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Physics entrance exams and main student problems

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Abstract

In the contribution we present an analysis of the main problems faced by students in the entrance exams in physics to study physics at the Faculty of Science, Masaryk University in Brno (MU). Every year, about 70 students from all over the Czech Republic and Slovak Republic are admitted to study physics and physics teaching at the Faculty of Science of MU (about a quarter of them are students from Slovak Republic). Therefore, the analysis of the results of the entrance examination in physics give a good overview of the level of physics teaching on Czech and Slovak (upper) secondary schools. (We believe that these experiences are similar elsewhere). We present here an example of a typical entrance exam assignment and process the results of solving open and closed problems from individual disciplines of secondary school physics and point out key problems leading to erroneous solutions. The assignment includes tasks from all eight basic areas of secondary school physics: Mechanics, Oscillations and waves, Thermics/thermodynamics and molecular physics, Electricity and magnetism, Optics, Physics of the microcosm, Astrophysics, Relativity. The aim of the assignment and subsequent analysis of the results of student solutions is to find out to what extent the physics education and textbooks at secondary schools contribute to the development of students physical thinking. The results of student solutions are commented for all monitored areas of secondary school physics, special attention is paid to mechanics and physics of the microcosm (disciplines from the beginning and end of secondary school studies, respectively). At the end of the paper, we comment on the possible causes of the not very great success of students in solving tasks from some areas of physics. In addition to our own experience, we also use the opinions of cooperating secondary school teachers and our first semester students.

Keywords: physics education, entrance exams statistics, secondary school physics

1. Introduction

Every year, about 70 students from all over the Czech Republic and Slovak Republic are admitted to study physics and physics teaching at the Faculty of Science of Masaryk University (MU) (about a quarter of them are students from Slovak Republic). Therefore, the analysis of the results of the entrance examination in physics give a good overview of the level of physics teaching on Czech and Slovak secondary schools. (We believe that these experiences are similar elsewhere). One example of such an analysis we present in our contribution.

The basis of the entrance examination for all study fields and specializations of all faculties of MU is the general test of study potential [1]. By passing this test, the candidate demonstrates the ability to think that will enable him or her to pursue higher education as such.

The second part of the entrance examination, which faculties may take (and do not have to do if they consider the general test sufficient) consists of tasks, problems or questions related to specific fields of study. At the Faculty of Science of MU, it is possible to study physics in the bachelor's specializations General Physics, Astrophysics, Nanotechnology, Physics with a focus on physics education, all of them can be followed by master's specializations Theoretical Physics, Astrophysics, Plasma Physics, Condensed Matter Physics, Upper Secondary School Teacher Training in Physics. Applicants for admission to the first year of the bachelor's degree programme in Physics take a written entrance examination in physics. It consists of closed and open tasks covering thematically secondary school physics fields: Mechanics, Oscillation and waves, Electricity and magnetism, Themodynamics and molecular physics, Optics, Physics of microcosm, Astrophysics, Relativity. The results were then scored and sorted into a final waiting list. In the section 2 we present an example of typical assignment including the justification of the concept, the method of evaluation (scoring) and the solution. In the following sections, we process the statistics of the results and comment on the most common solution errors. Evaluating student solutions, we focused in more detail on two areas—mechanics and physics of the microcosm (entry and final discipline of secondary school physics education, respectively).

Our analysis of results (especially in the field of mechanics) suggests that the physics education or physics textbooks in secondary schools focuses on memorizing facts and formulas rather than on physical thinking. Similar problems are also mentioned in other works on physics education, although not directly in connection with entrance exams: from the last 5 years of the development of didactics of physics as a science see e.g. the papers [2] (the necessity of a specific approach in teaching mathematics to physicists), [3] (adapting teaching to the conceptual needs of students), [4] (understanding work-energy relationships), [5] (strategies of conceptual problem solving by students versus algorithmic approach), [6] (revision of the educational objectives of laboratory courses to experimental skills before reinforcing lecture content), [7] (what students expect from studying physics—a survey).

Because the entrance exam included all thematic areas of secondary school physics, we could compare the knowledge, skills and ways of thinking of students in these areas. Perhaps the expectation could be that the results in mechanics would be significantly better than, for example, in Electricity and magnetism or optics, because mechanics is considered as more illustrative and accessible to sensory perception. However, it turns out that this is not entirely the case. (We will show this below for the case of simple pendulum—one of most useful models for explanation of the dynamics of curvilinear nonuniform motion—see e.g. [8]).

Terminological note: the terminology used to identify the types of schools is not completely uniform on an international level. In this contribution, by the general expression 'secondary school' we mean the upper secondary school, by 'grammar school' we mean the selective upper secondary school.

2. Typical assignment topics and evaluation of student solutions (scoring)

A typical assignment of the physics test consist of following types of tasks corresponding to the content of the official textbooks for grammar schools and secondary schools, see [9–16]:

- closed tasks with just one correct answer and four distractors: Mechanical oscillations and waves, Special relativity, Astrophysics,
- closed tasks with multiple choice item, 8 offered answers, the number of correct ones is not known in advance: Mechanics, Physics of the microcosm,
- open tasks: Thermics/thermodynamics and molecular physics, Electricity and magnetism, Optics.

The solutions of individual tasks are evaluated through scoring as follows.

- Closed tasks with just one correct answer: scoring 0 or 1.
- Open tasks: the range of scoring is [0; 1].
- Closed problems with multiple choice item: three variants of scoring:

(A) 'All-or-nothing rating'. Scoring 1 (student chose all correct answers and no incorrect answer) or 0 (other).

(B) 'Auxiliary point method'. The range of scoring is [0; 1] – one auxiliary point for each chosen correct answer and one auxiliary point for each ignored incorrect answer. The total score is obtained by dividing the number of auxiliary points by the number of all possible answers, so it ranges from zero to one point.

(C) 'Penalty point method'. The range of scoring is [−0,25; 1] – auxiliary points as in B), but a quarter of a point subtracted for every chosen incorrect answer, as well as for every ignored correct answer. The sum is divided by the number of all offered answers. Example: the task contains four correct answers and four distractors. The student chose three correct answers and two incorrect answers. Total scoring: $C = (5 - 3 \cdot 0.25)/8 = 4.15/8 = 0.53$. Converting between B) and C): $C = B - (1 - B) \cdot 0,25 = 1.25B - 0.25$.

In all variants tasks can be weighted according to its difficulty. (Various possibilities of scoring, as well as the optimal ratio of correct answers and distractors are to be discussed). The rating 'All-or-nothing' may seem to be too strict, which was also confirmed in our case. On the other hand, achieving full marks shows that the student understands the issue well and in depth with.

3. Specific assignment of tasks—option A/B—and characteristics of the required knowledge and skills to solve them

In the following text the correct answers are written by italics.

Mechanics A (a closed task with more correct answers)

The airplane flies horizontally with a constant velocity $\vec{v}$ with respect to the Earth surface. At the moment, the pilot freely releases a small heavy package (mass point) of mass m. We consider the Earth's gravitational field to be homogeneous, with gravitational acceleration g (magnitude). Frame of reference connected with the Earth is considered to be inertial, the resistance of the air against the motion of the package is negligible. Of the following statements, mark just all true ones.

(a) A loosely released package falls to Earth in free fall.

(b) The speed of the package with respect to the Earth is given by the relation $v(t) = gt$.

(c) *The acceleration of the package with respect to the Earth is* $\vec{g}$.

(d) *The magnitude of the acceleration of the package with respect to the Earth is* g.

(e) *The pilot sees the package at all times on a vertical line below the aircraft.*

(f) The package will hit the surface of the Earth sooner the larger it is the speed of the aircraft.

(g) The package will hit the surface of the Earth by earlier, the greater its mass m.

(h) If the package is dropped at height h, its kinetic energy immediately before hitting the ground takes on the value mgh.

Mechanics B (a closed task with more correct answers)
A boy shoots a stone of mass M with a slingshot at an angle $0 < \alpha < 90^{\circ}$ measured with respect to the horizontal plane. At the same time, he aims exactly at a pine cone with mass of m hanging on a tree at a height h above the ground. The surface of the Earth at a given location is horizontal. The initial velocity of a stone has a magnitude v with respect to the Earth. At the moment of the shot, the pine cone falls off. We consider the Earth gravitational field to be homogeneous, with gravitational acceleration $\vec{g}$. We consider the reference frame associated with the Earth to be inertial, the resistance of the air against the motion of the bodies is neglected. We follow the movement of both bodies only in the time interval before any of them hit the ground, or before they collide. Of the following statements, mark just all true of them.

