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Computer-assisted school experiments as a method for improvement of students' knowledge in mechanics and atomic/molecular physics in secondary school

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We investigate the possibility to improve the effectiveness of school teaching in physics by means of introducing a partially computer-based learning experiment. More specifically, we focused on the preparation and implementation of laboratory exercises in the fields of "Mechanics" and "Atomic/molecular physics" according to the educational content in physics in secondary schools in Bulgaria. The laboratory practicum which we offer for implementation was performed by a small group of 10-th grade (16-year old) students and we present the results as a case study. The pre- and post-practice survey identified areas where significant improvement was observed, as well as some that require additional approaches to overcome difficulties. The results of the research confirm the formulated hypothesis and give reason to claim that the use of a physical experiment in physics education leads to improving the understanding of the basic concepts in the field of mechanics and atomic/molecular physics; improving skills for working with certain devices and computer programs; creating a better understanding of scientific experiment and its relationship to the physical theory.

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1. Introduction

The present article introduces the results on investigation of the effectiveness of school teaching in physics with a partially computer-based learning experiment. More specifically, we focused on the preparation and implementation of laboratory exercises in the fields of "Mechanics" and "Atomic physics" according to the educational content in physics in secondary schools in Bulgaria. In our present work, we focus on molecular, rather than atomic spectroscopy, and the reason for this is not only that molecular samples are more readily available, but also they are more familiar to students in their everyday life experience, while at the same time from a spectroscopic point of view they are equally informative.

The work constitutes a continuation of a work reported in [1, 2], where two problem areas are identified in the understanding of the teaching material on mechanics in the general secondary school education in physics, namely the application of the principles of mechanics and some essential properties of harmonic oscillation. In the present work we extended our activity by expanding the mechanics practicum and including an additional area to be tested, namely atomic and molecular physics. It has been previously shown that problematic issues in the understanding constitute the explanation of atomic models [3, 4] and atomic spectra [5, 6]. A pedagogical experiment carried for one month with Bulgarian 10th grade students (48 students) (the topic of atomic physics is covered in the 10th grade in the Bulgarian school, corresponding to an average age of 16) supports these findings [7]. The main research objective there was to quantify the level of knowledge and skills achieved by the students in the field of atomic and nuclear physics by using a variety of interactive methods and approaches. The results of the conducted study showed that for better learning of the educational material in connection with atomic transitions and spectra, the 10th grade students need more than one approach in learning – preferably experimental.

Based on these preliminary studies as a motivation, we combined this idea with the computer-assisted experimental approach and developed experimental settings and questions to test the students' understanding of the atomic physics study material. In the experimental setups, we use a computer (controller) in two ways – as a replacement of a measuring device (i.e. timer), and also for data acquisition, processing and visualization, more specifically in the analysis of spectral data related to the material studied in the section "Atomic Physics" for 10th grade. The laboratory work offered in optics and atomic/molecular physics is interdisciplinary, as it includes areas such as physics, computer and information technology and mathematics. This will lead to establishment of a better idea about the real science experiment among students, as well as its relationship with physical theory.

After setting up and approbating the laboratory setups, a didactic experiment was conducted with students from 10th grade of the Sofia High School of Mathematics "Paisiy Hilendarski". The number of students was very small (12) and therefore we do not apply statistical processing of the experimental data, but we will describe the pre- and post-test method rather as a case study.

2. Hypothesis testing

The hypothesis we check with the present work is that computer-based school experiment will lead to an increased interest and better understanding of the studied material. This is realized by comparing the results from testing of students’ knowledge of atomic physics and mechanics before and after working on the laboratory setup constructed specifically for this purpose. The students who participated in the didactic experiment conducted a laboratory practicum including six laboratory exercises. At the beginning of the experiment and after the practicum the students completed a questionnaire that tested their knowledge in the field of mechanics and atomic physics targeting levels of remembering, understanding and application according to the Bloom's taxonomy [8]. The questionnaire, which is designed to test the working hypothesis, includes nine questions from section "Mechanics" (Part A), seven questions from section "Atomic Physics" (Part B) and seven questions about attitude to experimental work (Part C), completed only as post-testing.

