School János Garay, Szekszárd, Hungary

ABSTRACT

The National Curriculum of Hungary and the curriculum frameworks for all subjects were renewed in 2012. The curriculum framework "A" for physics corresponds to the Science Education Standards applied all over the world. Novel textbooks have been developed by the authors for teaching physics in secondary schools according to this curriculum framework. These textbooks were published by the Hungarian Institute of Educational Research and Development in 2015. They contain up to 30% of significantly new material, very close to everyday life, and the newly developed application-led classes. This paper presents the new textbook and some examples of the application-based classes.

INTRODUCTION

According to national surveys, we can say that physics education is in crisis in Hungary. Poor results of the PISA surveys and our teaching experiences made it clear to us that the majority of the students have serious problems in learning physics. We emphasize this fact not as a theoretical statement but rather as a practical consequence of the changes in physics teaching that have been made in the last decades. Another measureable fact is that students dislike physics and, as a consequence, there is a growing shortage of physics teachers in the secondary schools. One of the possible causes of this may lie within the inherent nature of the subject. Physics is a difficult subject to learn, requiring maximum effort, and the achieved grades may not always reflect the effort that students have paid [1]. For example, understanding modern physics needs strong abstraction far beyond everyday sensing. Further causes may arise from external circumstances. The time devoted to teaching physics in Hungarian schools has been reduced by approximately 50% during the last 25 years. In contrast to that, the content of the physics classes remained the same, or even increased. As a consequence, an average physics class today contains 40% of theory (definitions, laws, formulae), 40% of computational exercise and, only additionally, some practical knowledge about the applications and performing experiments. Young physics teachers often follow the way they where taught: standing in front of the board with a piece of chalk and explaining. This is the easiest way for the teacher, but not the best for the students.

PARADIGM SHIFT IN EDUCATION

The National Curriculum of Hungary and the curriculum frameworks for all subjects were renewed in 2012. Concerning physics, about 30% of new content appeared, in order to turn the subject into a more practical and useful one. Some examples from the new topics are: working principles of the radar and GPS, the way our cars get the energy to move (fuels), physical background of human live-functions and sensing, energy of the nutrition, physics of the weather and climate, global climate change, working principle of CCDs, and 3D displays, physical background of some medical therapies, etc.. These new topics give the teachers possibility and freedom to turn the traditional subject of physics into a more practical one.

The earlier paradigm for physics teaching was developed during the 1950s. According to this paradigm, the definitions of the physical quantities and the laws should be taught first, in their mathematical form. Every student should learn this scientific background and should be able to solve a set of basic computational exercises. The arrangement of the material, even the titles of the chapters, follow the order of the books used in universities. Applications are not in the focus of the teaching, or they have only supplementary role in the books and during assessment. From this point of view, following the logic of science, the material can be arranged only in a few ways: general mechanics is taught first, then the theory of heat, static electricity, electric current, electromagnetism, physical optics, atomic physics, nuclear physics, astrophysics.

At present there are two curriculum frameworks in Hungary. One of them, which denoted by the letter “B” follows this earlier paradigm of physics teaching. In curriculum framework “A” topics are not strictly arranged according to the logic of the science, but they try to follow the logic of everyday life instead.

Novel textbooks have been developed by our group and have been produced and published by the Hungarian Institute of Educational Research and Development (Fig.1.). At present at least fifty teachers have started to teach according to our textbook which follows more the logic of the appearance of the physical knowledge in everyday life than the logic of university books.

Fig.1. Cover of the new textbook for class 11 and an inner page, about the ways of transmitting television broadcast signals.

TOPICS OF THE TEXTBOOK

Let us provide a short list about the main topics of the textbook, following the order of their appearance:

class 9

Time scales and distances in the Universe, from the tiny up to the huge.

Physical background of transportation by vehicle. How are cars moving, how fast are they?

How to turn a car safely, what happens when we try to stop a car? How rockets work.

Movement of the objects of the Solar System: satellites, planets.

Energy, work and power: the main concepts.

Simple machines: torque and balance.

Waves and oscillations: La Ola wave, earthquake, resonance catastrophe.

Energy: The ways we consume energy, power stations, and many actual topics: calories, fuels, the Sun, passive houses, atomic energy, global challenges for mankind, energy crisis.

class 10

The water around us.

Motion of the air and water: winds, storms, oceanic streams, physics of flying and swimming.

Global environmental problems: ecological footstep and climate change.

How musical instruments work.

Sparkles and thunders.

Electric current: use of batteries

Safe usage of electric machines, domestic electric networks.

Creation and transportation of electric energy. Electric generators.

class 11

How do our eyes work? About eyeglasses, colours, the working principle of movies, imaging techniques in medical diagnosis (CT, MR, X-ray) and safety (X-ray at the airport).

Global communication: communicating via electromagnetic signals (television, mobile phone, digital coding of information).

What are things made of? Light sources, cameras, electrovoltaic cells, colours of different materials.

Radioactive radiation: medical applications, safety issues, nuclear power plants.

World of the stars: what does the star light tell us?

Universal questions: extraterrestrial life, "At the beginning…", is it really written in the stars?

Physics of the Solar System.

Space exploration.

The topics mainly were selected because of their importance and strong presence in everyday life. We tried to cover almost each phenomenon which could be important for a kid to now. Despite of the fact that applications are in the focus, arrangement of the topics sometimes follows the traditional order of physics teaching. For example knowledge about mechanics can be found mainly in class 9 in the topic of the transportation, but the inner coherence of the topics are not as strong as usually, it is easier to change them or to omit some of them.

To summarize: according to this approach we should teach physics as it appears in our everyday life, in the streets, in the kitchen, in the household, during transportation, while using our mobile communication devices, when going to the cinema, etc.

Let’s have an example about the waves. When we are teaching this topic according to the new book, the starting point of the teaching is not to give definitions of some quantities or draw up the definition of mechanical wave, transversal and longitudinal waves but to observe and examine the waves that are present around us. La Ola is similar to the shock wave, and a good example that a wave can transfer the energy in a certain direction without observable particle transfer. Students are interested in earthquakes, so it’s a good chance to give them simple explanations of the surface and bulk waves produced by the earthquake (Fig.2.). At this point it’s possible to speak about longitudinal and transversal waves as well, but the main aim is still not to define them very strictly, but to explain how the energy of the earthquake is dissipated and to expand the horizon of the students’ mind.

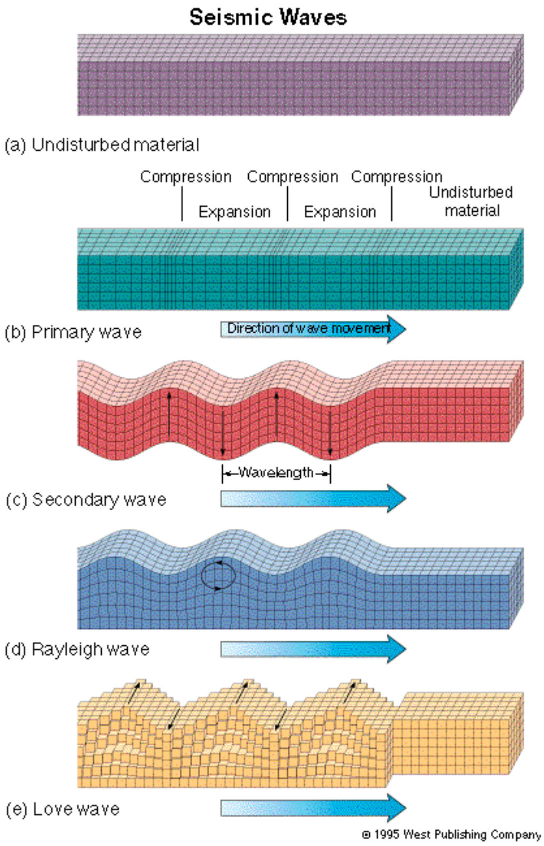

Fig.2. Different types of waves produced by an earthquake [2]

Standing wave and its frequency are coming into the picture when we are explaining how the guitar is able to produce a sound. The main aim in a normal group (having 2 hours of physics per week or less) is not to teach the formula of the frequency of a standing wave on a string with fixed ends, but to develop the qualitative understanding about the working principle of the guitar – up to a certain extent.

There are many advantages and disadvantages of teaching in this way to consider thoroughly, but what is more, there is a possibility to observe the behaviour of the teachers and the progress of the students working with the new textbooks.

INNOVATIVE TEACHING METHODS

In order to understand the approach, it is important to keep in mind that the main aim is not to teach and make the kids memorize each and every useful fact found in the books. There are plenty of them and they can be found either in the book, or on the World Wide Web later. We neither aim at teaching more and more definitions and formulae, nor try to teach how to solve different types of computational problems. The aim is rather to give scientifically correct explanation of everyday issues up to a certain level of abstraction that is affordable for the pupils. This level depends on many factors and can be changed according to the prior/background knowledge of the children, and according to the aims of the school. It is good to use innovative methods that develop creativity, communication, cooperation and critical thinking of the students. These are accepted as the key competences for building a successful career in our quickly changing world.

Gamification is one of the promising innovative methods [3]. Look at the board (Table 1.) of the game with atomic energy levels. To start the game, our electron should stand in the ground state.

Table 1. Board of the physics game.

electron energy	-12 eV	-7eV	-4eV	-2eV	-1eV	0eV	1eV	2eV	3eV
electron state	ground	excited	excited	excited	excited	excited	free	free	free

After throwing the dice the electron can move from one energy state to another one. The rule is the same as in photon excitation: the electron can accept the energy (the number) only if it is equal to the energy difference between the present state and a possible excited state. A controlled trial experiment was performed at the University of Debrecen in 2014 to find out whether playing this game helps the students. There were two groups selected from first-year students with about 15 pupils in each. Both groups got the same lecture about photons, photoelectric effect, and energy levels of atomic electrons. Group B played the game as the application of the theory, while group A solved some computational exercises. After 3 weeks both groups wrote a test without previous announcement. Overall performance of the gamified group was slightly better than that of the other group.

Mobile phones are getting used widely in active learning because they can be used as measuring instruments [4]. Camera (CCD detector), microphone (sound detector for examining waves), three-axes accelerometer sensor can be found in every phone, ambient light sensor, magnetic field sensor are usually available. Popular applications (like compass, spectrum analyzer, metal detector) and applications for physical measurements (like Physics Toolbox) are quickly downloadable.

Using a frequency meter application, it is easy to tune empty bottles to create a musical sound with the desired tone [5] (Fig.3.).

Fig.3. Making music with bottles from [5]

In our experiment six groups were formed from the secondary school pupils, there were about three members in each groups. The task of each group was to tune their bottle into the desired note of the tonal scale (do, re, mi, fa, sol, la, ti, do). Members of one group calculated the frequency for each sound using the formula in the book; while others found a musical sheet for a simple song (see Fig.4.).

Formula for the simple major scale.

$$do \cdot \frac{9}{8} = re\,,\ re \cdot \frac{10}{9} = mi\,,\ mi \cdot \frac{16}{15} = fa\,,\ fa \cdot \frac{9}{8} = sol\,,\ sol \cdot \frac{10}{9} = la\,,\ la \cdot \frac{9}{8} = ti\,,\ ti \cdot \frac{16}{15} = do \quad (1)$$

Fig.4. Sheet for a simple winter song starts with: do-do sol-sol la-la so, fa-fa mi-mi re-re do

At the end of the class it was possible to play a simple melody and that was a really good result of the cooperative effort.