(a) The stone cannot hit the pine cone, because the pine cone hits the ground before the path of the stone crosses the cross line along which the cone falls.
(b) If the pine cone was left hanging on tree, the stone would hit it reliably.
(c) *Stone acceleration with respect to the Earth is* $\vec{g}$.
(d) *The magnitude of the acceleration of the cone with respect to the stone is zero.*
(e) *The velocity of the pine cone with respect to the stone is constant.*
(f) The speed of the pine cone depends on its mass. The heavier the cone, the faster it falls.
(g) The stone will hit the cone in any case.
(h) *The kinetic energy of the pine cone just before hitting the ground takes on a valuemgh.*

To solve successfully problems in Mechanics A and B, it is essential for students to realize three fundamental things:

1) The acceleration of a mass point in a homogeneous gravitational field is always $\vec{g}$, while neglecting the air resistance.
2) The initial conditions different with respect to different reference frames determine the specific trajectory.
3) The change of the kinetic energy of a mass point is determined by (equals to) the work of all the forces exerted on the mass point by the surrounding objects.

Oscillations and waves A (a closed task with just one correct answer)
Waves are described by the relation $u(t,x) = 5 \cdot 10^{-3} \cos(440\pi t + 1{,}3\bar{3}\pi x)$, t is time, x is the coordinate, $u(t,x)$ is the deflection. The values of all quantities are given in the SI system of units. Of the following statements, exactly one is true. Label them.

(a) Waves cannot be longitudinal.
(b) The frequency of waves is 440 Hz.
(c) The deflection at time $t = 0$ and in the origin of the coordinate x is zero.
(d) The wave propagates in the direction of the positively oriented x-axis.
(e) *The speed of wave propagation is* $330\,\mathrm{m\,s^{-1}}$.

Oscillations and waves B (a closed task with just one correct answer)
Waves are described by the relation $u(t,x) = -5 \cdot 10^{-2} \cos(880\pi t - 2{,}6\bar{6}\pi x + \frac{\pi}{2})$, t is time, x is the coordinate, $u(t,x)$ is the deflection. The values of all quantities are given in the SI system of units. Of the following statements, exactly one is true. Label them.

(a) Waves are certainly transversal.
(b) *The frequency of waves is* 440 Hz.
(c) The deflection at time $t = 0$ and in the origin of the coordinate x equals to the amplitude of waves.
(d) The wave propagates in the direction of the negatively oriented x-axis.
(e) The speed of wave propagation cannot be determined from the given relation for $u(t,x)$.

To solve both mentioned problems of oscillations and waves it is essential for students to understand the following concepts and relations:

1) amplitude, frequency f (or period T) and wavelength λ of waves,
2) the phase of waves and the phase shift,
3) relation between the wavelength λ, frequency f and phase speed v of waves,
4) relation for the deflection $u(t,x)$ of monochromatic plane wave as function of time and the

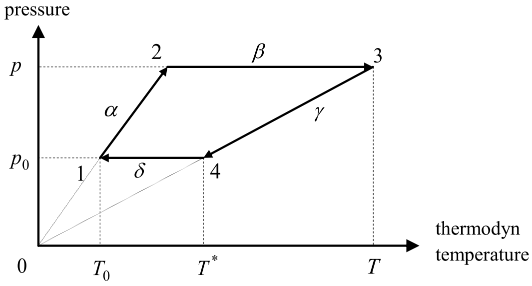

Figure 1. Cyclic process in ideal gas, T–p diagram.

coordinate along the direction of propagation of the wave (the direction of x-axis in our case).

Thermics/thermodynamics and molecular physics A (open task)
In a system of n mol of ideal gas a cyclic process takes place drawn on the following T–p diagram (see figure 1).

(a) Describe changes of pressure p, thermodynamic temperature T, and volume V of the mentioned body during partial processes α, β, γ, δ and name these processes.
(b) Express the temperature T^* at states 2 and 4:
b1) using values p_0, T_0, p and T,
b2) using limit values T_0 and T only.
(c) Calculate work done by the body during partial processes and express the complete work done by the body during individual partial processes α, β, γ, δ and express it:
c1) using values p_0, T_0, p and T,
c2) using limit values T_0 and T only.
(d) Determine the overall change in the inner energy of the body during the whole cycle, and calculate the total heat that the body change with their surroundings during the cycle.

Thermics/thermoodynamics and molecular physics B (open task)
In a system of n mol of ideal gas a cyclic process takes place drawn on the following T–V diagram (see figure 2).

(a) Describe changes of pressure p, thermodynamic temperature T, and volume V of the mentioned body during partial processes α, β, γ, δ and name these processes.
(b) Express the temperature T^* at states 2 and 4

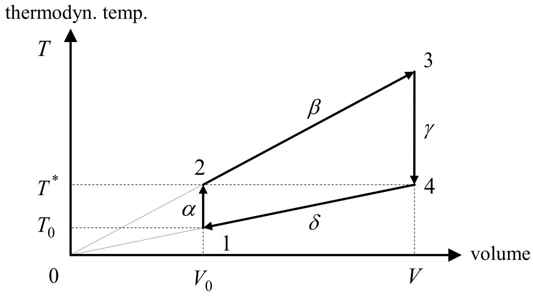

Figure 2. Cyclic process in ideal gas, T–V diagram.

- using values V_0, T_0, V and T,
- using n and limit values T_0 and T only.

(c) Calculate heat exchanged by the body and surrounding objects during partial processes α, β, γ, δ and express it with help of n and limit quantities T_0 and T.
(d) Determine the overall change in the inner energy of the body during the whole cycle, and calculate the total work done the body during the cycle.

To solve these open problems, it is essential for students to understand the following concepts and relations:

1) to use the state equation of ideal gas and its graphical interpretation in p–V, p–T and V–T diagrams,
2) understand the first thermodynamical law as the relation between the change of inner energy of a gas body (a state quantity) and two quantities depending on a concrete process, i.e. work done by the gas body and heat changed by the body and surrounding objects,
3) to calculate the quantities mentioned at 2) during a concrete process,
4) to understand the concept of cyclic process.

(The experience shows that, in general, the issue of thermodynamic processes is not easy for students, see i.a. [17, 18]).

Electricity and magnetism A (open task)
Two identical kettles are connected parallel to the circuit with a current power supply (see figure 3). (Such a power supply supplies to the circuit the current of a given fixed value). Water of volume V

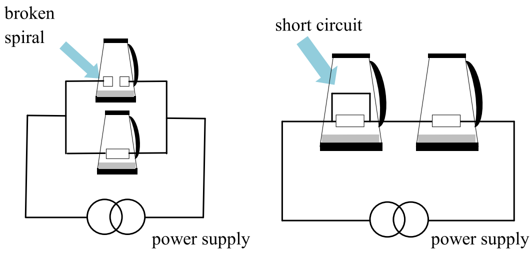

Figure 3. Electric circuit with two kettles.

is heated from temperature T to boiling point for time t in each of the kettles.

(a) Suppose that immediately after turning on the kettles, in one of them the heating coil burns out. How long does it take to start water in the second kettle to boil compared to the case of both working kettles?
(b) How will the experiment turn out if the kettles are connected in series and the heating coil of one of them is short-circuited when turned on?

Note: the water filling is the same in all cases as for volume and initial temperature. We neglect heat losses. Suppose that the resistance of heating coils does not depend on temperature.

To solve this problem, it is essential for students to understand the following concepts and relations:

1) To know and understand the Ohm law.
2) To calculate the resulting resistance of resistors in series and parallel connection.
3) To know and understand the relation for electric power.

Electricity and magnetism B (open task)
The free electron is in a hypothetical vacuum chamber in the (homogeneous) Earth's gravitational field. At the instant $t = 0$, the velocity of the electron is $v = 0\,\mathrm{m\,s^{-1}}$. The charge of the electron is $q_e \doteq -1,60 \cdot 10^{-19}\,\mathrm{C}$, the charge of the positron is $q_p \doteq 1,60 \cdot 10^{-19}\,\mathrm{C}$. The mass of both particles is $m_e = m_p \doteq 9,11 \cdot 10^{-31}\,\mathrm{kg}$. The acceleration of gravity is $g \doteq 9,81\,\mathrm{m\,s^{-2}}$, the permittivity of the vacuum is $\varepsilon_0 \doteq 8,85 \cdot 10^{-12}\,\mathrm{F\,m^{-1}}$.

(a) To what position with respect to the electron it is needed to place a positron, so that the acceleration of the electron is zero? Plot the situation and mark all the forces acting on the electron and positron.
(b) If we release the positron placed according to a), what will be the acceleration of both the positron and the electron at that moment?

To solve this problem, it is essential for students to understand the following concepts and relations:

1) To know and understand the Coulomb law (expression for the force between two charged particles).
2) To know and understand the relation for the gravitational force acting on a particle in a homogeneous gravitational field.
3) To apply the equilibrium condition resulting from the second Newton law.

Optics A (open task)
The thin lens C forms on the screen S the sharp image of the object P (see figure 4).