3. Description of the spectroscopy laboratory setup

First, we will describe the experimental setup related to the study of light spectra as a tool for explaining and understanding atomic models. The setups for the mechanics exercises will not be given in a separate section, rather they will be mentioned with the description of the relevant test results. Fig.1 is a sketch of the experimental setup and Fig.2 presents the scheme for registration of emission, transmission and fluorescence spectra, with subsequent calculation of absorbance spectra.

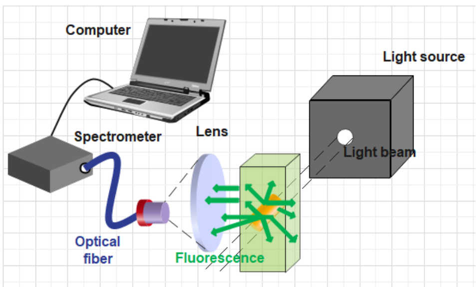


Figure 1: Laboratory setup for the spectroscopic school experiments

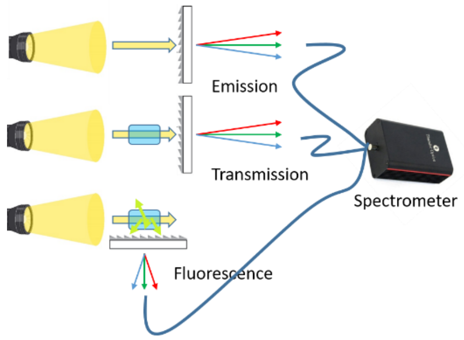


Figure 2: Schematic representation of the registration of emission, transmission and fluorescence spectra

The setup includes a ThunderOptics SMA-E spectrometer with an optical fiber and an optional collimator input. The spectrometer has an USB output to a computer with an appropriate software for spectra visualization and data export. The following emission sources were used: solar light, "white" LED source, luminescence light tubes, several LEDs (with wavelength from 380 to 630 nm), He-Ne laser generating at 632.8 nm. The absorbers for the transmission measurement were red wine and an ethanol solution of fluorescein. The materials used for fluorescence measurement were fluorescein, olive oil, rum and tonic, placed in plastic cuvettes and excited by a 405 nm diode.

4. Lab report results from the spectroscopy laboratory exercise

Here we present briefly some of the obtained spectral data exercise outcome results, later used for analysis and discussion by the students. Fig.3 presents emission spectra, where (a) is a comparison of a "white" LED with a luminescence tube (intensities normalized), and (b) presents the difference in the spectra of a LED and a laser with practically the same central wavelength.

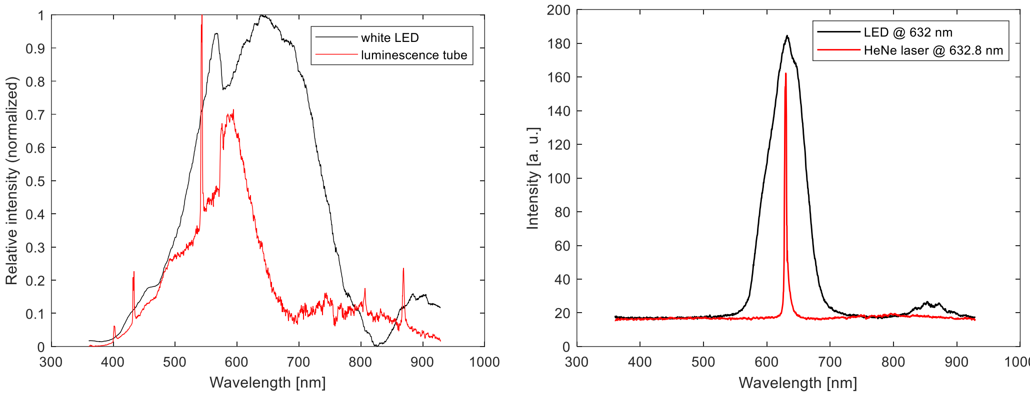


Figure 3: Emission spectra recorded. (a) “white” LED source and luminescence tube (intensities normalized), and (b) LED and laser.