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PUZZLING PROBLEMS ON GRAVITY

Tamás Tasnádi
Budapest University of Technology and Economics,
Budapest, Hungary, tasnadi@math.bme.hu

ABSTRACT

Although Newton's gravitational law is simple to state, it leads to a rich diversity of motions ranging from parabolic projectile motion to chaotic dynamics. The tools applied in these problems are also versatile. Here a bunch of puzzling problems on gravity is presented with the basic ideas of their solutions. Each problem requires a kind of unique, individual method and each solution teaches us something new. Some of the results are surprising. Most of the presented problems are used in the preparation for the International Physics Olympiad, and their solutions are attainable by elementary, secondary school methods.

INTRODUCTION

Throughout the history of physics the understanding of gravity went through several metamorphoses. The law of gravitational attraction was discovered in the early 17th century by Sir Isaac Newton, who has also realized that the same law governs the motion of a falling apple and the motion of the planets around the Sun. Later, at the end of the 19th century Roland Eötvös experimentally proved with high accuracy the equivalence of gravitational and inertial mass. In the beginning of the 20th century this fact became a cornerstone of Albert Einstein's general theory of relativity, which interpreted the gravitational interaction as the curvature of spacetime. Today, in modern physics we know that gravity is one of the four basic interactions of Nature.

In this work we are going to study gravity at the secondary school level, based on Newton's law of gravity. Apart from the first problem we restrict attention to regular planetary motions. The basic tools used in the solutions of the problems are Newton's gravitational law, Kepler's laws, conservation laws (energy, angular momentum, momentum), the geometry of conic sections, and in the last problem the theory of non-inertial reference frames.

In the first chapter five simpler problems are discussed, which are important either because of their final result or because of the methods used in the solution. In the 2nd and 3rd chapters single, more difficult problems are addressed. They are slightly beyond the secondary school level because of the mathematics and the abstractions used there.

Variants of some of the problems discussed here and other similar problems can be found in [1]. These problems are used in the preparation of the Hungarian team [2] for the International Physics Olympiad [3].

BASIC INSTRUCTIVE PROBLEMS

In this section we review some simple and instructive problems.

Problem 1 (Long pendulum): Find the period T of a mathematical pendulum whose length L is comparable to the radius R of the Earth. Assume that the angular deviation is small and that the mass of the pendulum is close to the surface of the Earth.

Solution: Let *m* be the mass of the pendulum. There are two forces acting on this mass; the gravitational force and the tension of the rope, as indicated in Fig.1.

In case of small angular deviations the magnitude of both forces is constant *mg*. In terms of the small angles α and β indicated in Fig.1, the equation of motion (in horizontal direction) has the form:

$$mL\ddot{\alpha} = -mgL(\alpha+\beta), \quad \text{where} \quad \alpha L = \beta R\,.$$

The solution of this equation is a simple harmonic motion with period $T = 2\pi\sqrt{\frac{LR}{g(R+L)}}$, which gives back the well-known formula for $L \ll R$.

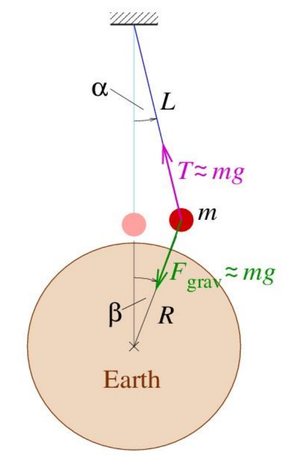

Fig.1. Forces acting on the long pendulum

Conclusion: The key point in the solution is that the magnitudes of the forces are constant (change only in second order of α) while their directions vary in first order of α. Generally, in the approximation of a vector field it is often useful to investigate separately the magnitude and direction of the vectors. This strategy is used also in the last problem.

The next problem is instructive for its own sake and it yields a result which can be used in other problems as well.

Problem 2 (Total energy of orbits): An object of mass *m* is orbiting another object of mass $M \ll m$. Express the total energy *E* in terms of the geometric parameters of the orbit. (These parameters are the semi-major axis *a*, the semi-minor axis *b* and the focal length *c*.)

Solution: First we assume that $E < 0$, so the orbit is an ellipse. Let r_P and r_A denote the distance of the perihelion *P* and aphelion *A* from the focal point at the central mass. The geometric relations between the distances indicated in Fig.2 are:

$$r_P = a - c\,, \qquad r_A = a + c\,, \qquad a^2 = b^2 + c^2\,.$$

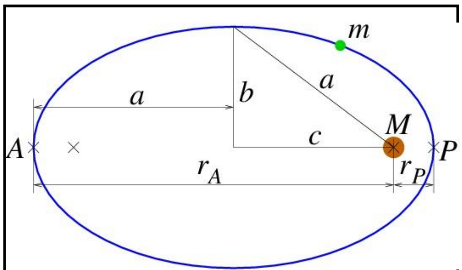

Fig.2. The elliptic orbit

The conservation of angular momentum and energy for the points *A* and *P* give the equations:

$$mv_A r_A = mv_P r_P\,, \qquad E_{ell} = \frac{mv_A^2}{2} - G\frac{mM}{r_A} = \frac{mv_P^2}{2} - G\frac{mM}{r_P}\,,$$

where v_A and v_P are the speeds of the orbiting object at the points indicated in the subscripts. Eliminating the speeds and the focal length *c* from these equations, after a straightforward calculation the result

$$E_{ell} = -\frac{mMG}{2a} \tag{1}$$

is obtained. (The negative sign indicates that the elliptic orbit is bounded.)

If $E > 0$ then the orbits are hyperbolas. The geometry of the hyperbola is not so familiar to secondary school students as that of the ellipse, so it is worth discussing it in detail. Fig.3 shows the hyperbola with its asymptotes and the lengths *a*, *b*, *c*. The aphelion is at infinity, so:

$$r_A = r_\infty = \infty\,, \qquad r_P = |PF| = c - a\,, \qquad c^2 = a^2 + b^2\,.$$

Again we have to use the conservation of angular momentum and mechanical energy between the point at infinity and the perihelion P:

$$mv_\infty p = mv_P r_P\,, \qquad E_{hyp} = \frac{mv_\infty^2}{2} = \frac{mv_P^2}{2} - G\frac{mM}{r_P}\,.$$

Calculations similar to the elliptic case give the result:

$$E_{hyp} = \frac{mMG}{2a}\,. \qquad (2)$$

Conclusion: The total energy of the elliptic or hyperbolic orbits depends only on the semi-major axis a, and it is independent of the other parameters (b, c) of the orbit.

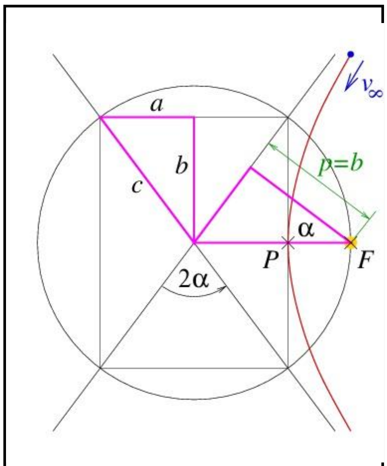

Fig.3. The hyperbolic orbit

Now we study in more detail another problem related to hyperbolic orbits.

Problem 3 (Deviation angle of hyperbolic orbits): A comet passes by the Sun. Determine its angle of deviation 2α in terms of the initial speed v_∞ (at infinity) and the impact parameter p (indicated in Fig.3).

Solution: With the use of the results of the previous problem the solution is simple. Using equation (2) and the formula $E_{hyp} = mv_\infty^2/2$, we get that $a = MG/v_\infty^2$. From Fig.3 it can be seen that $p = b$ and $\tan\alpha = a/b = \frac{MG}{pv_\infty^2}$.

Remark: Beside the conservation laws a key point of the solution is the relation $\tan\alpha = a/b$. This and the contents of Fig.3 should be discussed in more details in class [4].

Problem 4 (Racing satellites): Two satellites, A and B orbit the Earth on the same circular orbit, B lags behind A. How should B use its rocket in order to catch up with A? (Assume that the rocket can give only a quick impulse to the satellite.)

Solution: Our first, natural idea is to increase the velocity of B towards A. But this turns out to be wrong! Indeed, with this manoeuvre the total energy of the satellite is increased, so according to the result (1) of Problem 2, the semi-major axis a of the orbit increases. But due to Kepler's 3rd law, with increasing a the orbital period increases, too.

The above reasoning shows that paradoxically, the opposite manoeuvre has to be performed; the satellite should decrease its speed by giving an impulse opposite to its velocity. As a result of this, the satellite completes a faster cycle closer to the Earth, as indicated by the blue ellipse in Fig.4.

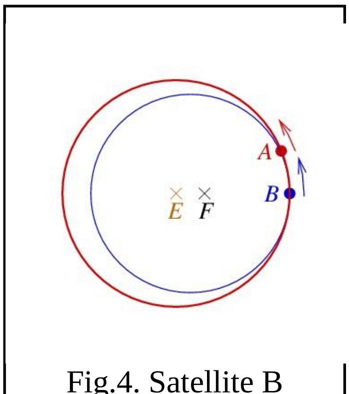

Fig.4. Satellite B decreases its speed

It is a nice exercise for practising first order approximations to find the relation between the change in the speed of the satellite Δv and the change in its period ΔT, provided that these quantities are small (relative to the total speed and total period, respectively). The result is:

$$\Delta T = \frac{6\pi R^2}{GM}\Delta v \qquad (3)$$

where M is the mass of the Earth and R is the radius of the circular orbit. The derivation of this formula is left to the interested students.

Problem 5 (Stopping the Moon): Imagine that the Moon's orbital motion around the Earth is suddenly stopped. How long would it take for the Moon to fall into the Earth? The orbital period of the Moon is T=28 days. (Assume that the Moon's orbit is a circle and neglect the Earth's motion around the Sun.)

Solution: The direct approach would be to solve the equation of motion but it is beyond the secondary school level.

A more tricky approach is to apply Kepler's 3rd law to compare the periods of the two different orbits of the Moon. The first orbit is the original circular orbit of radius R, period T=28 days and semi-major axis $a=R$. The second orbit is the degenerate ellipse corresponding to the motion of the Moon as it is falling into the Earth. The two foci of this ellipse are at the initial position of the Moon and at the Earth, so its semi-major axis is $a' = a/2$. Applying Kepler's 3rd law, the new period is $T' = T\sqrt{a'^3/a^3} = 2^{-\frac{3}{2}}T$. It means that the Moon would fall into the Earth in $T'/2 = 2^{-\frac{5}{2}}T = 4.95$ days.

ENVELOPING CURVE OF ORBITS

The problem discussed here is more difficult than the previous ones and it is for the best students.

Problem 6 (Enveloping curve of orbits): Let A be a fixed point in space at a distance d from a fixed sun S of mass M. Particles of mass m are shot from A in different directions at constant speed v. Which points can be reached by the particles? (Assume that v is small enough so the trajectories are ellipses.)

Solution: The arrangement has a rotational symmetry about the line AS, and all trajectories are planar curves, so it is enough to solve the problem in a single plane containing A and S. In this case our task is to determine the *enveloping curve* of a family of smooth curves.