(a) Determine the type of the lens (convex–concave), draw the usual designation of this type of lens.
(b) Describe the properties of the image obtained by the lens (enlarged-reduced, straight-inverted, actual-apparent).
(c) Calculate the magnification of the lens (including the $\pm$ sign).
(d) Determine the focal distance of the lens.
(e) Draw the path of the rays through the lens in the picture (including rays going through the edge of the lens). Draw the true rays with a solid line, the appearing rays with a dashed line, or use color differentiation.

To solve this problem, it is essential for students to understand the following concepts and relations:

1) To know and apply basic thin lens imaging rules (the path of the rays through the lens).
2) To know and apply the lens equation and the relation for magnification.

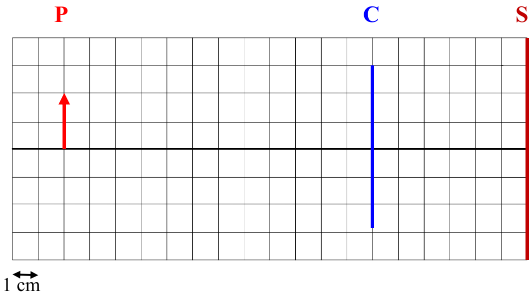

Figure 4. Lens imaging.

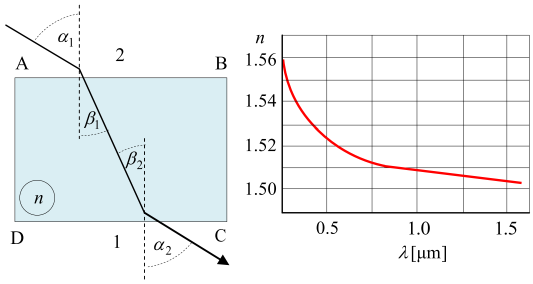

Figure 5. Light refraction by a glass block.

Optics B (open task)
Visible light falls from the air on a BK7 crown glass block at an angle $\alpha_1 = 60^{\circ}$ (see figure 5). (See the graph of the corresponding refractive index depending on the wavelength).

(a) Decide whether or not total reflection of light is present on the CD interface.
(b) Decide if the relation $\beta_1(\lambda = 0,40\,\mu\text{m} < \beta_1(\lambda = 0,75\,\mu\text{m}$ holds.
(c) Decide if the relation $\alpha_2(\lambda = 0,40\,\mu\text{m} \neq \alpha_2(\lambda = 0,75\,\mu\text{m}$ holds.
(d) Decide if there is a wavelength for which it holds $\alpha_1 = \alpha_2$.
(e) Point *P* is the source of the narrow beam of white light that falls on the block. The picture shows the path of a beam of green light through the block. Draw the sequence of blue ($\lambda = 0,40\,\mu$m) and red ($\lambda = 0.75\,\mu$m) of light through the block, i.e. before it hits the AB interface, between AB and CD interfaces and after leaving the block. To simplify, assume that the trajectories of the green, blue, and red rays are identical before the impact to the AB interface. Draw colour or differentiate the individual rays by the type of line. Using results obtained in the previous tasks and decide whether the light beam is, after leaving the block, diverging, converging, or parallel.

Parts (a)–(d) solve either by qualitative reasoning or by a relevant calculation.

To solve this problem, it is essential for students to understand the following concepts and relations:

1) To define and understand the concept of absolute and relative index of refraction.
2) To know and apply the law of refraction of light (Snell law).
3) To apply basic geometric considerations concerning the light reflection and refraction.

Physics of microcosm A (closed task with more correct answers)
Assess the correctness of the following statements and mark all the correct ones:

(a) A necessary and sufficient condition for the existence of the photoelectric effect is a sufficient intensity of incident electromagnetic radiation.
(b) *The velocity of electrons leaving the irradiated conductor in the photoelectric effect does not depend on the intensity of the incident monochromatic radiation that this phenomenon produces.*
(c) The source of energy emitted by the Sun is the fission of the atomic nuclei of the elements found in the Sun's interior.
(d) *The same molar quantities (the same number of molesn) of different substances occupy the same volume.*
(e) The reason for the stability of atomic nuclei is the predominance of gravitational forces acting between all nucleons over forces of an electromagnetic nature acting only between protons.
(f) *The probability of the radioactive decay of certain nuclei is the increasing function of the half-life of a nuclide.*
(g) For all types of radioactivity, the chemical composition of the radioactive sample changes.

(h) The absorption spectrum of an atom contains a smaller number of lines than its emission spectrum.

Physics of microcosm B (closed task with more correct answers)
Assess the correctness of the following statements and mark all the correct ones:

(a) *The number of electrons released by the photoelectric effect increases with the intensity of the monochromatic electromagnetic radiation producing the photoelectric effect.*
(b) The time it takes for photoelectrons to be released after the start of irradiation of the conductor can be shortened by increasing the intensity of the incident radiation.
(c) A mass spectrometer works on the same principle as an optical spectrometer; when describing its operation, it is only necessary to replace the wavelength of light de Broglie wavelength of studied particles.
(d) Equal molar quantities (the same numbers of moles) of different substances have the same mass.
(e) *Natural radioactive decay is always accompanied by the release of energy.*
(f) *The absorption of electromagnetic radiation by the body depends on the intensity and wavelength of radiation and on the material of the body.*
(g) The absorption spectrum of an atom contains the same number of lines as its emission spectrum.
(h) *The source of energy emitted by the Sun is nuclear fusion.*

Due to the content of secondary school textbooks in the field of Physics of the microcosm, both tasks A and B are (in addition to basic knowledge of the issue) focused on understanding of

1) the equation for the radioactive decay (the number of radioactive nuclei or the probability of radioactive decay as functions of time),
2) the concept of the half-life of a nuclide,
3) the concept of molar quantity,
4) the influence of intensity and wavelength of incident photons in photoelectric effect.

Special relativity A (a closed task with just one correct answer)
A particle with rest mass m_0 moves uniformly and straightforward with respect to the coordinate system S with the speed $v = 0,6c$. Of the following answers, just one is correct. Select it: The mass of the particle in the system S is

(a) $0,25m_0$, (b) m_0, (c) $1,18m_0$, (d) *correct answer*$1,25m_0$, (e) $1,50m_0$.

Special relativity B (a closed task with just one correct answer)
The axes of the two inertial reference frames S and S' are parallel. The system S' moves with respect to the system S with speed $v = 0,8c$ in the direction of the x-axis. The duration of a certain process with respect to an observer in the system S' is 12s. What duration does an observer find in an S system? (Just one answer is correct. Choose it).

(a) *correct answer* 20s, (b) 15s, (c) 12s, (d) $7,2$s, (e) $1,2$s.

A prerequisite for the successful solution of special relativity problems is the knowledge of the relations for length contraction, time dilation and the relationship between the mass and rest mass of a particle.

Astrophysics A (closed task with just one correct answer)
The ratio of squares of the orbital periods of two exoplanets around their parent star is 64. Of the following statements, just one is correct, select it: the ratio of the semi-major axes of their orbits is

(a) 64, (b) 32, (c) 16, (d) *correct answer 4*, (e) 2.

Successful solution of this problem requires knowledge of Kepler laws.

Astrophysics B (a closed task with just one correct answer)
The spectroscopic method determined the speed of the Galaxy's receding to be $3000\,\mathrm{km\,s^{-1}}$. If we accept the rounded value of the Hubble constant $75\,\mathrm{km\ s^{-1} \cdot Mpc^{-1}}$, its distance is

(a) 4 Mpc, (b) 10 Mpc, (c) *correct answer*40 Mpc, (d) 400 Mpc, (e) cannot be determined.

Successful solution of this problem requires

1) knowledge of the relation between the speed of receding of a Galaxy and its distance through the Hubble constant,
2) knowledge of length units used in astrophysics.

The duration of the entire test (8 tasks) was 80 min.

4. Evaluation of student solutions—closed tasks with multiple choice item

In this and the next section we analyze results of student solutions in above mentioned problems in variants A and B. First, let us to consider two cases of closed tasks with multiple choice item, i.e. Mechanics A/B and Physics of microcosm A/B.

The 'all or nothing' method of evaluation seems to be very strict. This is one of the reasons why some teachers reject this method. Others prefer open tasks to closed ones. There is no doubt that only the correct solution of a difficult or moderately difficult open problem guarantees the student's understanding of the issue. However, closed problems with multiple choice item represent certain instructive steps to solving the corresponding open problems. Student who completely succeeds in solving the closed problem with multiple choice item, demonstrates not only knowledge of the issue, but above all a deep understanding of it and excellent physical thinking. Then it is highly probable that he/she will successfully solve the corresponding open task independently and without instructions.