Fig. 4 presents transmission of fluorescein (the results were similar with red wine). Fig.5 presents four fluorescence spectra obtained by using the collimator.

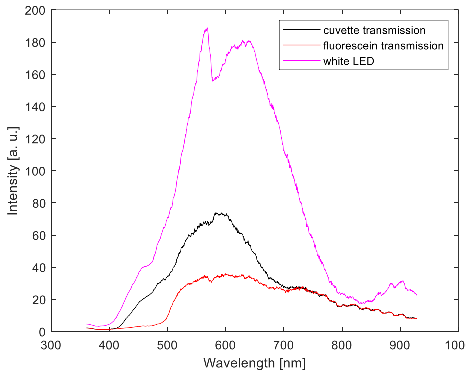


Figure 4: Transmission spectra of empty cuvette and fluorescein

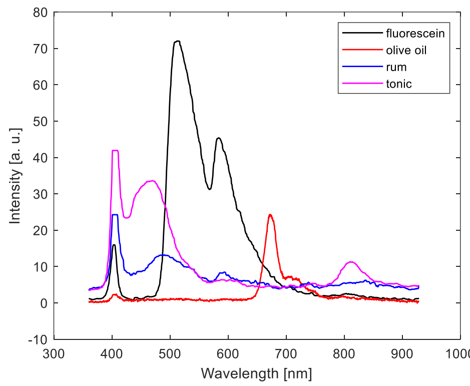


Figure 5: Fluorescence spectra registered

Theoreticaly, it should be possible to estimate the dye absorption from the transmission signal of the empty cuvette and the cuvette with dye, but this would yield correct results only for a spectrometer signal which is intensity-calibrated and not saturated, and also when the excitation spectrum is rather flat in the region of intrest, which is not true in our case. More specifically, for the spectrometer spectral sensitivity, there is a hardware-related decrease in the region around 550-560 nm. We have made a very preliminary correction for the transmission signals using a tungsten light source (not shown) calibration against a professional Ocean Optics 4000 spectrometer. The dips in the fluorescence signals for fluorescein, rum and tonic in Fig.5 are an example of these arfetacts. Work is in progress for a software correction which would make possible to perform more correct relative intensity measurements.

5. Spectroscopy pre- and post-test results analysis

In this section we will present the results of the students' work related to the spectroscopy laboratory exercise. The students' understanding of this learning material was assessed by using Tasks (Part B of the survey).

Generally, the students showed an improvement in their understanding of the learning material after conducting the laboratory experiments. Only the first question has a negative result: the number of wrong answers on the post-test is slightly increased compared to the pre-test – an absorption spectrum is indicated instead of an emission spectrum (Fig.6.).

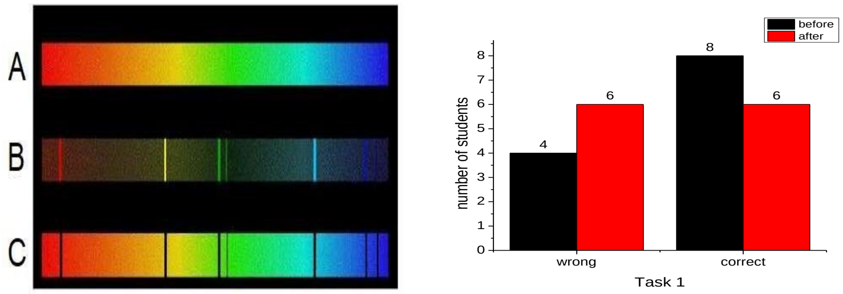


Figure 6: Figure from Task 1 from Part B of the questionnaire and answers of this question on the pre- (black) and post- (red) testing.

