Informal method of the research skills improving on the example of students’ projects

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Abstract. It is well-known that appreciation of physics beauty starts since the early school age (usually from 7-12). At ECYGDA laboratory (which is an NGO situated at Karazin Kharkiv National University) STEM teachers together with students have been working on a vocational physics course for primary and secondary school children since 2007. The developing of research skills has been demonstrated on the example of two projects: Heron Fountain model and The Droplets Hovering Above The Vibrating Liquid which has been done by primary and secondary school students from the Centre.

The main goal of the activities described below is to trigger a kids’ motivation to do simple physics research projects beyond the school curriculum. During such kind of regular laboratory trainings pupils have the opportunity to obtain an insight into scientific methods of investigation, to conduct their own projects, and promoting their activities and investigations at the different local and international conferences.

1. Introduction
At ordinary Ukrainian secondary schools physics lab (both in lyceums and gymnasiums) experiments and demonstrations during the lessons are carried out with pre-assembled equipment. More than 60% of Ukrainian schools have got serious lack of equipment at the lessons (Kazachkova et al. 2000, Kazachkova 2007); Moreover, in most cases the experiments are demonstrated using pre-assembled instructions. In spite of the fact that those activities are supported by Ukrainian National Doctrine of Science Education, students who are gifted in experimental approach should also have the opportunity to choose and carry out the projects they have thought up themselves. Similar problems have been mentioned in some articles such as (Trna 2005, Premier 2006, Dvorak 2007). For that reason the ECYGDA Laboratory has been created. That is a centre for the primary and secondary school students of three age groups (7-11, 12-15 and 15-18 years). The centre offers a special support for realising simple research projects. The SPTC staff encourages children to take part in annual local University and international Conferences to report about their achievements. Since ECYGDA has not got a financial support from the Government however there are three main sources of an income: parents’ monthly beneficent payments (30% of total expenses), support from some Kharkiv Industrial Factories (40%) and private firms (30%).
There are some reasons for the faculty of Physics and Technology to participate at ECYGDA activities: to find out the pupils and secondary school students who are gifted for the STEM subjects, select and bring up them as future university students and prepare young generation to the future research work.

One of the main problem of Physics education in Ukraine since 1998 that the number of lessons a week was being decreased. For example since 2007 secondary school students have got 1 hour of physics a week instead of 2 even at the beginning of learning (6-7 forms). The situation for the senior classes are similar: from 4 to 2 (in 8 and 9 forms) and from 5 to 3 (at 10 and 11 forms). However the demands of the official school curriculum to the students’ skills and knowledge hold the same so there is a contradiction between a possibility for teachers to give their students the necessary knowledge and experimental skills under the stipulation of lack of time for that. From the other hands students who keen on physics and their parents wanted to stimulate their interest so creation of the ECYGDA laboratory had been actual and relevant.

2. Methodology

How the extracurricular trainings have been organised. The ECYGDA has agreements with 25 Kharkiv Secondary schools, where science communicators from the Centre with the help of University lecturers and students from the Faculty of Physics and Technology regularly demonstrate Physics Theme Shows, in a format of entertaining physics competitions related to the 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 regular trainings on Saturdays at the Laboratory. Those selected primary and secondary school students have regular (once a week) short theoretical lectures (45 or 60 min), giving by university teachers accompanied by practical training (90 min) led by university teachers or students. In addition all our students have 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 there are three stages of experimental skills development.

The first stage is for all invited primary school pupils from 7-11. There are usually two groups of 20-25 pupils at that stage. At our theoretical training we proposed them 13 interactive theme physics lectures which have been elaborated by the teachers from the Centre. All of them have been adapted 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 Mechanics, Travelling in Sound Land, Physics in the Kitchen, Light and Colours, Paradoxes of Magnetic Fields, Wonders of Electricity etc. At the beginning visitors became acquainted with simple physics principles and laws and then they are able to do simple experiments themselves. After 5 months training they choose a 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 Conferences. In 2016 the best project was: Light and Sound waves with the help of simple models and toys (prepared by two primary school students).