- Out of the total number of 54 students (26 in variant A and 28 in variant B) only six demonstrated a deep understanding in Mechanics (specifically the motion of a mass point in a homogeneous gravitational field, the motion of a mass point in various reference frames), and only two in the problems of Physics of the microcosm (photoelectric effect, nuclear decay, absorption and emission of radiation, molar quantity, molar volume).
- With regard to the fact that the difficulty of variants A and B was comparable in the cases of Mechanics, Physics of the microcosm and Optics we present corresponding results in the summary graph. Although for the purposes of the entrance exam, the problems in Mechanics and Physics of microcosm were scored using the penalty point method, in the presented contribution we converted the scoring to type B (Auxiliary point method) and to the scale interval [0; 1]—for easier comparison of results in individual topics of physics. Basic statistical parameters of these distributions are in the following table:

Note that there is a problem to define median of a distribution, when the values of the variable $x(x_1, \dots, x_n)$ (score in our case) are so rare and distribution function is not simple (invertible) in general. We can calculate median μ as follows: if $F_i = \sum_{j=1}^{i} p_i = 1/2$, $p_i = n_i/n$, then $\mu = x_i$. For $F_{i+1} = \sum_{j=1}^{i} p_i < 1/2$ and $\sum_{j=1}^{i+1} p_i > 1/2$, then we put $\mu = 0.5(x_i + x_{i+1})$. Even this method is not satisfactory. It is more correct to specify an interval (x_i, x_{i+1}) for which $F_i < 0.5 < F_{i+1}$ and $\mu = x_i$ for $F_i = 0.5$.

In addition, we present the distributions of individual answers separately for Mechanics and Physics of microcosm (figure 7). Figure 7 left summarizes results of both variants A, B of Mechanics, figure 7 right both variants A, B of Physics of microcosm.

On the basis of these distributions, let us try to analyze the causes of only average results in those interested in studying physics, i.e. those interested in a future career as professional physicists or physics teachers.

Mechanics: let's look at the distribution of answers to closed problems in Mechanics with multiple choice item. The mechanical problems in variants A and B concern the motion of a particle in the homogeneous gravitational field of the Earth without air resistance. In the variant A, the correct answers are (c), (d) and (e), in the variant B (c), (d), (e) and (h).

- To understand the motion of a mass particle in a homogeneous gravitational field (Earth in our case) without air resistance, it is crucial to realize that all types of motion have the same acceleration, namely $\vec{g}$ (magnitude g), the individual trajectories differing only by the initial conditions (especially velocity). Nevertheless,

Table 1. Basic statistical characteristics for figure 6. n is the size of the sample (number of respondents), $\langle x \rangle$ is the mean value of the score x, σ is the corresponding standard deviation (square root of the variance) and μ is the median.

Topic	n	$\langle x \rangle$	σ	$(\langle x \rangle - \sigma,\ \langle x \rangle + \sigma)$	μ-interval
Mechanics	54	0.62	0.22	(0.40; 0.84)	(0.50; 0.625)
Microcosm	54	0.69	0.15	(0.54; 0.84)	= 0.625
Optics	55	0.42	0.33	(0.22; 0.88)	(0.30; 0.40)

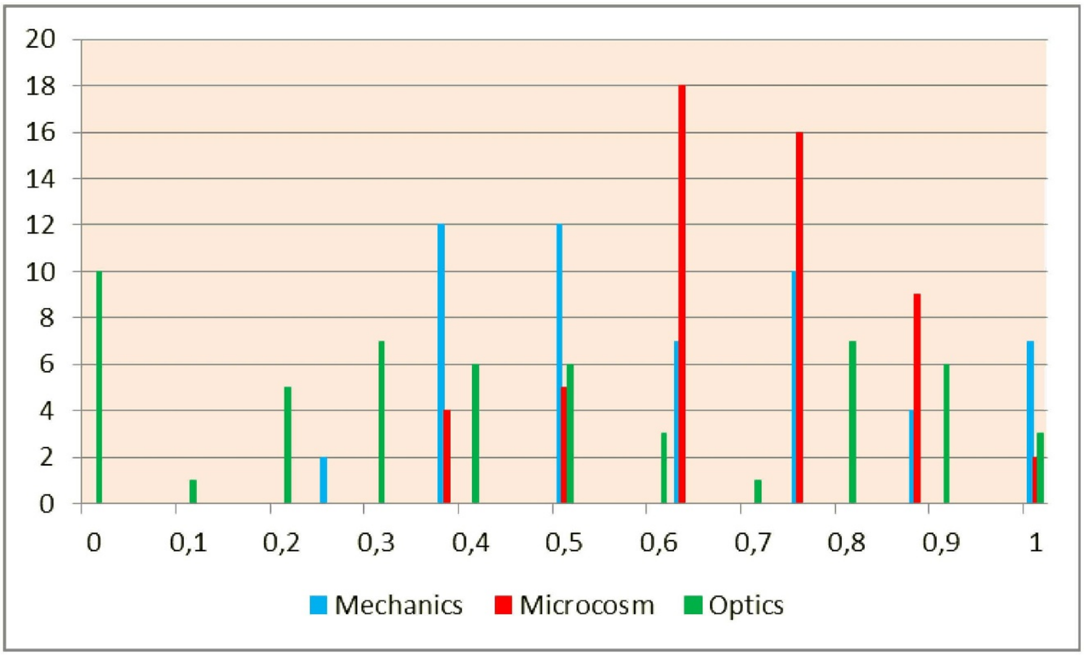

Figure 6. Summary of results: Mechanics, Physics of microcosm Optics. Horizontal axis x—score in the interval [0; 1], vertical axis $n_i = n(x_i)$—number of students.

answer (c) was recognized as correct by 50% of students only. The difference in the number of marked answers (c) and (d) is hard to understand, especially in variant A ((c) – 13 students, (d) – 7 students), when it is basically the same thing. (In variant B it was (c) – 21 students (d) – 15 students). There may be a problem with understanding the vector character of quantities.

- What is surprising is the number of markings of the obviously incorrect answer (a) in variant A (almost half of students), often in combination with the correct answer (e). This indicates a lack of understanding of motion with respect to different frames of reference. It can be assumed that the issue concerning reference frames does not receive enough attention in teaching physics at secondary schools.
- A record number of marked wrong answers (h) in variant A deserves attention. Either this is again an insufficiently understood problem of reference frames, or (and this is more probable) a thoughtless application of the 'theorem of conversion of potential energy into kinetic energy'.
- It can be considered positive that the apparently wrong answers (g) in variant A and (f) in variant B (neglecting the air resistance) were marked by only one student in both cases.

Physics of microcosm: in the case of problems in the Physics of the microcosm, the average rating is only slightly better than that in Mechanics, but the

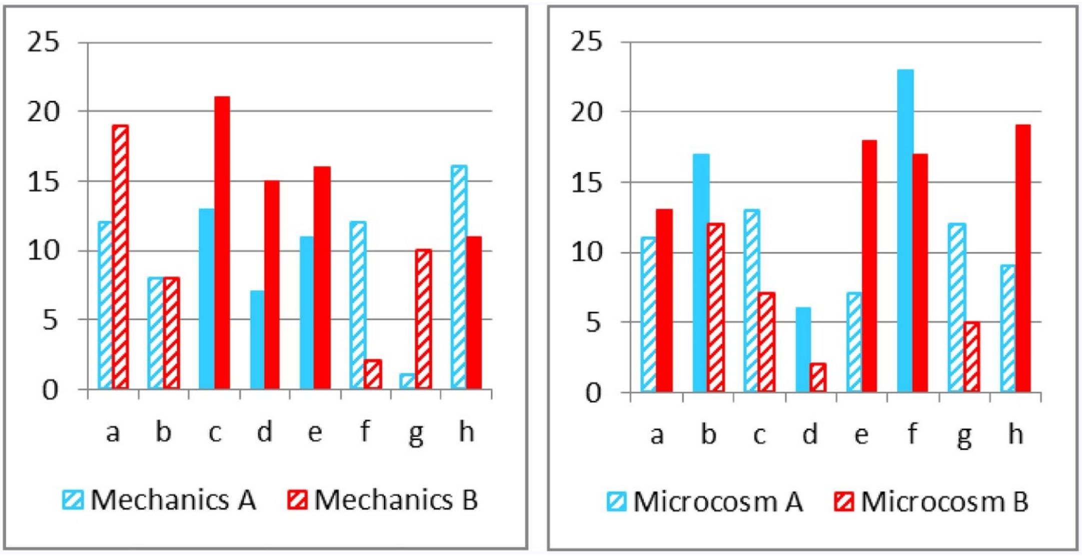

Figure 7. Distribution of answers (a)–(h): Mechanics A and B (left), Physics of microcosm A and B (right). Sample fill—incorrect answers, full fill—correct answers, vertical axis—number of answers.

distribution of individual answers is more favorable. (In particular, the choice of correct answers is satisfactory). This is probably due to the fact that teaching and textbooks in the field of Physics of the microcosm at the secondary school level give rather a factual overview, students learn the facts mechanically.