Let us address this question generally. Let $\{C_\alpha\}_{\alpha\in I}$ be a family of smooth curves depending continuously on the real parameter α in the interval I, as shown in Fig.5. Pick two curves C_α and C_β corresponding to the parameter values α and β, and let K be their intersection point. It is heuristically clear from the figure that as $\beta \to \alpha$, the two curves come closer and closer to each other and their intersection K approaches a point of the enveloping curve, i.e.:

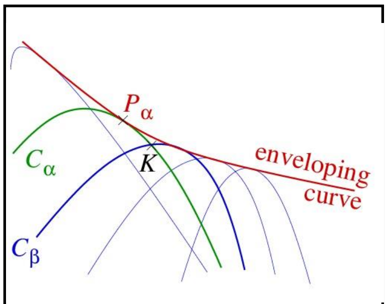

Fig.5. Enveloping curve of a family of curves

$$P_\alpha = \lim_{\beta\to\alpha} C_\alpha \cap C_\beta ,$$

where P_α is the point where C_α touches the enveloping curve. So a general point of the enveloping curve is the intersection of two curves lying very close to each other.

Now we return to the original problem. Since the speed v and thus the total energy E of the particles shot in different directions is the same, due to the result (1) of Problem 2, the semi-major axis

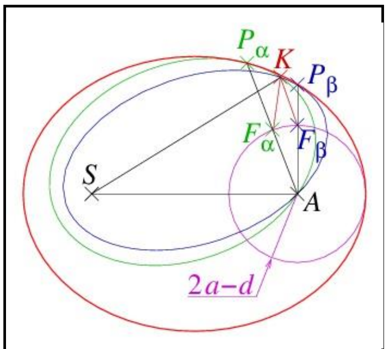

Fig.6. Two orbits (blue and green ellipses) touching the red enveloping curve

$$a = -\frac{mMG}{2E} = \frac{MG}{2MG - v^2 d} d$$

of the orbits is constant as well. Let us consider two elliptic orbits C_α and C_β lying close to each other, as indicated in

Fig.6. Let F_α, F_β denote their focal points (different from *S*), and let *K* be the intersection point of the two orbits (different from *A*). Since *A* is a point of both ellipses, $SA + AF_\alpha = SA + AF_\beta = 2a$, so $AF_\alpha = AF_\beta = 2a - d$. Thus the focal points F_α, F_β lie on a circle of centre *A*. Since *K* is also on both ellipses, $SK + KF_\alpha = SK + KF_\beta = 2a$, which means that $KF_\alpha = KF_\beta$. It means that in the limit $\beta \to \alpha$ the points *A*, $F_\alpha \approx F_\beta$ and $K \approx P_\alpha \approx P_\beta$ become collinear. Then for a general point P_α of the enveloping curve we have:

$$SP_\alpha + P_\alpha A = \underbrace{SP_\alpha + P_\alpha F_\alpha}_{2a} + \underbrace{F_\alpha A}_{2a-d} = 4a - d = \frac{2MG + v^2 d}{2MG - v^2 d} d\,,$$

so the enveloping curve is an ellipse of foci *A*, *S* and semi-major axis $2a - d/2$. Fig.7 shows a family of orbits which nicely fill out the enveloping ellipse.

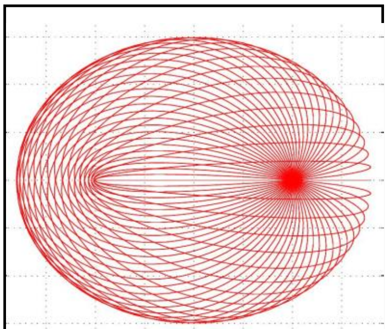
Fig.7. Many orbits fitting into the enveloping ellipse

Remark: Similar problems of finding the enveloping curves of certain trajectories can be formulated in optics (with light rays) and in hydrodynamics (with streams of fluids). The method discussed here helps in all cases.

MOTIONS OBSERVED FROM A SPACE STATION

In this section we discuss the motion of objects observed from a rotating reference frame. Non-inertial frames of reference and inertial forces are not involved in the Hungarian physics syllabus for secondary schools. The material of this section can be discussed in a special course for selected students after a systematic treatment of non-inertial reference frames and inertial forces [5].

Problem 7 (Motion around a space station): A space station is orbiting the Earth on a circular trajectory, facing always with the same side towards the Earth. A small object is thrown out of the space station with a small initial velocity $\mathbf{u}$. How does the object move *relative to the space station*?

Solution: We solve the problem in the uniformly rotating reference frame of the space station. The axes are directed as indicated in Fig.8. The mass of the Earth and the small object are *M* and *m*, respectively. The radius of the orbit of the space station is denoted by *R*, and ω is the angular speed of the station. Furthermore, we shall use the constant $F_0 = GmM/R^2 = mR\omega^2$ to denote the magnitude of the centrifugal and the gravitational force acting on the small object in the space station.

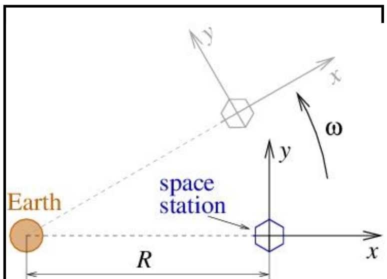

Fig.8. The reference frame of the space station

We expand all forces acting on the object in first order of the position $\mathbf{r} = (x, y, z)$ and the velocity $\mathbf{v} = (\dot{x}, \dot{y}, \dot{z})$ components of the small object. As we have seen in Problem 1, it is advantageous to expand first the magnitude of the forces and then the direction.

In first order the magnitude and the components of the gravitational force are:

$$F_g = \frac{GmM}{(R+x)^2 + y^2 + z^2} \approx F_0\left(1 - \frac{2x}{R}\right), \qquad \mathbf{F}_g \approx F_g \begin{bmatrix} -1 \\ -y/R \\ -z/R \end{bmatrix} \approx F_0 \begin{bmatrix} -1 + 2x/R \\ -y/R \\ -z/R \end{bmatrix}.$$

(We have used the fact that $\sin(\varepsilon) \approx \tan(\varepsilon) \approx \varepsilon$ and $\cos(\varepsilon) \approx 1$ for small angles ε.)

Similar expansions for the centrifugal force are:

$$F_{cf} = m\sqrt{(R+x)^2 + y^2}\,\omega^2 \approx F_0\left(1+\frac{x}{R}\right), \qquad \mathbf{F}_{cf} \approx F_{cf}\begin{bmatrix}1\\ y/R\\ 0\end{bmatrix} \approx F_0\begin{bmatrix}1+x/R\\ y/R\\ 0\end{bmatrix}.$$

Finally the Coriolis force is:

$$\mathbf{F}_{Cor} = -2m\boldsymbol{\omega}\times\mathbf{v} = -2m\begin{bmatrix}0\\0\\\omega\end{bmatrix}\times\begin{bmatrix}\dot{x}\\\dot{y}\\\dot{z}\end{bmatrix} = 2m\omega\begin{bmatrix}\dot{y}\\-\dot{x}\\0\end{bmatrix}.$$

Substituting these expansions into the equation of motion $m\ddot{\mathbf{r}} = \mathbf{F}_g + \mathbf{F}_{cf} + \mathbf{F}_{Cor}$, after some simplification (cancellations) we get:

$$\ddot{x} = 2\omega\dot{y} + 3\omega^2 x, \qquad \ddot{y} = -2\omega\dot{x}, \qquad \ddot{z} = -\omega^2 z.$$

The last equation decouples from the other two and its solution is a harmonic motion with angular frequency ω in the z direction. Differentiating the first equation and using the second one, the equation $\ddot{v}_x = -\omega^2 v_x$ is obtained, whose solution is a similar harmonic motion. Taking into consideration the initial conditions $\mathbf{r}(0) = (0,0,0)$, $\mathbf{v}(0) = \mathbf{u} = (u_x, u_y, u_z)$, $\dot{\mathbf{v}}(0) = \mathbf{F}_{Cor}/m = 2\omega(u_y, -u_x, 0)$ we obtain the following solution:

$$\mathbf{r}(t) = \begin{bmatrix}x(t)\\y(t)\\z(t)\end{bmatrix} = \frac{1}{\omega}\begin{bmatrix}u_x\sin(\omega t) + 2u_y(1-\cos(\omega t))\\ 4u_y\sin(\omega t) + 2u_x(\cos(\omega t)-1) - 3u_y\omega t\\ u_z\sin(\omega t)\end{bmatrix}. \qquad (4)$$

Remark: It is worth discussing separately the special cases of the problem, when the initial velocity has only one non-zero component. It is also instructive to solve these special cases in the inertial reference frame of the Earth. The result (3) of Problem 4 can also be obtained from the general solution (4). We leave these investigations to the interested reader.

CONCLUSIONS

We have presented the solution of seven problems related to gravity, ranging from relatively simple ones to extremely difficult ones. Via these problems not only gravity, celestial mechanics can be taught to students, but many other things which are applicable in other branches of physics as well (e.g. approximation techniques, the geometry of conic sections, application of conservation laws, enveloping curves, non-inertial reference frames, differential equations, etc.). We hope that student readers enjoy learning physics from these nice problems and teacher readers think further some of the problems discussed here, and build into their own methodology some of the ideas presented here.

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FUNNY MOTIONS OF BILLIARD BALLS

Máté Vigh[1], Péter Gnädig[1], Gyula Honyek[2]
[1] Eötvös University, Budapest, Hungary, vighmate@caesar.elte.hu
[2]Radnóti Miklós High School, Budapest, Hungary

ABSTRACT

The rolling and slipping motions of billiard balls on a horizontal surface are extensively studied in the literature. Most of these phenomena can be understood in the framework of high school physics. The variety of the possible motions and the difficulty of the physical ideas behind them make this topic interesting for a wide range of students from classroom physics to the level of International Physics Olympiad (IPhO). In this paper we present some interesting problems and examples related to the motions of billiard balls, which can be used in the preparation of talented students for international physics competitions such as IPhO and APhO.

INTRODUCTION

The detailed description of the various types of motion of billiard balls can be found in the literature. Gustave-Gaspard Coriolis, the famous French physicist was the first theorist who wrote a book about the subject in the 19th century [1]. Although Coriolis's calculations are based on Newtonian mechanics, for a high school student it is hard to follow the tedious explanations due to the complicated geometry of the three dimensional motions. Even Arnold Sommerfeld mentioned this topic in his famous books on theoretical physics [2]. Without the details he sketches a proof based on the rotational and translational equations of motion about the parabolic trajectory of the center of a billiard ball after a Coriolis-massé shot (see Problem 2). In a more recent book written by Alciatore [3] the Coriolis-massé shot aiming method is analyzed in more detail. In addition to the proof of the parabolic trajectory Alciatore presents a calculation about the final direction of motion of the ball. Although this derivation is surprisingly short and elegant, the effect of friction between the ball and the table during cue stick impact is completely neglected. However, as Coriolis showed this friction has no effect on the final cue ball direction.

In the following discussion we want to show that the essence of these phenomena can be understood on a high school level. We discuss two different situations (Problem 1 and Problem 2) in which the application of the conservation of angular momentum provides a simple and elegant way of solution. We have used these problems in the last couple of years during the Hungarian preparation courses for the International Physics Olympiad. According to our experience, these kind of problems help the students deepen their knowledge and understanding about angular momentum and rotational motion. The problems presented here can be found in the problem collection written by the authors [4].

PROBLEM 1: MOTION ALONG A LINE

Problem 1. A ball, initially at rest on a billiard table, is struck by a cue tip at the point T shown in Fig.1. The cue lies in the vertical plane containing T, the centre of the ball C, and the ball's point of contact with the table *P*; consequently, so does the line of action of the resulting impulse. Construct the direction in which the cue should be aligned in order that after the shot, the ball's subsequent rotational and slipping motions terminate at the same instant and the ball comes to a halt. (As a result of chalking of the cue tip, the coefficient of friction between it and the ball is sufficiently large that there is no slippage between them during the cue stroke.)