As shown in Fig.7, there were no wrong answers after the laboratory work on the questions related to:

• the phenomena of thermal radiation, photoeffect, dispersion and fluorescence (Task 2) – 3 wrong in the pretest;

• absorption/emission of a ground state atom (Task 3) – 4 wrong in the pretest;

• connection between frequency and wavelength of the light waves (Task 5) – 7 wrong in the pretest;

• application of the energy conservation law in the case of absorption and emission of photons with respect to their colour (Task 7) – 2 wrong in the pretest.

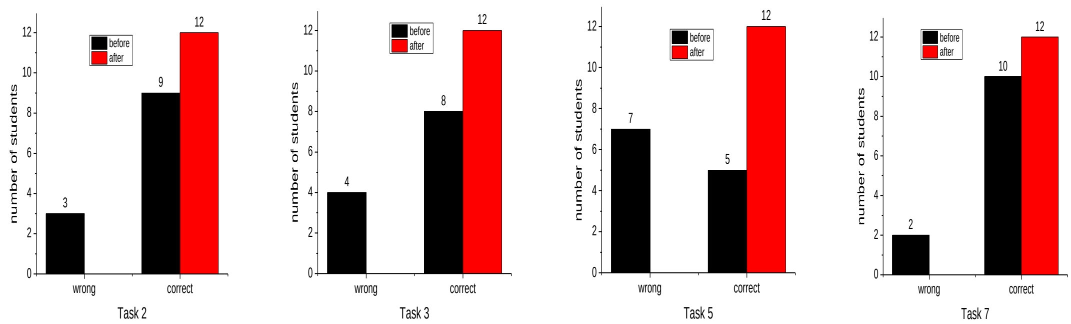


Figure 7: Answers of the questions 2., 3, 5.and 7. from Part B of the questionnaire

Regarding the question about identification of hydrogen spectral line series, the correct answers increased, but still four of the students did not demonstrate improvement in understanding (Fig.8 – Task 4). The same applies for the question about calculation of emission photon energy from the energy level diagram (Fig.8 – Task 6). We suppose (and this was confirmed by an interview with three of the students) that the reason for this is that students are confused by the negative energy values for the levels. Although they have mentioned at school that a negative value for the energy means that energy must be supplied to the system for the electron to overcome the attractive force of the nucleus, still this is not a notion fully comprehended by the students.

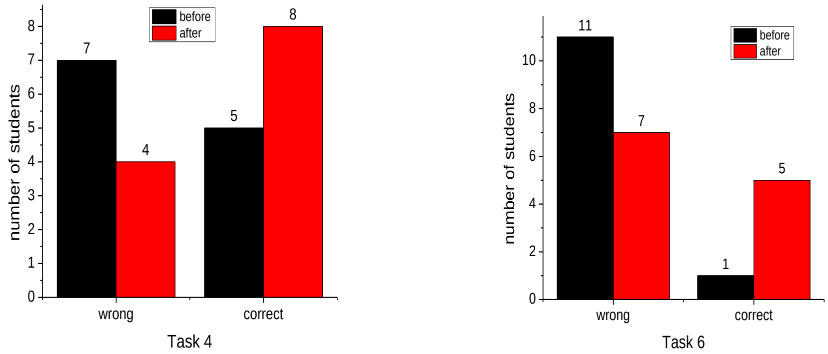


Figure 8: Answers of the questions of Tasks 4 and 6 from Part B of the questionnaire

6. Mechanics setups and test results analysis

The results of the questionnaire give reason to assert that there is an improvement in students' understanding, not only about the phenomena from the field of optics and atomic physics, but also from the field of mechanics (Part A). The questions from Part A of the questionnaire can be grouped into the following categories:

• determination of forces, determination of equivalent force and connection with the acceleration of a moving body through Newton's second principle and through kinematically measurable quantities;

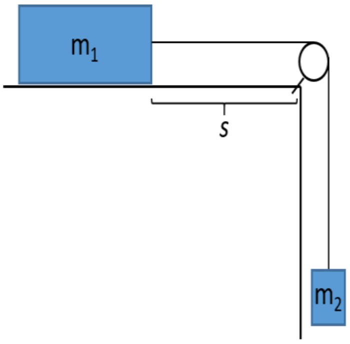
• characteristics of harmonic oscillation – period, dependence of the speed on time, characterization of the type of motion;

• measurement errors – determination of blunders, data selection for fitting (rejection of blunders), writing down the experimental result with error, minimizing error by multiple repetition and determining a reasonable (optimal) number of repetitions.