- It can be seen from graphs in figure 7–right that students do not make too many mistakes in choosing the correct answers. However, the proportion of incorrect answers reduces the positive assessment of this fact. Students are well aware of the fact that the frequency of incident electromagnetic radiation (energy of incident photons) is essential for inducing a photo effect, not its intensity.
- However, a lack of understanding or unfamiliarity of the essence of some phenomena is evident from a relatively large number of answers (b) and (c) marked as correct in variant B, or answers (a), (c) and (g) in variant A. The choice of answer d) in variant B as correct is unpleasantly surprising.

Partial summary: despite the relatively small number of students (54) whose solutions we evaluated in this section, we conclude:

- Teaching and textbooks in the field of mechanics should focus on a thorough understanding of the concepts of kinematics and Newton laws of motion.
- Teaching and textbooks in the field of Physics of the microcosm should focus on at least qualitative, but physically valuable explanation of individual phenomena of the microcosm rather than on a large set of unsorted facts. See e.g. [14].

These conclusions will be confirmed in section 6 after evaluating a much larger group of solved closed problems from mechanics and physics of the microcosm.

5. Evaluation of student solutions—remaining tasks

In this section we briefly comment solutions of remaining tasks: mechanical oscillations and waves, special relativity, astrophysics—closed tasks with just one correct answer (variants A and B – 29 and 31 answers, respectively). In these tasks the score is made as follows: if the correct answer is marked, the task is evaluated with one point, otherwise it remains without a point. Problems in Thermics/thermodynamics and molecular physics, Electricity and magnetism,

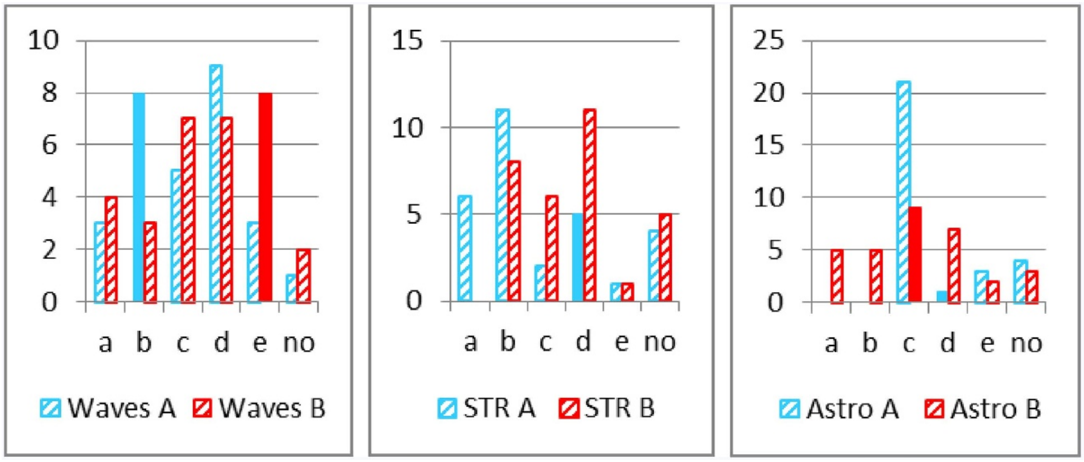

Figure 8. Distribution of answers (a)–(e): Mechanical oscillations and waves, STR, Astrophysics. Sample fill—incorrect answers, full fill—correct answers, vertical axis—number of answers.

Optics, was open ones. In figure 8 we present distributions of answers to closed questions (Mechanical oscillations and waves, special relativity, astrophysics). Results of solutions in Optics were presented in figure 6, together with Mechanics and Physics of microcosm.

Comments: Let's summarize the conclusions resulting from the graphs.

- In the case of both variants A and B of Mechanical oscillations and waves only 8 out of 29 and 8 out of 31 students (27% and 26%), respectively, answered correctly.
- This result (lying only slightly above the probability of a random guess) indicates that most of students do not know how to deal with numerical values in different representations of a plane wave traveling along the *x*-axis, namely

$$y = A\cos\left(\omega t \pm kx + \varphi\right),$$
$$y = A\cos\left(2\pi ft \pm \frac{2\pi}{\lambda}x + \varphi\right),$$
$$y = A\cos\left(\frac{2\pi t}{T} \pm \frac{2\pi x}{\lambda} + \varphi\right),$$

  and they do not have an established relationship between period, wavelength and phase velocity of waves, e.g.

$$v = \frac{\lambda}{T} = \lambda f = \frac{\omega}{k}.$$

  On the other hand, our experience in the first semester of university studies shows that there are not so many problems in tasks about oscillations. In the case of waves, problems can also arise from the fact that the function describing the waves depends not only on time, but also on position in space (insufficient linking of mathematics and physics education—see paragraph 8 as well).
- Unsatisfactory results in astrophysics and STR are not surprising. At secondary schools, the necessary amount of time is not devoted to these topics due to the gradual reduction of the time span of physics teaching by the so-called framework curricula (more details see in paragraph 8 which discusses other possible causes of unsatisfactory results). (From this point of view, the choice of tasks in astrophysics and the theory of relativity was probably too difficult).

Open tasks (Thermics/thermodynamics and molecular physics, Electricity and magnetism, Optics) were solved by 55 students (26 variant A, 29 variant B). Given the bad results (with the exception of optics), there is no point in evaluating them statistically.

- The worst results were in Thermics/thermodynamics and molecular physics and in Electricity and magnetism. The number of achievable points was always 5. In Thermics/thermodynamics and molecular physics, and in Electricity and magnetism 27 (49%) and 41 (75%) applicants, respectively, did not receive any points! In Thermics/thermodynamics and molecular physics only two students scored at least half of the points (concretely three out of a total of five points). The reason can be found in the fact that, as mentioned above, thermodynamics in particular is difficult and uninteresting for students ([17, 18]). (Students' interest in thermal phenomena can be gained through practical demonstrations. One such example can be found e.g. in [19–21]).

- In Electricity and magnetism ten students scored at least half of the points, two of them got 5 points (full score). The reason for such a failure may be the fact that the teaching of physics in grammar schools focuses more on 'theory', or memorizing 'theorems' and formulas, instead of practice in solving problems, especially in more difficult areas of physics for students, such as thermodynamics, molecular physics or Electricity and magnetism. (We also briefly address this problem in the paragraph 8).
- Of the three mentioned open tasks, optics turned out 'best'. The distribution of points (scoring after the method B reduced to the scale [0; 1]) is shown in figure 6. The point average 0.42 is, at a range from 0 to 1 points, worse than in mechanics and Physics of microcosm.

6. Once more mechanics: dynamics of a curvilinear motion as a 'stumbling block' of mechanics

While assignment of tasks from mechanics in entrance exams belongs rather to the kinematics of a mass point motion, we also tested (as a part of the entrance exam in another year) not very difficult dynamical closed problems on the grammar school level. A typical problem showing understanding/misunderstanding of the dynamics of curvilinear motion is the simple pendulum problem (see also [8] already cited above).

Mechanics C (a closed task with multiple choice item)

A little ball (point particle) of mass m is hanging on a thread of negligible mass and constant length ℓ in the homogeneous gravitational field of the Earth. Gravitational acceleration vector is $\vec{g}$. We deflect the ball from the equilibrium position (in which the thread is vertical) by an angle of $0 < \alpha_0 < 90^{\mathrm{o}}$ and release it freely. We observe the motion of the ball in the reference frame associated with the Earth, which we consider to be inertial. The resistance of the environment (air) to the motion of the ball is negligible. Of the following statements, mark all the true ones:

(a) As the ball passes through the equilibrium position, the gravitational force acting on the ball is just compensated by the tensile force of the thread.
(b) The magnitude of the resulting acceleration of the ball in every point of its trajectory is v^2/ℓ, where v is the speed of the ball at this point.
(c) The resultant of forces exerted on the ball by its surroundings at a general point of the trajectory is tangent to that trajectory.
(d) *The tensile force of the thread acting on the ball in the extreme position (maximum of the angular deviation from the vertical) is always less than the gravitational force.*
(e) If the initial deviation α_0 is larger, then the tensile force of the thread in the extreme position is larger too.
(f) *If the initial deviation α_0 is larger, then the tensile force of the thread in the equilibrium position is larger too.*
(g) There is the centrifugal force acting on the ball at every point of its trajectory; this force compensates the tensile force of the thread.
(h) *Kinetic energy of the ball in the equilibrium position is equal to the loss of potential energy during the ball transition from the extreme to the equilibrium position.*

Graphs on figure 9 show results of student solutions. The task was solved by 48 applicants to study physics and the same number of students MU after successful completing the course of Mechanics in the first semester. Table 2 presents basic statistical characteristic of distribution on figure 9 left.

Comments to solutions of applicants: the weighted point average for applicants in the problem of dynamics (Mechanics C—simple pendulum) is 0,57, i.e. only lightly lower than that

Table 2. Mechanics C. Basic statistical characteristics for figure 9 left. The meaning of notation is the same as in table 1.