The second stage is for students from 12 to 15 who are selected by methods mentioned above from Kharkiv schools and lyceums. Every year we have one group of 30 persons at theoretical training and not all of them have managed to finish their project to the end. 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 use simple tools like hand-saw, boring mill, perforator, vernier callipers, testers. They design and produce some exhibits for Physics Exhibition (Kazachkova 2007) or for the events which are organised in their schools (Week of Physics, Science Picnic, Night of Science) under the leadership of university students from the Department of Physics and Technology and research engineers from the Scientific Physics and Technology Centre. They gain a lot from such practical trainings and their experimental skills are seriously
improved by doing self-made experimental projects using recycled materials, simple household objects or ordinary toys. In Fig. 1 you can see and compare the self-made exhibit called Heron Fountain which had been created at the first stage with the help of ordinary plastic bottles and the “Fountain” designed and produced at the second stage by the same student two years later. Those pictures give the opportunity to demonstrate and estimate how the student’s research skills have been developed during two years of vocational trainings mentioned above.

![Fig. 1.](image)

The third stage of theoretical and research skills development. The prevailing lack of interest in physics matters among adolescents from 14 to 18 is obvious and common not only for Ukraine but also for all developed countries (Sjoberg & Schreiner 2006, Trna 2005). It most notably manifests itself in the steady decline in the number of students at Physics Departments at all Ukrainian universities. So the number of students who stayed to do research projects goes down to 10-15. ECYGDA with its location at the University mentioned above combined with the possibilities, associated to this fact – use of the machine laboratories and the electronic repair laboratories at the SPTC, subject-specific support by scientists, lease of equipment has got lots of advantages not only in Kharkiv Region, but also in Ukraine. The best research project of this year was done by a 15 year-old student who had not got an additional theoretical maths preparations. But his experimental skills had been developed through four years of trainings and it was his second research project. It was chosen by the student himself from the list of problems proposed by the International Young Physics Tournament, IYPT. From our point of view the problem can be useful and interesting to repeat during vocational training in any country so the detailed description will be proposed below.

### 3. The droplets hovering above the vibrating liquid

**Problem formulation.** “Hydrophobic Water” sets a dish filled with soapy water onto a loudspeaker or other vibrator. When it oscillates, it is possible to hold small droplets on its surface for a long time. Explain and investigate the phenomenon.

**Literature analysis.** Hydrophobic liquids are those ones, which surfaces are extremely difficult to wet. Droplets of such liquids have to float above the free liquid surface. Paradoxically, if a droplet falls down on the surface of vibrating water it can fully rebound like an elastic ball and then the droplet floats above the surface for a long time just like a hydrophobic one.
The phenomenon is a very exciting and interesting to investigate, that’s why that problem can be proposed for the students’ investigation at the high schools or a research project for training beyond the lessons. In spite of the fact that the phenomenon depends on a lot of parameters each of them can be investigated and described. It has been interesting to determine the influence of a regime of insonification on the state of the water surface. And next, to find a correlation between this state and the floating time of the droplets. It seems that the most important characteristics that may be used for study of the phenomenon are:

- sound frequency and corresponding wavelength,
- amplitude of surface waves,
- pattern of a surface mode as a function of amplitude and frequency.

4. Experimental part

Objects of investigation are low-concentration soap solutions in water, which have been placed in a Petri dish. Droplets which hover above the insonified water surface have been produced in two ways: (i) using a medical syringe and (ii) spontaneous droplets creation at a high level of sound.

Experimental setup

The sketch of an experimental setup is presented in Fig. 2.

![Figure 2](image-url)

Fig. 2. Experimental setup. 1 – Petri dish with aqueous soap solution, 2 – kitchen scratch plastic tape, 3 – plastic box as a frame work, 4 – polyfoam pedestal, 5 – loudspeaker

It contains a mechanical part, self-made AC amplifier based on the TFA8943j chip, sound frequency generator as computer software. The relative amplitude of the electrical signal supplied to the loudspeaker was measured by a digital tester. Time of the droplets floating was registered by a stopwatch.

Surface peaks measurements

Subject to the actual magnitude of surface waves they have been measured using two methods: (i) side view photography for the large magnitudes, and (ii) laser grazing beam reflection for smaller ones. The scheme of the last method is presented in Fig. 3.

![Figure 3](image-url)

Fig. 3. Experimental setup for surface waves detection of a small amplitude using grazing beam laser probe
The obtained results allowed the determination of the relationship between measured values of relative voltage amplitude on the loudspeaker and frequency of the sound with the actual amplitudes of the surface waves.