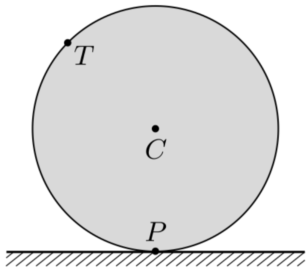

Fig.1. Position of the point of contact (P), the center of the ball (C) and the hitting point (T)

Solution 1. In general, after receiving an impulse from the cue, the billiard ball both rolls and slips and the instantaneous speed of its point of contact with the table is not zero. This 'grating' continues until, as a result of kinetic frictional forces, the velocity of that point relative to the table decreases to zero; after that, the ball continues to roll but without slipping.

Consider the point *P* at which the ball touches the table before the shot is taken. Note, that *P* denotes a *fixed* point *on the table*, and not the current contact point of the ball and table (which accelerates, or decelerates, during the stroke and the subsequent 'grating'). The total angular momentum of the ball about this point is zero before the shot, as well as at the simultaneous end of the rolling and slipping motions (when the ball again becomes stationary).

During the motion that follows the cue stroke, the net torque about *P* of the forces acting on the ball is zero, because the gravitational force and the normal reaction of the table cancel each other, and the line of action of the frictional force always passes through *P*. The angular momentum of the ball about *P* can only remain at zero throughout (from before the stroke until after the final halt) if it does not receive any during the stroke itself; this requires that the line of action of the impulse, and hence that of the cue, must be directed through point *P* (see Fig.2).

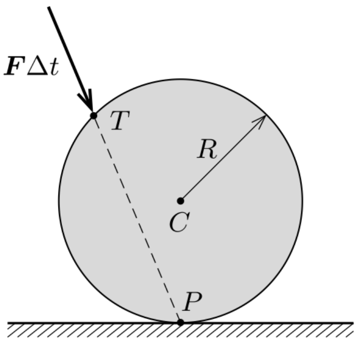

Fig.2. The direction of the cue must go through the point *P*

PROBLEM 2: MOTION IN 3D – THE 'CORIOLIS-MASSÉ' SHOT

Problem 2. If the line of action of the impulse in *Problem 1* does not lie in the vertical plane defined by the points *T*, *C* and *P*, then, just after the shot, the ball's angular velocity vector will not be perpendicular to the velocity of its centre of mass. Billiard players call this shot a *Coriolis-massé*.

Such a shot is shown in Fig.3, in which the line of action of the impulse meets the ball's surface (for a second time) at T' and the table at A.

a) What kind of trajectory does the ball's centre of mass follow from just after the shot until the point at which simultaneous rolling and slipping ceases?

b) In which direction, relative to the line PA, will the ball continue its path once it starts to roll without slipping?

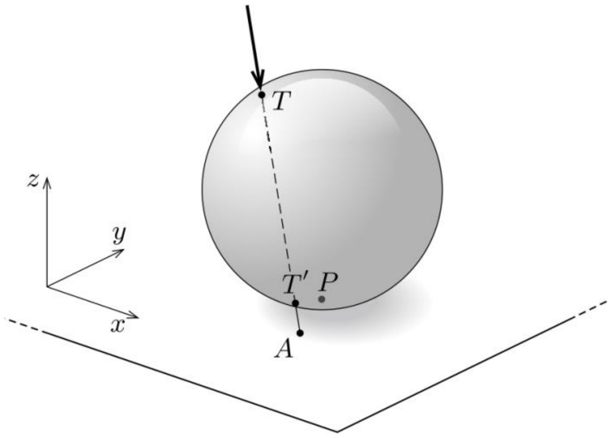

Fig.3. The direction of impulse in Problem 2.

(Assume that, whatever the downward force acting on it, the billiard cloth does not 'become squashed', and the ball's contact with it is always a point contact.)

Solution 2. Denote the vector pointing from the centre C of the billiard ball to its lowest point (where it touches the table) by $\boldsymbol{R}$, the mass of the ball by m, the velocity of its centre of mass by $\boldsymbol{v}$, and its angular velocity by $\boldsymbol{\omega}$.

As noted in the problem, for a general *Coriolis-massé* $\boldsymbol{\omega}$ will not be perpendicular to $\boldsymbol{v}$, and so the velocity of the lowest point of the ball,

$$\boldsymbol{v}_P = \boldsymbol{v} + \boldsymbol{\omega} \times \boldsymbol{R},$$

will not be parallel to the velocity of the centre of the ball, even at the start of the motion. A similar connection holds between the corresponding accelerations and the angular acceleration:

$$\dot{\boldsymbol{v}}_P = \dot{\boldsymbol{v}} + \dot{\boldsymbol{\omega}} \times \boldsymbol{R}. \qquad (1)$$

During the 'grating' motion, the horizontal acceleration of the ball and its angular acceleration are both caused by the frictional force $\boldsymbol{F}$, and so the dynamical equations for the translational and rotational motion can be written as follows:

$$\boldsymbol{F} = m\dot{\boldsymbol{v}},$$

$$\boldsymbol{R} \times \boldsymbol{F} = \frac{2}{5} mR^2 \dot{\boldsymbol{\omega}}.$$

Inserting expressions for $\dot{\boldsymbol{v}}$ and $\dot{\boldsymbol{\omega}}$, obtained from these two equations, into equation (1):

$$\dot{\boldsymbol{v}}_P = \frac{1}{m}\boldsymbol{F} + \frac{5}{2mR^2}(\boldsymbol{R} \times \boldsymbol{F}) \times \boldsymbol{R}.$$

Now $\boldsymbol{F}$ and $\boldsymbol{R}$ are necessarily mutually perpendicular, and so using either the right-hand rule or the vector triple product identity, it follows that

$$(\boldsymbol{R} \times \boldsymbol{F}) \times \boldsymbol{R} = R^2 \boldsymbol{F}.$$

So finally we have that

$$\dot{\boldsymbol{v}}_P = \frac{7}{2m}\boldsymbol{F}. \qquad (2)$$

The magnitude of the kinetic frictional force is μmg (where μ is the coefficient of friction), and its direction is opposed to that of the velocity of the lowest point of the ball:

$$\boldsymbol{F} = -\mu mg \frac{\boldsymbol{v}_P}{|\boldsymbol{v}_P|}. \qquad (3)$$

Combining this with equation (2), we have

$$\dot{\boldsymbol{v}}_P = -\frac{7}{2}\mu g \frac{\boldsymbol{v}_P}{|\boldsymbol{v}_P|}. \qquad (4)$$

Equation (4) shows that the velocity of the ball's lowest point has a constant direction throughout the simultaneous rolling and slipping motion, and that its magnitude decreases uniformly to zero at a rate of $-(7/2)\mu g$. It then follows from (3) that not only the magnitude of the frictional force, but also its direction, is constant. As this direction does not coincide with that of the initial velocity of its centre of mass, the billiard ball moves along a *parabolic* (rather than a straight) trajectory (see Fig.4).

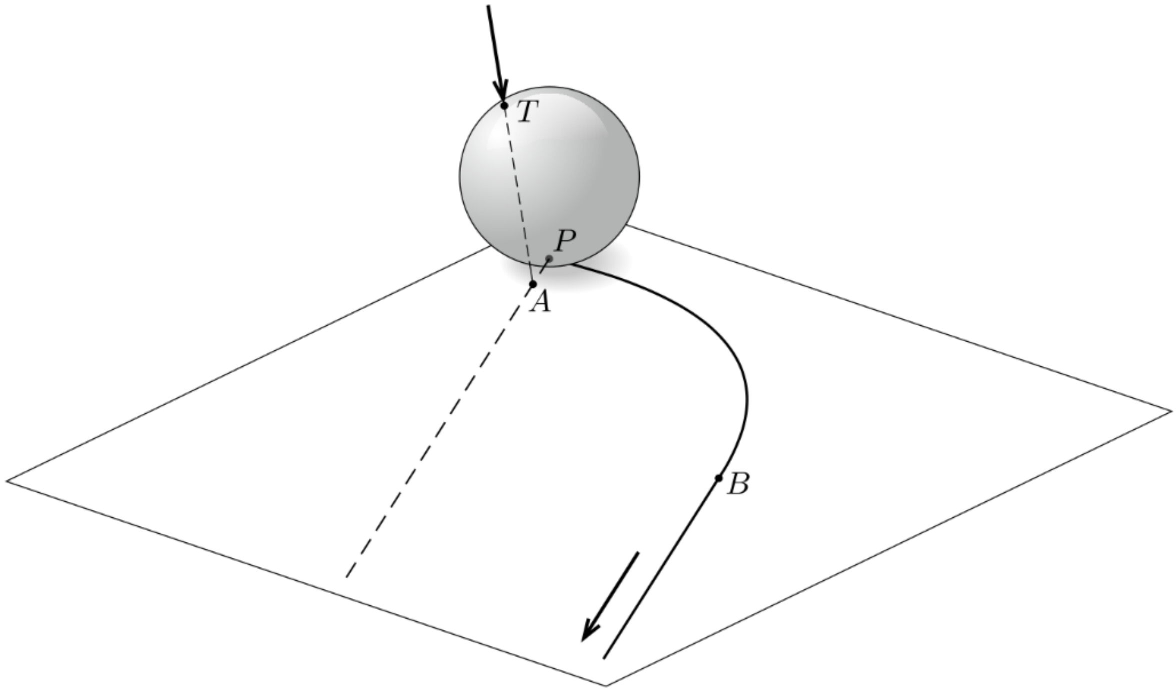

Fig.4. The parabolic trajectory of the center of the ball in the case of a Coriolis-massé shot

When the velocity of the lowest point of the ball becomes zero (this happens at *B* in Fig.4), the ball continues to roll, but without any slipping, until air drag and rolling friction bring it to a halt. Its straight-line path is along the tangent to the parabola at point *B*.

b) The final direction of the ball's motion can be found with the help of the law of conservation of angular momentum. We investigate the angular momentum of the ball about the line *PA*.

Angular momentum is a vector quantity, which is defined relative to a fixed (but arbitrarily chosen) *point* in space. But, it is also the case that a component of angular momentum in a given direction can be defined by an *axis* which lies in that direction. In this problem, for example - as will be shown later - the angular momentum of the ball relative to the *point P* is not conserved, but the component of angular momentum parallel to the line *PA* does remain constant.

Initially, the ball is at rest, so its angular momentum is zero. During the short time interval of the shot, the lines of action of the forces acting on the ball (the force of the shot exerted by the cue, the normal reaction force of the table, the frictional force, and the gravitational force) all pass through various points on the line *PA*. So, just after the shot, the angular momentum component defined by this line is also zero. This situation does not change as the ball moves along the parabolic arc *PB*, because the gravitational force and the normal reaction of the table cancel each other out, and the torque about this axis due to the frictional force is always zero (since the force and the axis lie in the same plane).

So, on the one hand, after finishing the 'grating' section of the motion the angular momentum vector of the ball remains constant -- it is horizontal, and perpendicular to the velocity of the centre of mass. But, on the other hand, as we have just shown, its component parallel to the line *PA* is zero. There is only one way to reconcile these two conclusions, and that is that the ball's path is *parallel* to the line *PA*.

CONCLUSIONS

In this paper we presented two sample problems which can be used to illustrate the usefulness of conservation of angular momentum when describing the quite complicated motion of billiard balls on a horizontal surface. Problems like these can be used for probing and improving the creative physical thinking of the gifted students, so such exercises could help the preparation of pupils for international physics competitions (such as APhO and IPhO) for high school students.