Respondents	n	$\langle x \rangle$	σ	$(\langle x \rangle - \sigma,\ \langle x \rangle + \sigma)$	μ-interval
Applicants	48	0.57	0.19	(0.38, 0.76)	(0.50; 0.625)
Students MU	48	0.69	0.18	(0.51, 0.87)	= 0.625

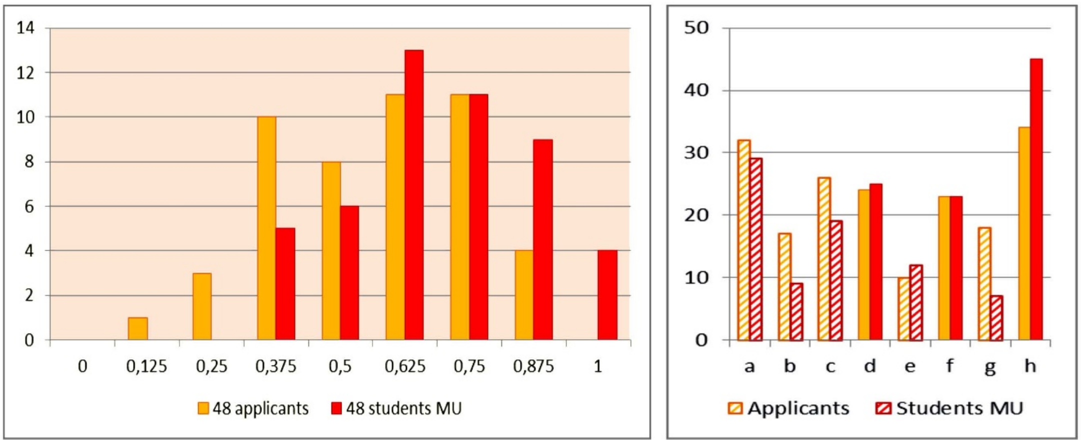

Figure 9. Summary of results: Mechanics C, applicants versus students MU (the same task for both groups). Left: horizontal axis x—score in the interval [0; 1], vertical axis $n(x)$—number of respondents. Right: distributions of answers. Sample fill—incorrect answers, full fill—correct answers, vertical axis—number of answers.

of kinematics (0,62 in Mechanics A and B). What can we see from distribution of individual answers:

- The distribution of individual answers in Mechanics C shows almost fatal misunderstanding of the dynamics of curvilinear motion. The proportion of erroneous answers a) (67%) and c) (54%) ignoring the connection between the normal component of the resultant acceleration of the pendulum and the curvature of the trajectory is surprisingly high.
- Also the proportion of incorrect answers b) (35%) confusing centripetal and total acceleration shows a misunderstanding of the kinematics of curvilinear motion.
- On the contrary, a large proportion of correct answers h) (71%) was expected due to the memory-fixed 'theorem' of conversion of potential energy into kinetic energy and vice versa.

At the same time, the simple pendulum can be considered as a very illustrative and simple example (if properly interpreted) of the dynamics of non-uniform curvilinear motion. This seems to indicate that the teaching of physics in secondary/-grammar schools does not place much emphasis on physical thinking and focuses more on memory learning.

The same problem concerning the simple pendulum was given to the students who completed the course Mechanics in the first part of their physics studies at the Faculty of Science of MU (32+16 students). The result are summarized again in figure 9.

Comments to solutions of students MU: the weighted point average for students MU in the problem of dynamics (Mechanics C—simple pendulum) is 0,69, which seems better than for applicants. However, intervals $(\langle x \rangle - \sigma,\ \langle x \rangle + \sigma)$ for applicants and for students MU overlap. What can be seen from distribution of individual answers:

- More than half of the students made no more than two mistakes. This fact seems to be positive.

- Nevertheless, the results cannot be considered satisfactory due to the significant number of marked incorrect answers a) (58%) and c) (40%).
- On the contrary, 94% of correctly labeled answers h) were to be expected.

How to explain this shortcoming? Experience shows that faulty thinking fixed by grammar school teaching is difficult to unlearn. Inappropriate or misleading images in textbooks often contribute to the fixation of errors. Specifically, these are incorrect force diagrams of the simple and physical pendulums. The reader can see this in a number of commonly used physics textbooks, both high school and university. (Typically, for example, the high school textbook universally used in the Czech republic [11], and a very popular university textbooks [22] and [23]).

Experience shows that especially problems and questions concerning simple or physical pendulums and generally problems concerning non-uniform curvilinear and rotational motions are difficult for students to understand in more depth than at the level of formal description or memorization of formulas.

We expected that the results for MU students who have already completed the course of Mechanics should be significantly better than for applicants. However, if we take into account that MU students take the course in mechanics in the first semester of their studies, i.e. immediately after the transition from secondary schools to university (which is more of a leap than a transition—see e.g. [24]), and errors in the interpretation of the Newton laws from secondary school are fixed, the difference in success rate can be considered acceptable.

In papers focused among others to physics education one can find so to speak an inexhaustible amount of high quality and informative articles on pendulums (from the last five years, see only a representative selection, [25–31] and others of many articles of Rod Cross in EJP) and rotating systems ([32–34]). Many of them are, of course, too advanced for students in the entry phase of university studies. Unfortunately, these recent works in the field of physics education do not deal with the dynamics of the pendulum at a level accessible to students. That is a pity, because the simple pendulum is one of the most suitable mechanical model allowing a deeper understanding of Newton laws, on which whole classical mechanics is based. (There are, of course, exceptions, see e.g. among which the beautiful example of a didactically perfect approach is [8]. A Czech textbook [35] is from recent times, and from the past, for example, [36, 37]).

7. Mechanics and Physics of microcosm—global summarizing of results from various sets of assignments

In this section we globally summarize results of student solutions of closed tasks with multiple choice item in Mechanics, separately those focused on Kinematics (motion in the homogeneous gravitational field of the Earth) and Dynamics, and Physics of microcosm obtained from various sets of assignments of the same type submitted to groups of applicants for the study of physics. Such a summary is made possible by the fact that the assignments are very similar each to other and they have the similar difficulty. The numbers of students: Kinematics ($n = 132$), Dynamics ($n = 82$), Physics of microcosm ($n = 196$). The summary results are presented in figure 10. The scoring is again of the type B (Auxiliary point method) reduced to the scale interval $[0;\ 1]$

Comments: from the point of view of the simplest statistical processing, the results of Kinematics, Dynamics and Physics of microcosm practically the same (with the exception of somewhat lower mean value for Dynamics). An interesting result is obtained when using all-or-nothing method to evaluate the solutions. (Let us remind that only this method of evaluating closed problems with multiple correct answers gives relevant information about the depth of understanding of the issue, unlike other methods). While 10% percent of students succeeded in Kinematics according to this method, only 3.5% succeeded in the Physics of microcosm, no student was successful in Dynamics. An objection may arise that

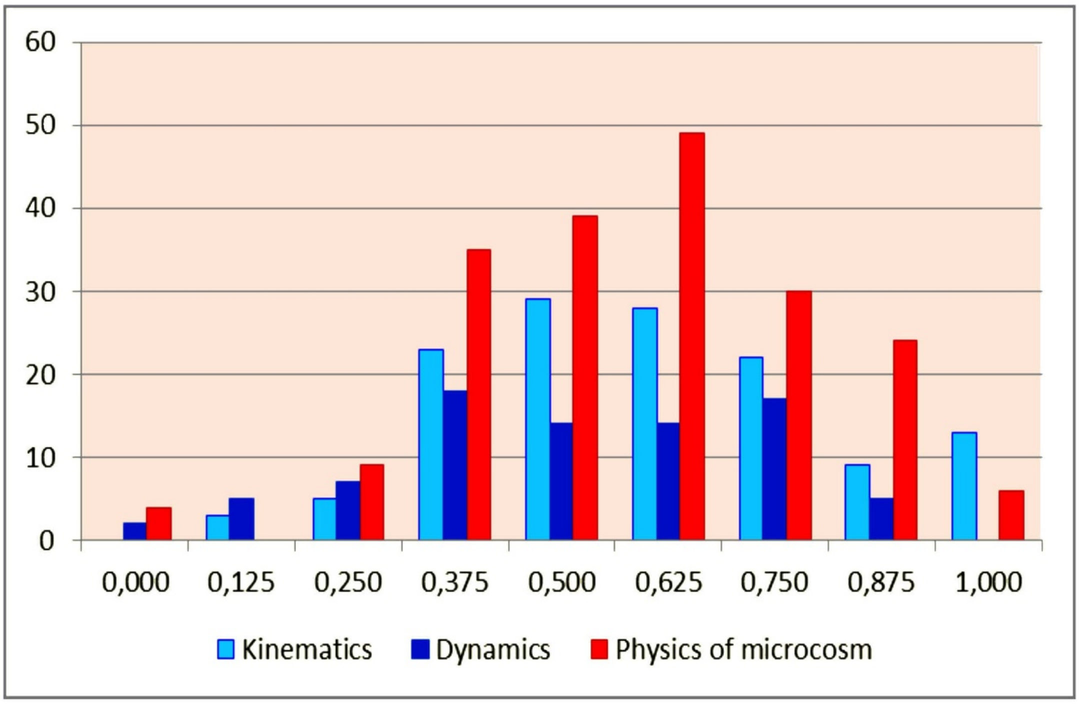

Figure 10. Results of applicant's solutions in Kinematics, Dynamics, Physics of microcosm. Horizontal axis *x*—score in the interval [0; 1], vertical axis *n*(*x*)—number of respondents.