The laboratory setups used for the mechanics practicum are: (1) The sketch shown with reference to Question 3, where the friction forces are neglected; (2) The same diagram but with non-negligible friction forces. These exercises included deriving and determining the acceleration of the mass system using the connection between dynamic (forces) and kinematic (measurable parameters) expression of acceleration. (3) The third exercise was to calculate the Earth acceleration by measuring the time of free fall. For the three exercises, Adruino controller was used with two photo-gates and a display showing the time between consecutive activation of the gates. (4) The fourth setup was a model for mathematical pendulum realized in bifilar configuration, with a photogate trigerring the counted of a controller at equilibrium position of the bob. The output was taken for two triggering signals, thus values corresponding to the period of oscillation were recorded and then exported to the computer for post-processing (i.e. testinc the isochronical oscillation even for large number of periods when the amplitude visibly decreases). (5) The fifth setup was designed for producing strongly damped oscillation by using a magnet as a bob and oscillating it past a metal rail.

Below we will present the comparison of the pre- and post-testing answers to some of the questions in Part A ("Mechanics").

Question 3. Body 1 begins to move with friction on a horizontal surface. The friction force is equal to the coefficient of friction k multiplied by the size of the normal reaction.



A) Draw and denote the forces acting on the bodies

B) Determine the equivalent F of the forces applied to body 1 in terms of the masses of the two bodies $m1$ and $m2$ and the coefficient of friction k on body 1 with the surface.

C) Write down the second law of mechanics by using the expression for the acceleration a from task 1b and the measurable quantities (the masses m_1 and m_2, the distance s and the time t).

D) Write down the expression for the coefficient of friction in this case by using the measured quantities.

After completing the laboratory exercises from the practicum, the majority of students drew the forces correctly (9 out of 12 students), three gave a partial performance, and there was no one who refused to determine the forces. An improvement was also observed when expressing the second principle of mechanics through the kinematic parameters – initially only one student derived a correct expression, while after the laboratory exercises more than half of the students managed it (Fig. 9). Thus, we came up with the conclusion that even with some inaccuracies, the picture of the acting forces begins to form in the students consciousness, and they gain confidence to show this on the tests.

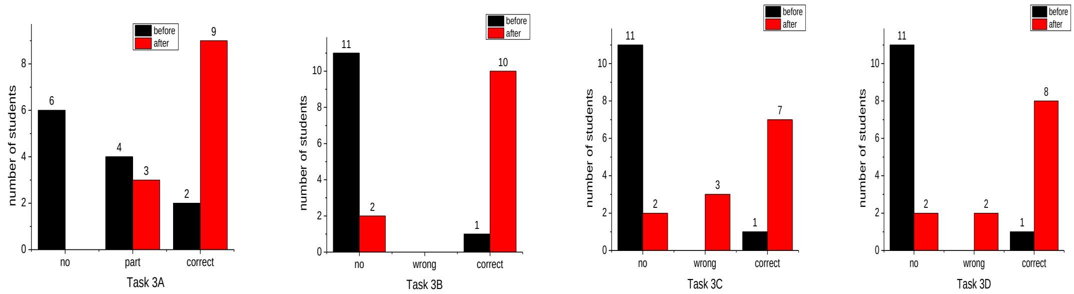


Figure 9: Answers of the questions 3 from Part A of the questionnaire

The questions related to the parameters of harmonic oscillations were also three, two of which the students did better after the conducted practicum. Surprising responses were received to question 6 of Part A of the questionnaire, preceded by question 5, which students answered correctly. Below we set out questions 5 and 6.