5. Theoretical part

Model
In order to describe the effect of droplet floating it has been supposed that there is a thin air interlayer between the surface of the liquid (water in our case) and a droplet. Time needed for the droplet to coalescence to the main volume is the time when the distance between two surfaces exceeds a certain threshold. That time the air in the interlayer is squeezed out in the conditions of viscous flow. Equilibrium form of curved liquid surface under the droplet and form of the droplet itself are the topic of enough complicated calculations that may be implemented numerically only. Here we only estimate the influence of individual model parameters (geometry sizes and matter properties) on the lifetime of a droplet.

Usable geometrical parameters are presented in Fig. 4c. A curved liquid surface is modelled as a spherical indentation with deepness $h$, radius of edge circle is $R$, and spherical radius is $R_{\text{drop}}$. The last is also the radius of the droplet, which is believed to be spherical, the form distortions have been ignored.

**Fig. 4.** Distribution of the velocities $v_x(y)$ in the viscose flow between two parallel plates distanced on $l$ (a). Scheme of a viscous substance efflux from the space between parallel discs during the process of their closing (b). Schematic representation of a droplet hovering on the surface of liquid (c)

Theoretical estimations
At lamellar flow of viscous media along a space of a height $l$ between two parallel planes in the direction $x$ (see Fig. 3a) has been described by the following equation:

$$\frac{P(x) - P(x + \Delta x)}{\Delta x} = \mu \frac{8v_{\text{max}}}{l^2},$$

where $P(x)$ is the normal pressure, and its loss along the direction of a flow has been expressed via the coefficient of dynamic viscosity $\mu$ and the maximal velocity of the flow in the center of the space $v_{\text{max}}$. The velocity distribution under those circumstances along a vertical direction $y$ can be described by the equation:

$$v_x(y) = \frac{4v_{\text{max}}}{h^2}(yh - y^2),$$

which allows to determine an average velocity $v_{x,\text{ave}} = 2v_{\text{max}}/3$.

In the case of a viscous media an efflux from the space between two closing discs, a radial velocity and the normal pressure distributions keep their functional binding. So we can rewrite the equation written above with polar coordinates:
The continuity equation requires that a volume of the viscous medium flowing through the cylindrical lateral border has to be equal to the loss of the space between the disks, so \( v_{\text{ave}}(r) = rU/2l \), where \( U \) is a velocity of the discs closing (Fig. 3b). Putting this equation into (1) and integrating it results in the explicit form of the radial pressure distribution function:

\[
\Delta P(r) = \frac{12 \Delta v_{\text{ave}}(r)}{l^2}.
\]

(1)

Because of the global character of \( P_{\text{atm}} \) we can exclude it from the further consideration keeping the part connected with the viscosity only:

\[
\bar{P}(r) = \frac{3U}{l}(R^2 - r^2).
\]

(2)

The force of the discs closing has been calculated by integration of (2) from 0 to radius of the disc \( R \):

\[
f_p = \mu \frac{3\pi UR^4}{2l^3}.
\]

(3)

For the task of the droplet on the liquid surface \( f_p \) is its gravity force \( \frac{4}{3} \pi R^3 \rho g \). So, the expression for the quantity \( U \) may be easily obtained from (3):

\[
U = \frac{8}{9\mu} \rho_{\text{water}} g l l_1 \frac{4R^3}{R^3}.
\]

(4)

The time of a motion \( t \) of the droplet while \( l \) exceeds some threshold value \( l_t \) has been calculated by integrating the reciprocal velocity \( U^{-1} \), so called slowness. The result can be seen in the formula below:

\[
t = \frac{9\mu}{8\rho_{\text{water}} g} l l_1 \frac{R^4}{l_1} \frac{1}{16g l l_1 \rho_{\text{water}}} \frac{R^4}{R^3}.
\]

(5)

For the estimation of \( R \) the principle of the potential energy minimum have been used. Potential energy of a droplet on the curved surface of liquid in frames of above mentioned model limitations (see Fig. 3c) has a form:

\[
E = \pi \rho_{\text{water}} g \left( \frac{1}{12} (4R_{\text{drop}} - h)h^3 - \frac{4}{3} R_{\text{drop}}^4 h \right) + \pi \sigma h^2,
\]

Where \( h \) is immersion depth of a droplet in the liquid, and \( \sigma \) is the coefficient of surface tension. Minimum is achieved at the conditions:

\[
h^3 - 3R_{\text{drop}} h^2 - \frac{6\sigma}{\rho g} h + 4R_{\text{drop}}^3 = 0.
\]