the number of students who solved the problem of Dynamics is only 62% of those who solved Kinematics and even only 42% of solvers of a Problem of Physics of microcosm. Even so, this result can be summarized as follows: in problems of Dynamics and Physics of the microcosm, students are basically completely unsuccessful according to the all-or-nothing method. The explanation is not difficult. While secondary school kinematics is about describing the simplest motions (rectilinear uniform and uniformly accelerated, uniform on a circle), and in microcosm physics the teaching is essentially limited to factography without a deeper understanding (and students forget the facts), Dynamics is actually difficult for students. Teaching is not focused on demonstration experiments and practical laboratory works (see e.g. [38, 39]). Experiences show that appropriate methods are not chosen in its teaching (solving of problems, laboratory and demonstration experiments, development of physical thinking).

8. Additional 'statistical' note

We made our investigation primarily with the aim to test the adequacy of various tasks of physics given in entrance exams to applicants of physics studies on MU. We mainly focus on the evaluation of results of these exams in terms of physical content and students skills to solve both conceptually and formally problems on the level of secondary school physics. Nevertheless, it appears the possibility to compare results in different areas of physics, as well as the results of applicants and MU students in the same area of physics. After evaluating results (see paragraphs 4, 5 and 6) we can state:

- Considering the failure of the students in the open tasks in topics 'Electricity and magnetism' and 'Thermics/thermodynamics and molecular physics', it is not possible to include these tasks in 'statistical' processing.

Table 3. Kinematics, Dynamics, Physics of microcosm. Basic statistical characteristics for figure 10. The meaning of notation is the same as in table 1.

Topic	n	$\langle x \rangle$	σ	$(\langle x \rangle - \sigma,\ \langle x \rangle + \sigma)$	μ-interval
Kinematics	132	0.60	0.22	(0.38; 0.82)	(0.50; 0.625)
Dynamics	82	0.51	0.22	(0.29; 0.73)	(0.375; 0.50)
Physics of microcosm	196	0.59	0.21	(0.38; 0.80)	(0.50; 0.625)

- It makes no sense to process statistically the results of tasks with just one correct answer, because their distributions correspond rather to the random choice. (Comments see in paragraph 5).
- For comparison we take into account following samples (basic statistical data summarized graphically on figure 11):

1) Mechanics A+B (closed tasks with multiple choice item), Physics of microcosm A+B (closed tasks with multiple choice item), Optics A+B (open tasks) with the same size (in the graph on figure 11 denoted as ME, MI, OP). Here, we have for possible comparison the results of three various topics of physics solved by the same group of students. See also figure 6 and table 1.
2) Mechanics C: A task with multiple choice item solved by two various groups of students with the same size = number of respondents (applicants for physics study and first-semester students, in the graph on figure 11 denoted as AP, ST). See also figure 9 and table 2.
3) Kinematics, Dynamics, Physics of microcosm (closed tasks with multiple choice item) solved by groups of applicants of various sizes: Kinematics $n_1 = 132$, Dynamics $n_2 = 82$, Physics of microcosm $n_3 = 196$, (in the graph on figure 11 denoted as KI, DY, MI). The relation between these three groups is such that third group of respondents is the set union of first two groups. See also figure 10 and table 3.

For an immediate visual representation of the similarities or differences of individual distributions, see the graph on figure 11.

(We do not present standard box plots, because 0.25- and 0.75- percentils are not well defined for our rare ensemble of values of the score—see the note concerning the definition of the median).

For comparing the agreement of the mean values of individual distributions it could be suitable e.g. t-tests or ANOVA methods. After comparing the requirements imposed on the distributions of random variables for performing t-tests or ANOVA methods, we decided to use the independent two-sample t-test (see e.g. [42, 43]) for selected pairs of distributions. This type of t-test allows to compare the mean values of two samples of different sizes and variances and does not require normal distributions. The prerequisites for using the t-test, the relevant formulas and tables can be found elsewhere, see e.g. [40–43].

For our data following results were obtained (table 4):

We can summarize:

- Taking into account the level of significance corresponding to $\alpha = 0.05$ and the critical values (CVs) tables for two-sample t-test, then for our sample sizes we can conclude that only with the exception of the pair Kinematics—Physics of microcosm (KI-MI) the populations in all pairs differ. (For $\alpha = 0.05$ and all values of degrees of freedom of our pairs of distributions it holds CV< 1.68). This conclusion was, of course, expected due to the different content and difficulty of individual parts and different approaches to solving problems in school physics.
- The agreement of results in the pair Kinematics—Physics of microcosm (KI-MI) is undoubtedly accidental. Kinematics is studied in the first class of the 4 year grammar school, and kinematical tasks are standardly solved during school lessons, while Physics of microcosm is taught in the fourth class focusing more on

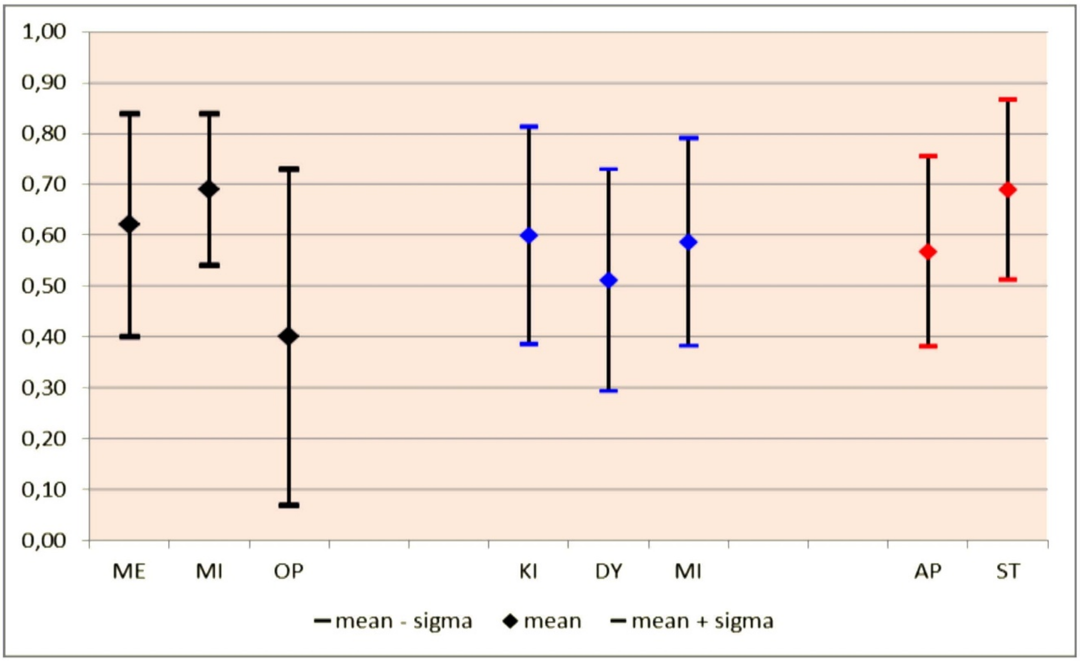

Figure 11. Data of distributions: 1) ME, MI, OP, 2) AP, ST and 3) KI, DY, MI. For individual distributions there are shown intervals $(\langle x\rangle - \sigma, \langle x\rangle + \sigma)$ with marked mean value.

Table 4. Values of two-sample t-test for pairs of distributions of students results.

pair	t-value	pair	t-value	pair	t-value
ME-MI	1,92	KI-DY	2,99	AP-ST	3,29
ME-OP	4,06	KI-MI	0,70		
MI-OP	5,89	DY-MI	2,65		

memorizing facts. (Secondary school students are not sufficiently equipped for a deeper understanding of the laws of the microcosm).

- On the other hand the difference of results in Mechanics C AP-ST (the same task for two different groups of respondents—applicants for physics studies and first-semester students MU) was expected.
- The difference of Mechanics—Optics (ME-OP) and Physics of microcosm—Optics (ME-OP and MI-OP) was expected as well because of the fact that solving open tasks, requiring independent thinking without help, is for students more difficult than closed tasks with multiple choose item, where the offered answers represent a certain hint, whether positive or negative.