ACKNOWLEDGMENTS

We would like to thank Péter Vankó for his useful comments and remarks regarding the text of the problems and the solutions.

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BENEFITS OF IYPT IN PHYSICS EDUCATION

Mihály Hömöstrei[1], Ábel Beregi[2]
[1]German Nationality High School, Budapest, Hungary, hmisko83@hotmail.com
Physics Education PhD program, Eötvös University, Budapest
[2]Baár-Madas High School, Budapest, Hungary

ABSTRACT

The International Young Physicist´s Tournament (IYPT) is not a new thing in the world of physics education. Hungary has also been a successful participant of this competition since 1989. From the end of 2013 a new leader team helps the preparation of the Hungarian secondary school students. Since then we have been trying to invent and improve the teaching-learning process, which is based on the idea of IYPT and can help any participating Hungarian students to find their own way of getting better in physics. In this short article we would like to show how we are trying to improve the essential skills that are needed because of the special form of this competition – open ended problems, presentation, discussion etc.) - not only physics knowledge but much more!

INTRODUCTION / IYPT IN GENERAL

The International Young Physicist´s Tournament (IYPT, Fig.1.) is one of the most important worldwide physics competitions for secondary school students. It is also called the Physics World Cup [1], because it is not a competition for individuals but for teams. And this is not the only difference from the usual physics contests. Around 150 students of approx. 30 countries of the world are competing one another since 1988. This means as well that the official language of the tournament is English. Therefore, besides good physics knowledge students must have relatively high language and communication skills, too.

Fig.1. Logo of the IYPT [2]

The other very important specialty of IYPT is that the problems are 17 open-ended phenomena. This means that there are not any known solutions, for every precise result, the students have to work hard on their own. In the competition, students have to present their own results and defend it in a discussion with another opponent team. That needs obviously good presentation, discussion and communication skills. But to be honest, these skills are very important in the 21st century no matter if one is a physicist or not.

PROBLEMS IN IYPT

Every year after the actual competition, the International Organizing Committee (IOC) selects 17 open-ended problems. The problems are formulated in an easy and well-understandable short form. For such problems there are not any well-known solutions or even if there was a known physical background, the solutions of the different students would be very distinct from one another. Besides good knowledge of physics, creativity and preciseness in the measurements are essential to get a sufficient solution.

HOW TO SOLVE PROBLEMS?

Solving IYPT problems is a really hard task because of their complexity and not having an exact solution, but of course, it is not impossible. It takes significantly more time than finding a solution to a secondary school level theoretical exercise. The best way to describe the process is a year-long research (see Fig. 2.). To help students make the first steps, the IOC publishes a document called the Reference Kit, where some articles and webpages can be found which help getting the first ideas and objectives of a problem.

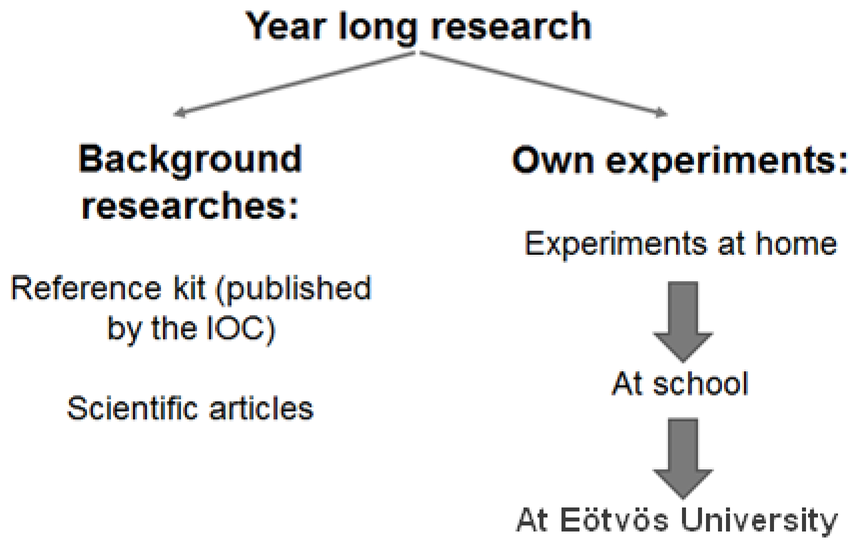

Fig.2. Structure of the preparation process

The Reference Kit is often not enough to set up the theoretical model, thus further investigation is needed from other scientific articles. Sometimes even physicists do not know what the exact explanation of the given phenomenon is, so students need to find out a simple theoretical model.

Since IYPT is about research, besides theory, conducting experiments has a major role in solving a problem. Choosing the right experiments and the right method is one of the hardest part in the process. Measurements are done at home firstly but usually the results are not precise and accurate enough, therefore a more sophisticated experimental method and apparatus is needed which can be found in secondary schools. After getting into the Hungarian team, students work in the laboratories of the Eötvös University where the required accuracy and precision can be obtained because of the better equipment, set-up and the help of the academic staff.

THE PHYSICS FIGHT

The main scene of the IYPT is called the Physics Fight (PF). During the tournament, each team has 5 PFs in which they compete against 2 or 3 teams from other countries depending on the number of participants. There are 3 main roles (see Table 1.), each team takes a role (in the case of 4-team fights, one team is just an observer), then they switch roles.

Table 1. Subjects of the three roles in a physics fight

Reporter	Opponent	Reviewer
- Presents own solution. - Defends it in a discussion.	- Gives an overview of the report. - Challenges the reporter in the discussion.	- Tests the knowledge of the reporter and the opponent. - Gives a review of the report and the discussion.

The structure may be complicated at the first sight but it is very logical (see Fig.3.) The first role is the reporter, who presents own solutions and defends it in a scientific discussion with the opponent. The opponent's job is to give an overview of the report and to challenge the reporter's understanding of the presented concepts; theories and principles in a discussion (see Fig.4.). The third role is the reviewer, who tests the knowledge of both the reporter and the opponent, and gives an objective summary of the report and the discussion. The performances of the reporter, opponent and the reviewer are graded by an international jury, whose members can test the knowledge of any of the 3 teams by questions. (see Fig.5.)

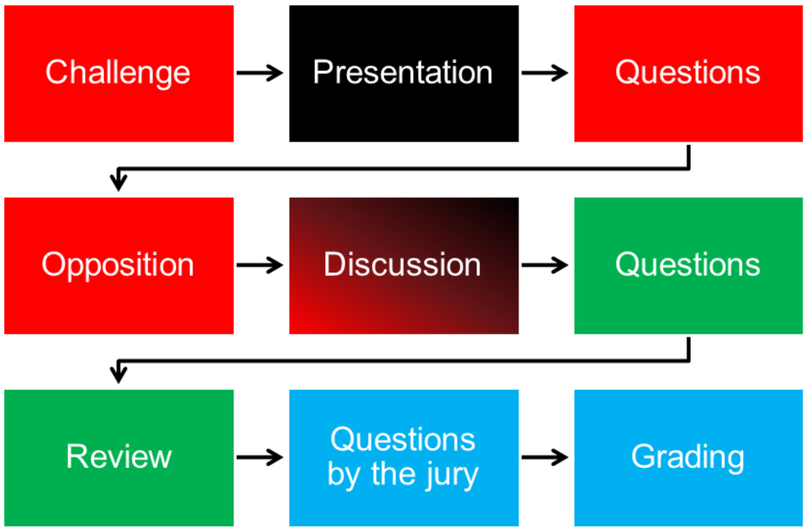

Fig.3. Structure of a physics fight

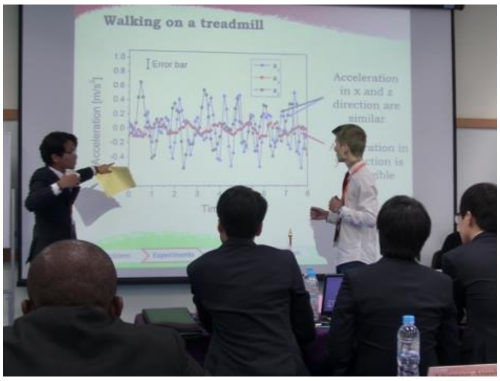

Fig.4. Discussion

Fig.5. Scores of the jury

BENEFITS FOR STUDENTS

Preparing for IYPT takes a lot of free time from students but it has numerous advantages. It is a significant opportunity for one to learn about some really interesting topics in physics which are not covered by secondary school curriculum. Also, they learn how to plan and conduct experiments, which is an essential skill for a physicist. Furthermore, they learn how to evaluate experimental data using basic and more advanced computer methods. After the national selection tournament, students work in pairs, this way teamwork can be learnt.

Fig.6. Hungarian team in an ancient Thai temple

They also spend significant time on meetings with the team leaders so they can get an insight into the work of a physicist. At the university high-class equipment is available which was never used by an average secondary school student. For those who get into the team, the IYPT is also a great opportunity to get to know different countries and cultures. (see Fig.6.) Above all, a really good community is built between the students and the team leaders.

DIDACTICAL ASPECTS

It is very important for us that every Hungarian high school student gets the chance to participate in the Hungarian selection process. To reach this aim, we publish a call to participate in the KöMaL (Mathematical and Physical Journal for Secondary Schools) every year in September. Furthermore, we send posters and calls for many Hungarian high schools directly and we are using the internet as well as possible. The selection process has three rounds. Each round is a bit different so we can improve a wide spectrum of skills [3].

The 1st round: writing a scientific essay. Till the end of November students have to investigate a self-selected problem and write a scientific essay in the limit of 8 pages in Hungarian language. The improved skills and capabilities in the 1st round are:

- reading scientific papers (English comprehension, finding the main points),

- doing own research (logical structure, precision),

- improving creativity (using physics in practice),

- cooperating with the teacher as a workmate (a new role for teachers and students, too),

- writing a scientific report (how to explain findings to others).

The 2nd round: Hungarian Young Physicist´s Tournament. This round is for the best 15 students based on the written essay mentioned above. In the middle of December students present their results in 10 minutes using English as the language of presentation. The jury is made up of professors of the Eötvös University. Beside the presentations the participants have to oppose an old IYPT presentation to show how good they are in finding the errors and shortcomings in someone's presentation. The best eight students can work further at the Eötvös University. The improved skills and capabilities in the 2nd round are:

- using criticism in a positive way (evaluation of the 1st round can help to improve the first results),

- creating appropriate presentation (logical structure, easy to follow and to understand),

- English language and presentation skills,

- getting deeper and more detailed physics knowledge in the selected problem.

3rd round: Selection of 5 team members for the team Hungary in IYPT. The selected 8 students work in pairs after the 2nd round. This is the first step of the team building. Since IYPT is a team competition, working together and team building are essential, just as they are in the real life. The team members can learn presentation and communication and IT skills from experts in the Hungarian IYPT committee.

To be a member of the 8 students' team is a great feeling for our students because they can work together with professors of the ELTE University. A laboratory is available for the IYPT students where they can conduct experiments in pairs under the supervision of the university professors. In the middle of March the best 5 students are selected after another presentation of their problems. The three students who do not make it into the team can participate in an international preparation contest, the Austrian Young Physicists' Tournament. Improved skills and capabilities in the 3rd round are:

- working in pairs and smaller teams,

- using lab equipment (mostly at Eötvös University but sometimes at the Technical University of Budapest and at Szent István University)

- presentation and communication skills.