Question 5. Which of the figures represents correctly the dependence of speed on time in harmonic oscillation?

A) Fig. 10 a.
B) Fig. 10 b.
C) Fig. 10 c.
D) Fig. 10 d.

PoS(BPU11)249

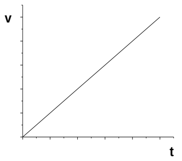


Fig. 10 a

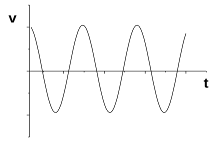


Fig. 10 b

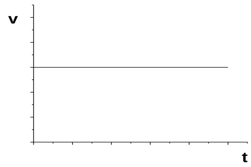


Fig. 10 c

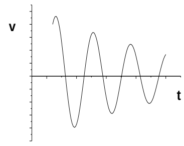
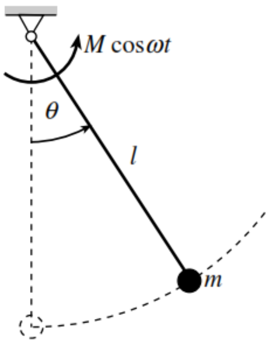


Fig. 10 d

Figure 10: The figure for question 5 from Part A of the questionnaire



Question 6. A ball hung on a string is deflected from its equilibrium position and it is released to move. In its movement towards the equilibrium position, the body is described by:

A) constant acceleration motion
B) constant deceleration motion
C) uniform motion
D) none of the mentioned.

Almost all the students pointed out to question 6 answer A) "constant acceleration motion". They correctly state that the dependence of velocity on time in case of uniform acceleration is a straight line (with a positive angular coefficient). On the other hand, it is interesting that on the previous task (task 5, printed on the same page), they correctly indicated a sinusoidal dependence of the speed during oscillation (answer C in Fig. 10 b). This shows that the students not only didn't make a connection between the two tasks, but they most probably would not make a difference between accelerating (general) and uniformly accelerating (particular case) motion unless it is specifically pointed out to them. What is the reason for this? Apart from the fact that iso-variable motions have been studied in school for a much longer time and are associated with motion with acceleration in principle, we believe that there is another explanation that lies not in physics knowledge, but rather in the psychology of students when solving tests. Specifically, students a priori rule out the absence of a given correct answer among the listed distractors.

The following three question of Part A of the questionnaire are related to the understanding of errors in the measurement of physical quantities. Two questions are connected with formal denoting and error assessment. After the practical exercises, the results show that the students have developed an intuitive sense of blunders and the idea of excluding them from the processing of the results has already been formed as an ideology.

The final task of this section of the questionnaire is also indirectly related to error estimation. The results showed that the students perceived the limit of increasing accuracy with multiple measurement.

We were interested to check out if there would be a difference in the understanding of isochronicity of oscillations after doing the laboratory exercise with examining the period of the mathematical pendulum model over time. The question which the students had to answer was connected with selecting of factors that limit the number of repetitions they would probably make when measuring a period of a pendulum in order to reduce the time measurement error with a stopwatch. After choosing a proper interval of repetitions, they are given the following suggested factors:

A larger / smaller number of periods is avoided because:
- *reaction speed when working with the chronometer;*
- *reduction of the oscillation amplitude with time;*
- *reduction of the oscillation period over time;*
- *increase in oscillation period with time;*
- *shorter time to conduct the experiment.*

In the previous study, the results showed that more than half of the students associated the decrease in the oscillation amplitude with a change (increase or decrease) in the period [1], with no significant improvement in the correctly listed factors after laboratory exercise. In the current study, the laboratory practicum was completed with a new laboratory setup that allows the study of damped oscillation, for comparison with the harmonic oscillation model of a mathematical pendulum. A metal construction protractor was mounted on a tripod, to the center of which a small strong neodymium magnet is attached in a bifilar thread configuration (Fig. 11). The magnet can move both inside a rail and along a metal plate, in which Eddy currents are induced.