9. Analysis of possible causes of unsatisfactory results

In this paragraph, we briefly analyze possible causes of student failures in entrance exams in some areas of secondary school physics. Our qualitative analysis is based on

- the opinions of cooperating secondary school teachers (we obtained a summary of these experiences in personal contact, see [44]),
- the answers of our first-semester students of physics in specific questionnaire (48 respondents),
- our own opinions and long-term experience in teaching mathematics and physics on MU.

We summarize these experiences in the following three areas: 1) competencies,2) priorities, 3) educational system.

1) **Experiences and opinions of teachers.**

   Competencies: in the opinion of grammar school teachers the problem lies mainly in mathematics. It is due mainly to the overall change in lifestyle, technologies, the setting of society, etc. The problems are: concentration, time spent to training, 'endurance'. Our conclusion at the grammar school is therefore that a) some things cannot be changed and it is better to adapt to them, b) some things can be changed, but it means working on it already in primary school, which means: precise development of competencies, but carried out honestly and with judiciously. Concentration, hard work, honesty, resilience, ... all this can be trained. But it has to actually happen. It will help a lot in teaching.

   Priorities: it must be admitted that there are many more options and fields of study today than before. Many more of those very high-quality students today simply go somewhere else than physics at the Faculty of Science of the MU. For example only cca 10% secondary school graduates of prestigious Brno grammar schools want to study natural sciences (mathematics, physics, chemistry, biology, geology and geography), of which, of course, physics is a minority (representative data we get from [44]).

   Educational system: here is the root cause of the problems. Grammar schools are no longer a guarantor of quality of education, the state system has completely abandoned it. There is extreme variation between and within schools. In principle, this in itself is not harmful. It's about the absence of a system to work with it. Physics, i.e. a highly demanding and specialized course, is often attended by 'random' interested parties. Those who do not have the proper training for it from high school. *This is the fault of the secondary schools, which did not prepare them for this, and the university, which accepted them at all.*

2) **Experiences and opinions of first-semester MU-students of physics.**

   With our first-semester students of physics, we mainly discuss problems related to their transition between secondary school and university. This jump between those two levels of education turns out to be significant and problematic. In 2024, we ascertained the circumstances of their studies at secondary school using a brief questionnaire. 48 students responded. (Usually, in the first semester, cca 70 students begin their studies, whereas cca 20–30 percent does not meet the requirements for to be admitted to the semestral exam of Mechanics (first discipline of general physics on MU). We summarize opinions of students:

   Competencies: students themselves feel a lack of competencies in mathematics and, in particular, the ability to apply the mathematical tools for solving physical problems. A fundamental problem for students is the absence of a connection between mathematics and physics education Only 7% of respondents demonstrate the connection of mathematics and physics in secondary school education, for 26% of them mathematics and physics were completely separate and unrelated disciplines, the remaining 67% experienced the connection of mathematics and physics education only exceptionally. (Teachers emphasize the lack of mathematical skills of students as well). Another problem lies in the small number of hours of mathematics and physics per week. While in mathematics it is an average of 4 h per week, in physics it is only 2.7 h. Only 11 percent of students answered that laboratory exercises were also a part of physics lessons.

   Priorities: not all current first-semester students of physics had this field as their first choice. Only two-thirds of our first-semester physics students graduated in physics. A third of the number of students who met the requirements for admission to the exam of Mechanics, primarily applied to study fields other than physics. (See also experiences of teachers).

   Educational system: students do not comment on the teaching system as such.

3) **Our own opinions and long-term experiences**
Competencies: every year we observe a gradual decline in students' knowledge and skills in mathematics, inexperience in routine calculations or application of simple relationships, ignorance of basic relationships (e.g. trigonometry), errors in simple calculations without a calculator or software. Students do not have developed physical reasoning, they have experienced relatively fundamental errors in reasoning. Even official textbooks do not contribute significantly to the development of physical thinking and problem-solving skills. (Even though problems are solved in physics lessons on secondary schools – at least one task in each lesson, it is mainly about substituting into simple formulas without deeper understanding).

Priorities: one of our main priorities is the systematic linking of mathematics with physical application. This is missing not only in secondary schools, but also often in university teaching. (The teaching of mathematical disciplines (analysis, algebra) is not usually linked, with exceptions, to physical applications). Additional emphasis is placed on performing demonstration experiments during theoretical teaching of general physics. (Practical exercises are a separate topic of curriculum).

Educational system: the Czech education system operates on the basis of Framework education programs (RVP), whose content is often affected by reforms. As a result of school reforms, teaching hours of physics in secondary schools are reduced. In addition, physics is not obligatory in the fourth year of upper secondary or grammar school (there is only an optional physics seminar). Counterproductive changes in physics curricula are continuously proposed—for example, removing Newton's laws from teaching at the lower secondary schools! The inclusion of laboratory exercises in physics education is exceptional, or rather marginal. In our opinion, there can be also observed a shift of the 'centre of gravity' of primary and secondary school teaching to existing and new 'soft' disciplines. (The current reform is being proposed in January 2025). The organizational system of education does not force graduates to choose a specific field of university study, the applicant can submit an application to several universities, he can even be enrolled at several universities at the same time, some of them then leave. What the results look like afterwards, there is no need to comment.

10. Conclusions

In our contribution, we presented an analysis of the results of the entrance exams to study physics at the Faculty of Science, MU. Entrance examinations of the type described have already taken place in the past few years and the analyses always show roughly the same results of different types presented above. Due to the fact that the author's own experience with secondary school teaching is short-term (2 years of teaching mathematics), and due to the current situation of teaching mathematics and physics in secondary schools (see opinions of teachers), it is difficult to give any fundamental recommendations. Our recommendations for secondary school physics education therefore relate to partial problems resulting from the results of the entrance exams and our own experiences with university physics and mathematics education.

- *'universal' recommendations:*
  - Cultivate and strengthen mathematical skills.
  - Strengthen the connection between mathematics and physics and the ability to use appropriate mathematical tools in physics.
  - In teaching physics in general, use as many demonstration experiments as possible and more laboratory exercises.
  - Strengthen students' interest in mathematics and physics in non-traditional forms, for example KvIS—this method is very effective for studying physics at MU, see [46].
- In the field of mechanics, it turns out that a deeper understanding of Newton's laws and skills in applying them are at a low level.

The focus lies more on strengthening formal knowledge, and it is not at a satisfactory level. (Mechanics is taught in the first year of upper secondary schools, and before entering university, the forgetting effect is probably manifested). A manifestation of underdeveloped physical thinking lies an almost fatal failure to solve closed problems with multiple correct answers in the 'all or nothing' evaluation. (Less strict methods, such as the method of 'auxiliary point method' or the 'penalty point method', show rather the existence of knowledge of certain facts without their connection and without the ability to think about them as a whole).

Recommendations: strengthen the understanding of the laws of mechanics, especially dynamics, by solving problems that require not only substitution into formulas, but also more complex thinking.

- The results in Thermics/thermodynamics and molecular physics, and Electricity and magnetism, partly also in Optics, are poor, probably due to the fact that the teaching is focused on formal knowledge and explanation without solving problems and without demonstration experiments (financial problems can also be the cause here). Students have fundamental deficiencies in solving open tasks, where helplessness is usually manifested. In particular, thermodynamics appears to students to be too abstract, and teaching is not supported by demonstration experiments, see formerly mentioned papers [17, 18]), [19–21].

  Recommendations: strengthen the experimental component of teaching even in seemingly abstract disciplines and using appropriate simulations and animations (both these aspect see e.g. in [45])
- In the field of waves, there is a misunderstanding of the expression for wave deflection as a function of two or more variables (time and position), the problem may lie in mathematics.

  Recommendations: to create a clear idea of the functions of two variables, use appropriate graphic presentations and animations, but also to a greater extent mechanical and optical demonstration experiments.
- Astrophysics, elements of STR and Physics of microcosm are treated only factually, which does not lead to more lasting knowledge. *Recommendations:* although a deeper understanding of the essence of these physics topics is apparently not possible at the secondary school level, appropriate popularization can at least increase students interest in physics as such.

Summarizing we can state: teaching physics at secondary schools does not effectively lead to the development of physical thinking. It is based more on factual presentation, with a minimum of experiments and laboratory works, a minimum of solving physical problems. We consider the causes to be the constant reducing of time for physics teaching and changes of curricula resulting from frequent educational reforms, lack of demonstration experiments and laboratory exercises in physics lessons, little emphasis on solving physical problems, insufficient emphasis on mathematical skills in general and when solving physical problems, insufficient effort to strengthen students' interest in physics through appropriate, but not superficial, popularization and with help of modern software tools.

Data availability statement

The data cannot be made publicly available upon publication because no suitable repository exists for hosting data in this field of study. The data that support the findings of this study are available upon reasonable request from the authors.

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