NO FUTURE WITHOUT TRADITIONS

Whatever we have done in the last few years for the preparation of the Hungarian IYPT team, it was obviously not without antecedents. As it was mentioned at beginning of the article, Hungary has participated in the IYPT since 1989 with numerous [2] [4] medallions. The team leaders Zsuzsanna Rajkovits, Lajos Skrapits, Judit Illy, and Péter Kenesei between 1989 and 2012 were not only preparing the students for the competition, but also built the most important communication channels to students and teachers. Without their work and help it would have been impossible to reach a wider range of Hungarian students. Beside all of this they could evenorganize the IYPT in Budapest in 2000. Their work made an excellent basement for the cooperation with many physicists of the Eötvös University [4], which is essential for the future teams, too.

As a proof of the success of the former leaders we could mention many names of the former Hungarian teams who have become great engineers and physicists in many countries of the world. Some of these former participants help the further work of the Hungarian team. What could prove the success of the pioneer team leaders and the IYPT itself more than the ex-team members who join the Hungarian team of future physicists?!

CONCLUSIONS

The benefits of the IYPT, such as the preparation itself, are based on the modernity of this physics competition. The Hungarian education system actually raises mostly students who have a relatively huge amount of lexical knowledge but they are not practiced in working in teams. We have to face that the keys of success in the future are creativity, good practical sense and capability for teamwork. With this competition we can reach students who may not be the best in theoretical physics but are capable of learning by doing. Meanwhile our students improve their communication, presentation and language and team-working skills which help them to be successful in their entire life!

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MIKOLA COMPETITION

Miklós Kiss
Berze High School, Gyöngyös, Hungary, mikloskiss2630@gmail.com

ABSTRACT

Back in 1981 it was realized that there is no nation-wide competition in physics for the ninth and tenth grade high school students. To be able to recognize students talented in physics as early as possible, a new competition named after a famous Hungarian physics teacher Mikola was organized for them. The competition consists of three rounds. The first and second rounds mainly focus on theory and problem solving. The final round consists of both theoretical questions and experiments. The usual venues of the finals are the Berze High School in Gyöngyös (ninth grade) and Leőwey High School in Pécs (tenth grade). This year (2015) the 34th Mikola competition was held.

INTRODUCTION

Between 1978 and 1980 a new curriculum was introduced in Hungary. According to this curriculum physics began in the high schools at the ninth grade. In 1981 it was realized that there is no nation-wide competition in physics for the ninth and tenth grade students. To be able to identify students talented in physics as early as possible, it was desirable to organize one. In the following a short history of the competition and, to illustrate the spirit of the competition, an example from the problems of it will be shown.

SHORT HISTORY

Fig.1. Left panel: Lajos Kiss (1939-1995). Right panel: Márton Nagy [1]

International Physics Olympiad (IPhO) was established in 1967 by Czechoslovakia (Rostislav Kostial), Poland (Czesław Ścisłowski) and Hungary (Rezső Kunfalvy and Géza Tichy). When the Hungarian organizers were looking for new members for the students' Olympic team, they recognized that there is a need for a nation-wide competition in physics for the 9/10th graders. With the help of György Marx a new competition was founded for them. The two organizers of the finals were Lajos Kiss (Berze High School, Gyöngyös) and Márton Nagy (Berzsenyi Dániel Gimnázium, Sopron) Fig.1.

1981/82: The first competition was held with two rounds (regional and national). In the first round only two students per school could participate. The final was held with 40-40 participants. 1982-84: The competition was adopted by the Ministry of Culture as a nationwide physics contest for talent scouting. (Its Hungarian name was: Országos Középiskolai Tehetségkutató Tanulmányi Verseny, OKTTV). In the next academic year (1985/86) the competition had already got three rounds. In its first round the number of participants was not limited, and separate categories were introduced for high school and vocational school students. 1986/87: The competition got its present name after Sándor Mikola, the famous Hungarian physics teacher. The homepage of the competition (edited by Miklós Kiss) started in 1998. From 2001 it was edited by Gergely Kiss. In 2008 the four-day finals were changed to a three-day one.

ROUNDS OF THE COMPETITION

In the first and second rounds of the contest students should solve theoretical problems. Participants reaching a 50% result in the first round can enter into the second round where the best 40 or 50 students are selected for the finals of both grades. Finals are in 2 parts. The theoretical competition consists of some theoretical questions (problems). In the practical exam the competitors complete one or two experimental problems in a laboratory. Initially the number of first-round participants was a few thousand but unfortunately this number is decreasing continuously. The venues of the finals (Figs.2. and 4.) are the Berze High School in Gyöngyös (nine graders) and Leőwey High School in Pécs (ten graders), the latter was held earlier in Sopron.

Fig.2. Left panel: 1999 (Zoltánné Bóna, Dr. László Zsúdel, Béláné Farkas, Miklós Kiss). Right panel: 2000 (Miklós Kiss, Andrea Gyebnárné Nagy, András Mester, Dr. József Kopcsa, János Suhajda, Dr. László Zsúdel, Dr. Péter Czinder)

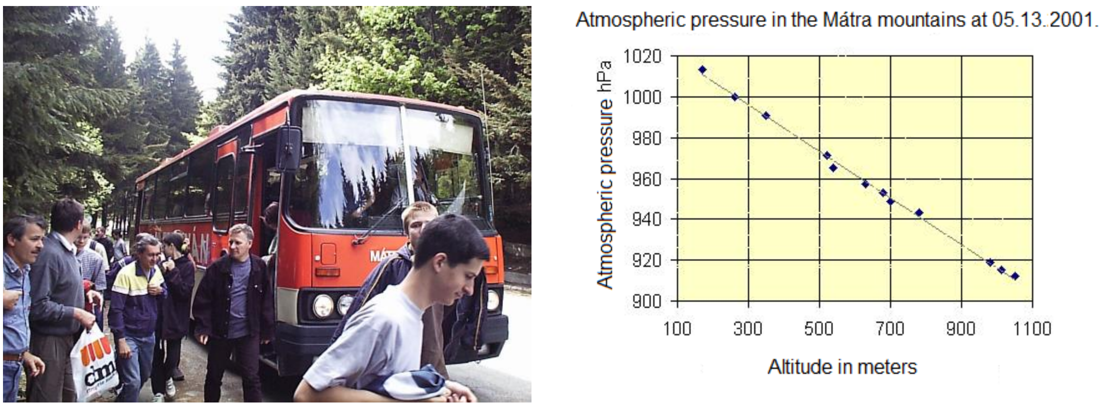

Fig.3. Left panel: 2001 A trip to Kékestető. Right panel: Air pressure in the Mátra Mountains

Fig.4. Left panel: Péter Simon, president of the jury and Ádám Varga, the winner in 2008.
Right panel: 2014 Measuring in the BERZELAB

The program of the competition often included a short excursion to the countryside where the participants performed physical experiments, too. Fig.3. shows the result of the atmospheric pressure measurement performed during a trip to the highest mountain of Hungary. The competition is closed with a ceremony of the announcement of the results. The ceremony begins with a scientific presentation which is delivered by a well-known Hungarian physicist. (You can see more pictures at the homepage [2]. A complete report about the 27th final is in [3]. Results, problems, measurements and solutions are in the references [2-10]).

EXAMPLE: THE MEASUREMENT TASK IN THE 33RD FINALS
Investigation of non-central collision of coins

Devices:

-1 pc 50 HUF coin

-1 pc 5 HUF coin

-2 pcs template to mark the centre of the coins

-1 pc short ruler

-1 pc long ruler

-1 pc triangle ruler

-1 pair of compasses

-2 pcs A3 measuring sheets of paper

-Blu-tack (glue)

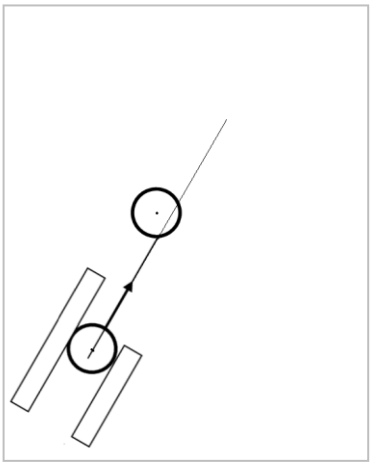

Fig.5. The arrangement of the coins and rulers

The measurement

Investigate the non-head on collisions of coins. The target coin is at rest, while the velocity of the other coin (the projectile coin) can be varied. Let the angle between the velocity vector of the projectile body and the line going through the centres of the coins be 45°. The figure (Fig.5.) and the measuring sheet prepared in advance help to set up. The initial and final position of the coins can be marked on the measuring sheet. It is advisable to fix the rulers with the blue-tech. Templates may help to mark the centre of the coins.

It can be assumed that the coefficient of kinetic friction is the same for every coin.

Make a plan for the evaluation of the measurement!

Tasks:

1. Verify that the velocity of coins is proportional with the square root of the covered distance.

2.

a) Collide the fifty-forint coin with the five-forint coin, which is at rest. Mark the positions of the coins at the moment of the collision and where they stopped.

b) Measure the displacement of the coins. (The direction of the motion of the projectile coin will also be required.)

c) Determine the velocities of the coins after collision. The velocities can be given in convenient arbitrary (freely chosen) unit.

d) Measure the angle of velocities after collision.

e) Construct the velocity of the five-forint coin. Determine the mass ratio of the fifty-forint and five-forint coins.

f) From the measured data determine the collision number (coefficient of restitution) and the energy ratio. (The latter is the ratio of the whole energy of the two coins after collision, divided by the energy of the projectile coin.)

3. How does the measurement verify the assumption concerning the coefficient of kinetic friction?

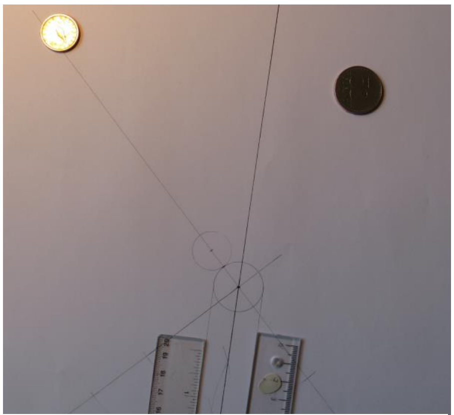

Fig.6. The initial and final position of the coins

The initial positions of the coins should be indicated in advance (Fig.6.). Draw the coins around and mark the centre of the coins with the template. Care should be taken to ensure that the displacement of the coins is determined relative to their own initial position.