The experimental setup enabled students in the present study to obtain the magnitude of 150 consecutive periods of the pendulum and to process the obtained data with a computer program. This led to increased understanding of the processes, evident from the results shown in Fig. 12.

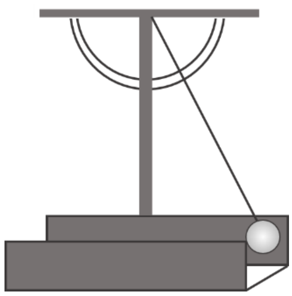


Figure 11: Scheme of the experimental setup to research of damped oscillation

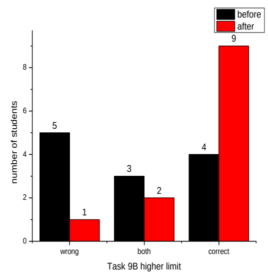


Figure 12: Answers to question 9 of Part A of the questionnaire - reason for choosing an upper limit of measurements of a physical quantity

It can be seen that the completely wrong answers have decreased, and the proportion of correct answers has doubled. Also, some students marked two possible factors, one wrong and one true. The part of these answers also slightly decreases at the expense of the completely correct ones.

Here we would like to point out the students' surprise at finding the isochronicity of the pendulum oscillations. This confirmed to a large extent also our hypothesis that the direct comparison of the data on the oscillation period of the bifilar pendulum (used as a mathematical pendulum model) after a large number of oscillations (so that its amplitude visibly begins to decay) with the behavior of a classically performed damping oscillator will help to change the incorrect association of the decrease in amplitude with increasing oscillation period.

7. Attitude test results analysis

The last part (Part C) of the questionnaire includes six questions related to the students' attitude towards the performing laboratory work in physics:

PoS(BPU11)249

1. Evaluate how important you think it is to report the errors in measuring the numerical value of a given quantity when conducting the school physics experiment.

2. Evaluate how important you think it is to estimate measurement errors in your daily life.

3. Did the teamwork help you while doing the laboratory exercises?

4. In your opinion, to what extent does the use of modern equipment in the teaching laboratory make physics experiments more interesting?

5. To what extent did the inclusion of a computer in the experimental work help you to understand the processes investigated in this practicum?

6. To what extent do you think the laboratory exercises support the understanding of the studied material in physics?

7. Mark 2 for attention check.

As some of the questions are related to the laboratory exercises, Part C was only included in the post-test. Responses represent a 5-point scale, where 1 corresponds to a response of “not at all” and 5 to a response of “largely”. There was also a control question at the end about marking a number (in this case "2"), with the aim of checking attention, since in this type of questions there is often a tendency to put a number without reading the questions in detail. In our case, this reduced the number of the questionnaire cards we evaluate, as seen in the summary results below.