The value \( r_0 = \sqrt{6\sigma/\rho g} \) can be interpreted as characteristic radius, which for the water at 20°C has value 6.68 mm (\( \sigma = 72.9 \cdot 10^{-3} \text{ N/m}, \rho = 1000 \text{ kg/m}^3, g = 9.81 \text{ m/s}^2 \)).
can be expressed by \( h \) and \( R_{\text{drop}} \) as \( R = \sqrt{2hR_{\text{drop}} - h^2} \). It is convenient to represent above equation in dimensionless variable \( \xi = \frac{h}{R_{\text{drop}}} \):

\[
\xi^3 - 3\xi^2 - \left(\frac{r_0}{R_{\text{drop}}} \right)^2 \xi + 4 = 0.
\] (6)

Its physically allowed root lies in the range 0-1. Analysis showed, that for \( R_{\text{drop}} \ll r_0 \) the root has asymptote \( \xi = \left(2 \frac{R_{\text{drop}}}{r_0} \right)^2 \). That gives also the asymptotic behavior of \( R \):

\[
R \approx 2\sqrt{2} \frac{R_{\text{drop}}^2}{r_0}.
\] (7)

Substitution (7) to (5) leads to the equation:

\[
t = \frac{36\mu R_{\text{drop}}^4}{g l_1 \rho_{\text{water}} r_0^4}.
\] (8)

Numerical calculation for the water droplets shows that the dependence \( R(R_{\text{drop}}) \) is only slightly deviates from the asymptote (7) as can be seen in Fig. 5.

![Fig. 5. The graphs of R by R_{\text{drop}}: squares – calculation using equation (6), red straight line is asymptote.](image)

**R** is the radius of the contact circle between droplet of radius \( R_{\text{drop}} \) and the surface of liquid.

### 6. Results and discussion

The analysis given above shows that the life time of the floating droplets depends on their radii essentially. Moreover the quantity \( t_0^4 \) in the denominator of (8) corresponds to the inverse square proportionality of a droplet lifetime to the coefficient of surface tension. Experiments were carried out mainly with one concentration of a soap solution. Experimental investigation of the surface tension influence on the behavior of this physical system is an open question.

The fact that the drop can hover a long time on the insonified surface of the liquid occurs due to frequent jumping, during which an interlayer of air insulating droplets from the surface is restored. It may occur only in the conditions when surface oscillation imposed acceleration to the droplet greater
than the free fall acceleration. That is why we investigated parameters of waves on the liquid surface. Unfortunately surface waves depend in a complex way on intensity and frequency of the sound. Fig. 6 represents some examples of different surface wave modes. Such variety of behavior complicates investigations and requires examining of each type of surface mode.

![Fig. 6. The photographs of different modes obtained at low 20 Hz (a, b) and high 150 Hz (c) frequencies of sound. The modes in (a) and (b) are produced at the same frequency, but different intensity of a sound. Pattern (a) appears at lower intensity.](image)

In the limit of low frequency and long wavelength droplet time of life is strictly dependent on its position. That is because the surface mode pattern contains areas with high amplitude of oscillation (loops) and small one (nodes). Our observations have shown that at favorable conditions (area of a loop) the lifetime of a bounced droplet can exceed several tens of minutes.

Photos of low-frequency mode patterns are shown in the Figs 6a and 6b. At the intensive insonification and high frequency the self-organized structure of nodes and loops on the surface of the liquid looks like a two-dimensional square lattice (Fig. 6c). Survival of a droplets under these conditions is caused by the fact that distances between loops becomes smaller than the droplet dimension, so in any position the droplet experiences action of the surface. Examples of the observed hovered droplets are presented in Fig. 7.

![Fig. 7. The photographs of droplets that live a long time on the insonificated aqueous surface.](image)

Experimental observations and research project presented in this part of article are only the start of the investigation that will be continued in future. Of course the informal teaching techniques described in the article are not able to decide the problem of decreasing students’ interest in physics. Only 15 students stayed at the third stage of preparation and usually nearly five of them throw their career with IT or enter the other universities on STEM specializations but every year the Faculty mention above
bring up about 10 particularly motivated, with a strong interest in science and developed research competences who desire to connect their future life with research career.

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