Fig.6. shows the result of a collision. After the collision the coins are at rest. The position of the coins at the moment of the collision and the line of the projectile velocity inclining 45° to the line through the centres of the coins are also denoted in the figure. From the magnitudes of the displacements after collision, the velocities can be gained in arbitrary units:

$$\mathrm{v}_1 \sim \sqrt{s_1} \quad \text{and} \quad \mathrm{v}_2 \sim \sqrt{s_2} \tag{1}$$

Using the momentum conservation law for the collision we get:

$$M\mathbf{v} = m\mathbf{v}_1 + M\mathbf{v}_2 \tag{2}$$

where M and m are the mass of the fiftyforint and that of the five-forint coin, respectively. In the equation $\mathbf{v}$ and $\mathbf{v}_1$ are the velocities of the fifty-forint coin before and after the collision and $\mathbf{v}_2$ is the velocity of the five-forint coin. The momentum equation can be transformed to a velocity addition rule, where $\frac{m}{M}\mathbf{v}_1$ is called the modified velocity of the projectile coin:

$$\mathbf{v} = \frac{m}{M}\mathbf{v}_1 + \mathbf{v}_2 . \tag{3}$$

This provides a way of construction. Having known $\mathbf{v}_2$ (direction and magnitude), and the direction of $\mathbf{v}$ a parallelogram can be constructed and the value of $\frac{m}{M}\mathbf{v}_1$ can be determined. Comparing this with the magnitude of $\mathbf{v}_1$ the mass ratio can be obtained:

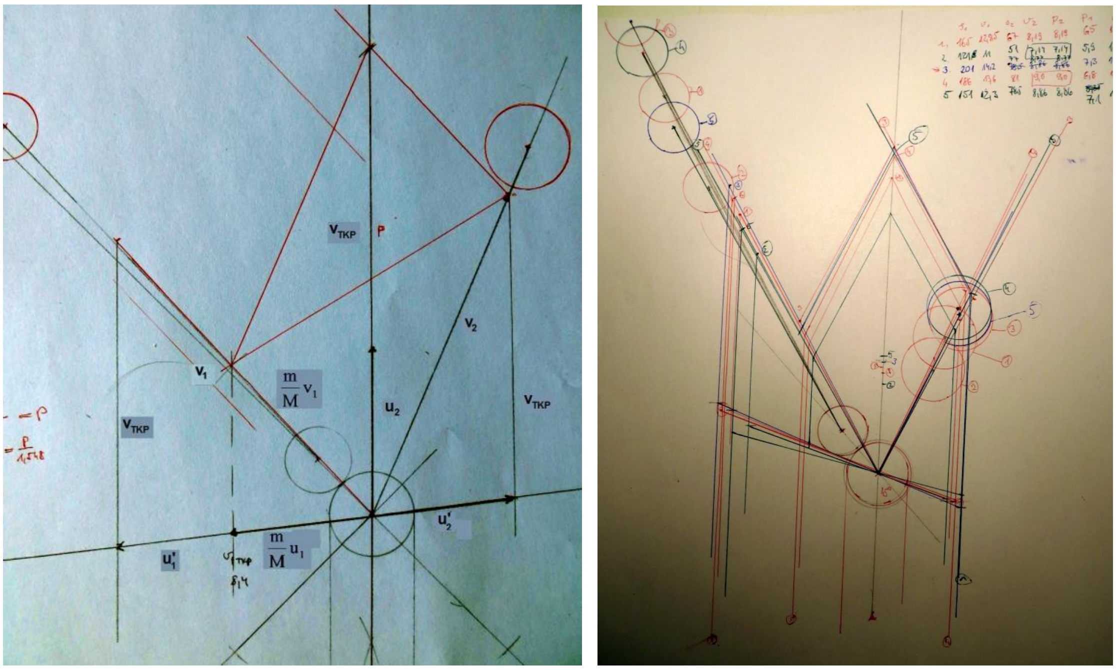

Fig.7. Left panel: Construction of the parallelogram from a measurement, Right panel: Construction of the parallelograms from many measurements

$$\frac{m}{M} = \frac{\frac{m}{M}v_1}{v_1}. \tag{4}$$

By the use of the mass ratio the velocity of the centre of mass can be determined.

$$(m+M)\mathbf{v}_{TKP} = m\mathbf{v}_1 + M\mathbf{v}_2 = M\mathbf{v} \tag{5}$$

$$(m+M)\mathbf{v}_{TKP} = M\mathbf{v} \text{ hence } \mathbf{v}_{TKP} = \frac{M\mathbf{v}}{m+M} = \frac{\mathbf{v}}{\frac{m}{M}+1} \tag{6}$$

Subtracting this from the velocities (cf. Fig.7.) we get the velocities in the system of the center of mass: $\mathbf{u}$, $\mathbf{u}_1'$ and $\mathbf{u}_2'$, $\mathbf{u} = \mathbf{u}_2 = \mathbf{v} - \mathbf{v}_{TKP}$. In this system the whole momentum of the colliding bodies both before and after the collision is zero. Therefore $\mathrm{mu}_1 + \mathrm{Mu}_2 = \mathrm{mu}_1' + \mathrm{Mu}_2' = 0$. Hence:

$$\frac{m}{M}u_1 + u = \frac{m}{M}u_1' + u_2' = 0. \tag{7}$$

It shows that the vectors which are on the same side of the equation are opposite ones.

Now we can calculate the collision number as well:

$$k = \frac{p_{2TKP}'}{p_{2TKP}} = \frac{u_2'}{u_2} = \frac{u_1'}{u_1} \tag{8}$$

The energy ratio is:

$$\varepsilon = \frac{\frac{1}{2}mv_1^2 + \frac{1}{2}Mv_2^2}{\frac{1}{2}Mv^2} = \frac{\frac{m}{M}v_1^2 + v_2^2}{v^2} = \frac{\frac{m}{M}s_1 + s_2}{s} \qquad (9)$$

where *s* is given from the square of the initial arriving velocity.

Table 1. Measurement data

	s1	v1	s2	v2	p2	p1	p	m	v_{TKP}	p_{2TKP}	$p_{2'TKP}$	k	s	ε	α
1.	149	12,21	131	11,45	11,45	6,7	15,3	0,55	9,88	55	46	0,836	234,1	0,91	66
2.	165	12,85	67	8,19	8,19	6,5	13	0,51	8,63	44,5	35,4	0,796	169,0	0,89	54
3.	121	11,00	51	7,14	7,14	5,9	11,5	0,54	7,49	40	32,5	0,813	132,3	0,88	58
4.	201	14,18	78,5	8,86	8,86	7,3	14,4	0,51	9,51	49	39	0,796	207,4	0,88	58
5.	186	13,64	81	9,00	9,00	6,8	13,9	0,50	9,28	42	36,5	0,869	193,2	0,90	56
6.	151	12,29	78,5	8,86	8,86	7,1	14,1	0,58	8,94	51,5	38,5	0,748	198,8	0,83	58
							average:	0,53				0,809		0,88	58,33
							deviation:	0,03				0,041		0,03	4,08

The actual mass ratio is $\frac{m}{M} = 0.555$. The calculated result agrees well with the real mass ratio of the coins.

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ON THE FIRST YEAR STUDENTS OF THE PHYSICS TEACHER TRAINING PROGRAMME AT EÖTVÖS UNIVERSITY

Cs. Wiener
Eötvös University, Department of Materials Physics, Budapest, Hungary,
kadar@metal.elte.hu

ABSTRACT

Eötvös Loránd University (ELTE) is the most prestigious university in Hungary in the field of teacher training. However, since there is no entrance exam, many physics students lack even an average level knowledge of high school physics. To overcome this problem new courses were introduced to the physics teacher training program, where high school physics is taught. Still, experience has shown that these courses are efficient only for approximately 40% of the students. The reason is that besides the absence of physics knowledge, students also have problems with mathematical knowledge, formal thinking and some basic skills, like reading comprehension, study skills, and note-taking skills.

INTRODUCTION

Most of the papers concerning physics teaching deal with teaching in high school or secondary grammar school. Since the introduction of the new university admission system in Hungary, questions of high school level teaching also appear on the undergraduate level.

One of the reasons is that physics students are admitted to the universities primarily based on the results of their high school final exams of two subjects of their choice from the following list: biology, chemistry, geography, informatics, mathematics, and physics. That is, students can be accepted at universities (including the most prestigious universities) without a significant background in physics. Moreover, the minimum score for admission is rather low for the physics-related courses, especially for the teacher training programme. In order to handle the situation, extra physics courses were introduced for students with incomplete high school physics knowledge. These extra courses were mandatory for approximately 70-80% of the admitted students.

In this paper some typical (high school level) problems are studied that were found hard-to-understand for at least 30 % of the students taking the extra physics courses. The observations are based on the monitoring of individual problem solution and midterm exams of approximately 20-40 students per semester for 6 semesters. Notice that the difficulties of the students arose not just when they first met the problems, but also when the problem types were already discussed in detail in class.

EXAMPLE 1. GRAPH-DRAWING, INTERPRETATION OF GRAPHS

Problem 1. A car is moving along the x-axis according to the graph of velocity versus time (Fig.1., left panel). Determine the position of the car as a function of time. The starting position is $x=0$ *m*.

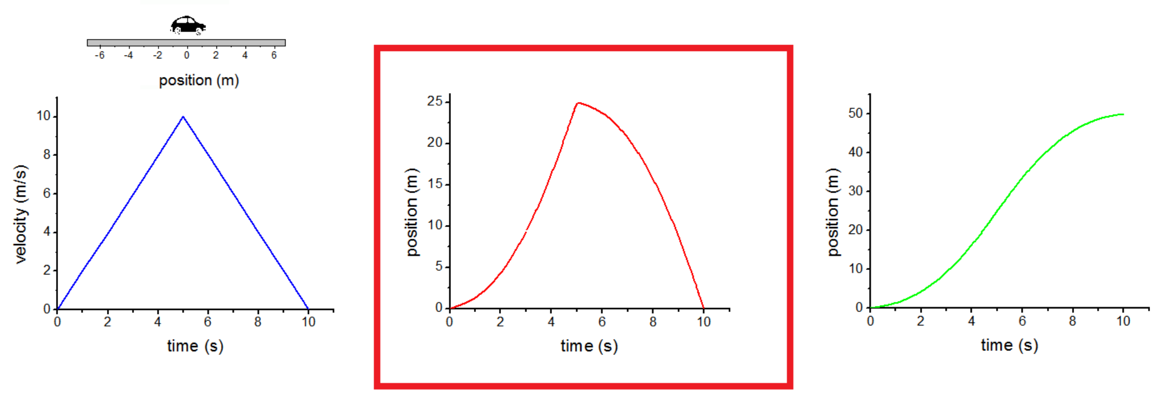

Fig.1. Motion in one dimension. Left panel: the velocity-time function given in Problem 1, middle panel: the typical incorrect answer, right panel: the correct solution

The middle panel of Fig.1. shows the typical incorrect answer. According to the (wrong) solution, after reaching the maximum velocity, the direction of the motion changes. The wrong answer originates from correlating the slope of the velocity-time function to the direction of the motion, i.e. if the slope of the function $v(t)$ is positive, the car goes in the positive direction, and in case of negative slope the direction of the motion is negative. However, it is obvious that the direction of the motion does not change, since the velocity is still positive.

In order to change this concept it is effective to link the negative velocity to an “activity-image”, e. g. to back up. The discussion of problems of the following kind is also useful.

Problem 2. Draw the velocity-time function of the following stories. Kati would like to go shopping. The shop is along a long and straight road.

a) First she rides on a bicycle. For 30 *s* she accelerates to 5 *m/s*, then rides at constant velocity for 15 minutes and when she notices the shop, she starts to decelerate for 20 *s*, then she stops.

b) Second she goes by car. It takes 2 minutes to accelerate to 20 *m/s*, then travels with constant velocity. Unfortunately she notices the shop too late, so after deceleration for 20 *s* she has to back up: she accelerates to 5 *m/s* for 1 s, then decelerates to zero to stop at the shop.

EXAMPLE 2. NEWTON’S LAW.

Problem 3. A hockey puck struck by a hockey stick is given an initial speed of 20 *m/s*. The puck slides 120 *m* on the ice, slowing down steadily until it comes to rest. Determine the coefficient of kinetic friction between the puck and the ice.