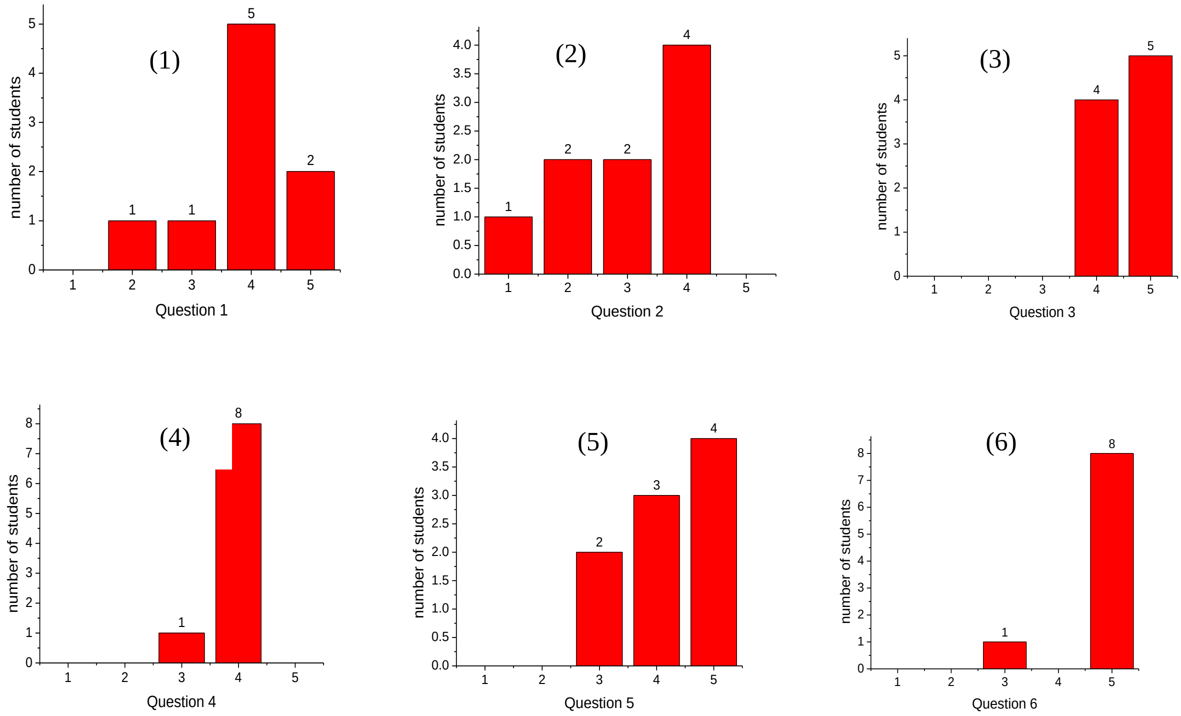


Figure 13: Summary of the answers to the attitude questions

In general, a positive attitude prevails, as only for the second question, related to the need to evaluate mistakes in everyday life, the answers are in the lower evaluation zone. An additional motivation with real life situations is needed to overcome this.

On the other hand, according to students, the availability of modern equipment and computer technology is important, but unfortunately, both are not available in a big part of the schools, also in some teaching laboratories of the faculty.

In overall, we believe that computer-assisted laboratory exercises have an advantage over classical setups in three directions. First, the students' interest is heightened because these technologies are an invariable part of their world. In our case, there was a strong interest in Arduino programming and its capabilities, with requests for organizing a specialized course. The second advantage is the possibility to implement compact installations (photogating yielding time measurement sensitivities in the ms range), which are not always possible to build in the classroom. And third, the possibility of collecting and subsequent processing of the obtained data and the application of knowledge from various fields (for example, information technology and mathematics) provides an opportunity for a deeper understanding of the obtained results and the studied phenomena.

8. Conclusions

In summary, the laboratory practicum which we offer for implementation was performed by a small group of students, and because of that we present the results not through statistical analysis, but as a case study. The pre- and post-practice survey identified areas where significant improvement was observed, as well as some (variable force – variable acceleration in mechanics and working with energy diagrams in atomic physics) that require additional approaches to overcome difficulties.

From a didactic point of view, the sequence in carrying out the laboratory work was very useful: (part A) damped oscillation right after the mathematical pendulum model with preservation of the period of oscillation; (part B) the possibility for the students to see the color of the fluorescence light with the naked eye and then to explain it on the spectral graph – the greenish of fluorescein, orange-red of the olive oil and the blue of the tonic and rum. Moreover, the conversations that took place showed that the students are intrigued and excited about the laboratory exercises carried out, and especially the practical exercise related to fluorescence.

In the analysis of the questions from Part C of the questionnaire also was confirmed the generally positive attitude of the students towards the practical work performed, and the possibilities of the computer presentation and processing of the experimental results as a prerequisite for increasing the effectiveness of the training.

The results of the research confirm the formulated hypothesis and give reason to claim that the use of a physical experiment in physics education leads to: improving the understanding of the basic concepts in the field of mechanics and atomic physics; improving skills for working with certain devices and computer programs; creating a better understanding of scientific experiment and its relationship to the physical theory.

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PoS(BPU11)249

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