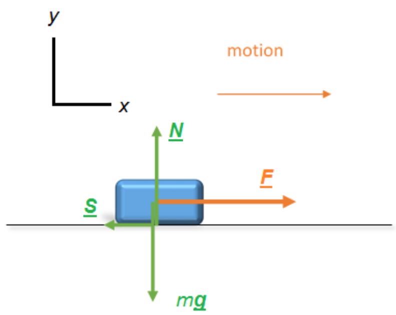

Fig.2. The free-body diagram of the motion of a hockey puck. The introduced force ***F*** indicates that the student uses Aristotle's concept of physics. (The vectors on the figure are a bit shifted for the sake of clarity.)

Since the puck moves to the right, many students think that there must be a force ***F***, which acts on the puck in the direction of the motion, and therefore they write Newton's law in the *x* direction in the following form:

$$F - S = ma, \tag{1}$$

where *S* is the friction force. This means that these students think the force is related to the velocity of the object, i.e. they use Aristotle's concept of physics.

One possibility to avoid the introduction of non-existing forces is to emphasize that force is the consequence of interaction. Here the puck interacts only with the ice (the origin of forces ***S*** and ***N***) and with the Earth (*m**g***). Therefore force ***F*** is not a consequence of interaction (in an inertial frame), thus it does not exist, so Newton's second law gives

$$-S = ma. \tag{2}$$

EXAMPLE 3. VECTORS, ABSTRACTION

Problem 4. A man pulls a 2 *kg* box on a frictionless incline with a horizontal force ***F*** (*F=20 N*) upward. The acceleration of the box is 3.66 m/s^2. Determine the angle of the ramp with the horizontal.

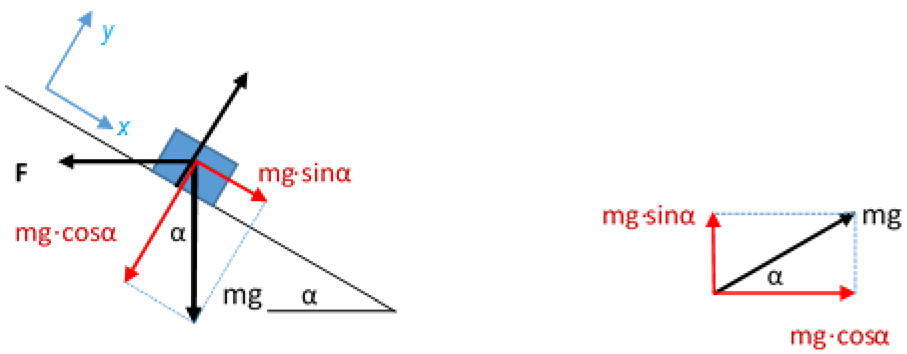

Fig.3. Left panel: The free-body diagram of a box pulled with horizontal force. Right panel: computing the components of the gravitational force in the "usual" coordinate system

The strategy to solve this problem is to compute the x- and y-components of the forces using trigonometry. (The x-axis is parallel and the y-axis is perpendicular to the slope.) By taking the sum of the x-components one can obtain the x-component of the resultant force, which is ma, according to Newton's second law. (Here m and a are the mass and the acceleration of the box, respectively.)

Approximately 35% of the students cannot determine the components of the forces in the tilted coordinates in Problem 4, though they can determine the components in the "usual" coordinate system (with horizontal and vertical axes) (Fig.3., right panel). Many students just memorize the x- and y-components of mg exerted on the object on a slope inclined at an angle α. These students typically lack the mathematical skills needed to solve an equation or an equation system, where the coefficients are not given constants, therefore missing the chance to understand how the result depends on the coefficients.

EXAMPLE 4. FRICTION FORCE

Problem 5. A block of mass $m=3\ kg$ is pulled by a string with a force $F=10\ N$ at angle α above the horizontal. Determine the coefficient of kinetic friction (μ), if the block/sled moves with constant velocity.

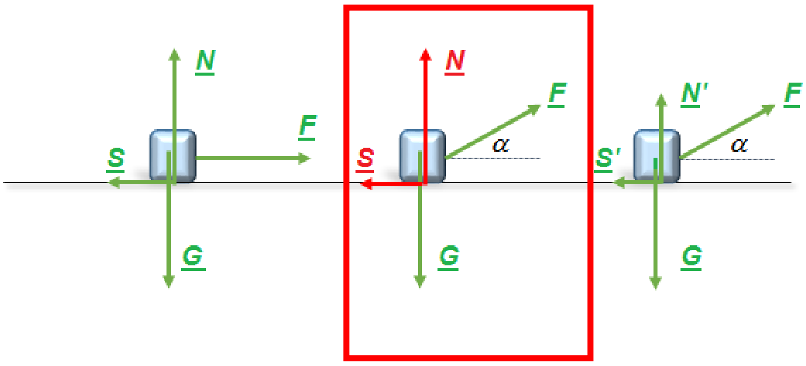

Fig.4. Changes in friction force and normal force as the angle of the pulling force is changing from zero (left panel) to α (right panel) and the typical incorrect answer (middle panel)

In the case of $\alpha = 0°$ almost everyone finds the correct solution. The two components (horizontal and vertical) of Newton's second law for the block/sled are:

$$F - \mu \cdot mg = m \cdot a = 0 \tag{3}$$

and

$$N - mg = 0. \tag{4}$$

However, many students use the same equations also in case of $\alpha > 0°$: $F \cdot \cos\alpha - \mu \cdot mg = m \cdot a = 0$ and $N - mg = 0$. These students think that changing the angle of the string does not have an effect on the friction force (and the normal force). As it is well known, the vertical component of the pulling force reduces the normal force to

$$N = mg - F \cdot \sin\alpha, \tag{5}$$

and therefore the friction force is

$$S = \mu \cdot (mg - F \cdot \sin\alpha). \tag{6}$$

Thus Eq. (3) must be changed to

$$F \cdot \cos\alpha - \mu \cdot (mg - F \cdot \sin\alpha) = m \cdot a = 0. \tag{7}$$

EXAMPLE 5.

Problem 6. A uniform horizontal beam of length 2 *m* and weight 300 *N* is attached to a wall by a pin connection that allows the beam to rotate. Its far end is supported by a cable that makes an angle of 30º with the horizontal. Find the magnitude of the tension in the cable. Indicate the forces acting on the beam.

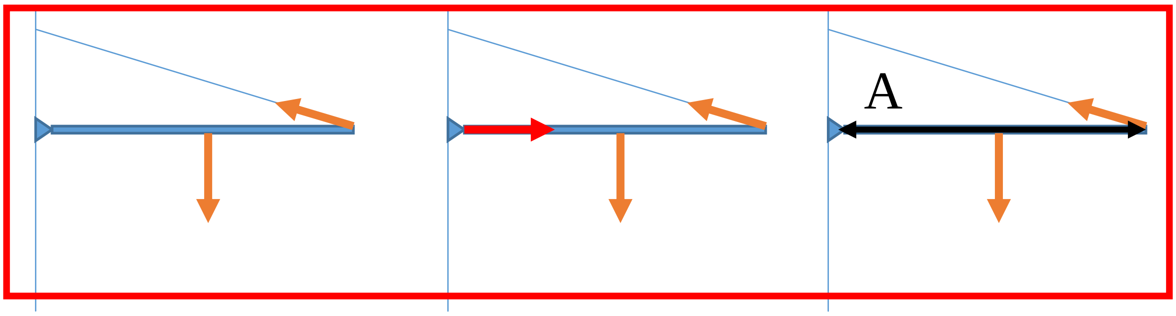

Fig.5. Problems emerging during the solution of Problem 5. Left panel: missing force, middle panel: misdirected force, right panel: wrong determination of the lever arm

More than 50 % of the students commit (at least) one of the following mistakes:

1) They forget about the force on the beam exerted by the wall, therefore on the free-body diagram only the gravitational force and the tension in the cable are identified. (Fig. 5, left panel).

2) They notice the force exerted by the wall, but they think its direction is the same as the direction of the beam (horizontal, in this case) (Fig. 5, middle panel).

3) During the calculation of the torque, the lever arm is taken as the distance between A and the point of application of the force, where A corresponds to the axis of rotation, perpendicular to the plane.

The first five examples suggest that the introduction of extra courses for approximately 70-80% of the students is unavoidable, since without these courses students cannot make up for their shortage in high school physics and mathematics. However, there are other types of problems as well. The average result of a test concerning definitions and formulae is about 60% if the test was announced before and 10% if it was not. It appears likely that this is caused by (besides the ever-present laziness and disinterest) the lack of studying skills. It is worth noticing that these results were obtained by students who chose to study physics. Solutions of midterm tests suggest that several students misinterpret or do not understand the problems, which may be caused by the low level of reading comprehension.

EXAMPLE 6. ABSTRACTION

Problem 7. An object weighing 100 *N* hangs tied to two cables that are fastened to the ceiling, as in Fig. 6, left panel. The cables make angles of 37º and 53º with the horizontal. Find the tension in the cables.

Problem 8. Four charges ($Q_1=Q_2=Q_3=-1\ C$, $Q=1C$) are placed according to Fig. 6, right panel. The distances from charge *Q* is 1 *m*, 2 *m* and 1.5 *m*, respectively. Is charge *Q* in equilibrium?

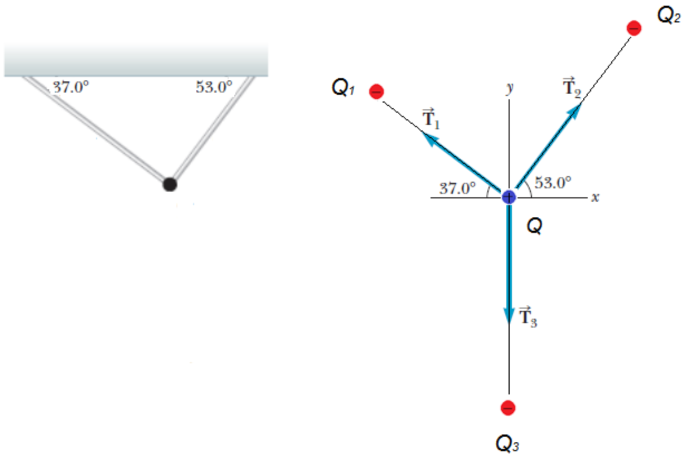

Fig.6. Left panel: object suspended by cables (Problem 7). Right panel: arrangement of charges (Problem 8)

The solution of equilibrium problems in mechanics is usually easy for the students if they do not have to use the concept of torque. But this is not the case if the topic is no longer mechanics. While 80% of the students solve Problem 7, only 20% of the students can solve Problem 8, though the two problems have the same free-body diagram. Most students can calculate the forces between the charges, but they think that the Coulomb's force is a force only in its name, so they do not use the strategies they used to solve Problem 7. Even after a detailed discussion of the problem still 40 % of the students are incapable of solving a problem of this kind.

Problems 3 and 6 suggest that capability of solving problems does not depend on just the physics and mathematics knowledge, but also on the cognitive structures of the students. It seems likely that a high percentage of the students are not operating in the domain of formal thinking, as was found in [1]. For students whose cognitive structures have not reached the formal thinking stage the extra courses are not sufficient, individual methods are needed.

CONCLUSIONS

Physics students are accepted at Hungarian universities without a significant background in physics. To handle this situation, high school level physics courses were introduced that are mandatory for approximately 70-80% of the students. We have shown several examples for problems arising in these courses that are caused by various reasons besides the lack of physics knowledge, such as problems in mathematics, reading comprehension, study skills. It also seems likely that the cognitive structures of many students have not reached the appropriate level.

ACKNOWLEDGMENTS

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