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JIF = 1.500 | SJIF (Morocco) = 7.184 | OAJI (USA) = 0.350

SOI: 1.1/TAS DOI: 10.15863/TAS

International Scientific Journal
Theoretical & Applied Science

p-ISSN: 2308-4944 (print) **e-ISSN:** 2409-0085 (online)

Year: 2024 **Issue:** 08 **Volume:** 136

Published: 20.08.2024 **http://T-Science.org**

Issue Article

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INDUCTIVE-HISTORICAL AND DEDUCTIVE-THEORETICAL METHODS OF TEACHING PHYSICS

***Abstract**: Using the example of the history of teaching physics in Russian universities from the end of the 19th century to the present day, the inductive-historical and deductive-theoretical methods of teaching physics are considered. At the end, modern educational technologies that help to deliver high-quality lectures are briefly described.*

***Key words**: Inductive-historical method, deductive-theoretical method, teaching physics in universities, history of science and pedagogy, general physics course.*

***Language**: English*

***Citation**: Kozhevnikov, V.A. (2024). Inductive-historical and deductive-theoretical methods of teaching physics. *ISJ Theoretical & Applied Science, 08 (136),* 51-59.

***Soi**: http://s-o-i.org/1.1/TAS-08-136-6 ***Doi**: crossref https://dx.doi.org/10.15863/TAS.2024.08.136.6

***Scopus ASCC**: 3304.*

Introduction

This work is a continuation of the work [1] on the methodology of teaching physics in universities. While the previous article talked about the Olympiad movement for talented students, this work examines two common methods of teaching physics to all students. This paper examines the teaching of physics in Russian universities in the late 19th – early 21st centuries, and at the end briefly describes some pedagogical tools to help the teacher. This work is based on a lecture given by the author in 2023 at a methodological seminar within the framework of the project “Pedagogical Workshops of the Polytechnic University”, which is organized by the Center for Education Quality at SPbPU [2].

Inductive-historical method of teaching physics

There is no point in talking about the importance of studying physics once again. I will simply cite two very famous quotes – from Ernest Rutherford: “All science is either physics or stamp collection” and the famous mathematician V. I. Arnold: “Mathematics is a part of physics” [3].

From the point of view of teaching physics in Russian universities, the discipline "Physics" in the curriculum was promoted to the group of basic disciplines at the end of the 19th century. At the end of the 19th century, reforms were carried out in Russia and new polytechnic and technological institutes were opened – in Riga (1862), in Kharkov (1885), in Tomsk (1896), the Imperial Moscow Engineering School (1896), in Kyiv (1898), and in St. Petersburg (1899). Classical physics was taught in classical universities and these polytechnic institutes. One of the most famous courses was taught at St. Petersburg University by a graduate of this university, Orest Danilovich Khvolson [4], the author of the fundamental “Physics Course”. This was a course initially in 3 volumes (the first edition was published in 1897-1900), then in 4 volumes, then in 5 volumes (the fifth volume, entitled “Additional Volume,” was published in 1926 in two parts). I believe that any university physics teacher should take this course. The fundamental nature of this course is demonstrated by the fact that each volume was about 700-800 pages long. This course was called “a handbook for every physicist,” and in 1908 Khvolson became a laureate of the Lomonosov Prize for creating this course. The course went through several editions, was translated into foreign languages (German, French, Spanish), was world famous and, for example, was highly appreciated by Einstein. This was a course in classical physics (i.e. physics before the beginning of the 20th century – the newest physical concepts were included later in the "Additional Volume"), with fairly simple mathematics, and much attention was paid to experiments. Figure 1 shows a screenshot of a typical page of Khvolson's course - he has a lot of diagrams and drawings of experiments in the course. For example, in the four-volume course (1900-1913) there were about 1800 drawings. In addition to Khvolson's course, there were, of course, less grandiose courses, for example, courses by Borgman [5], Mikhelson [6], Lazarev [7], Rozhanskiy [8], Malinin [9], Tsinger [10], Petrushevskiy [11], but for a long time Khvolson's "Physics Course" remained the main textbook in universities of the Russian Empire, and then in Soviet universities. Khvolson wrote: "So, the discovery, study and explanation of phenomena, these are the three great goals that physics strives for." [12].

And such a presentation of the physics course – an inductive-historical approach to the subject – was characteristic of that time [13], and not only in Russia. That is, the mainstream of that time in teaching physics was to first talk (usually in historical sequence) about the particular laws of physics with a detailed description of the corresponding experiments and phenomena, and then move on to the general fundamental laws. That is why this method of teaching is called inductive-historical or historical-inductive.

Revolutionary changes at the beginning of the 20th century

But at the beginning of the 20th century, revolutionary events took place both in the world of physics and in Russian society.

Quantum mechanics and the theory of relativity appeared in physics, which completely broke the generally accepted ideas about the description and interpretation of physical phenomena. The laws of quantum physics seemed crazy to many physicists, even to the founders of the new physics themselves. Much has been written about this, I will give only a few very famous quotes from great physicists dedicated to quantum mechanics – this is a quote from Einstein, who for a long time could not accept quantum mechanics "At any rate, I am convinced that He [God] does not play dice"; the words of Niels Bohr "Those who are not shocked when they first come across quantum theory cannot possibly have understood it"; Max Planck called his work "an act of desperation".

There were heated discussions between representatives of classical and new physics, and, by the way, SPbPU was one of the arenas of such discussions in Russia. For example, there was a heated discussion about the nature of the electromagnetic field - on one side was academician Vladimir Fedorovich Mitkevich, he adhered to the theory of ether, and on the other side was corresponding member Yakov Ilyich Frenkel - he denied ether. This discussion lasted almost 10 years. And there were similar heated discussions on many issues of new physics, so the question of how to teach physics in general became very acute.

And the second revolution was the revolution of 1917. The country's leadership set the task of creating a complete picture of the social and technical movement towards building socialism [14], and new textbooks were needed. There were pedagogical experiments and educational reforms – for example, in 1931 a new method was introduced – the laboratory-team method of teaching [15]. The class (or group) was divided into teams of 4-6 people. The teacher gave the team a book and a list of questions to which they had to give a coherent answer. One student answered for each subject, and the entire team received grades. The brigade was headed by a foreman, and he was in contact with the teacher. This was an attempt to collectivize student learning and concentrate it in laboratories; the brigade method pursued a goal that eluded standard teaching methods: to combine lecturing with textbook study. However, this method did not live up to expectations (it did not provide systematic knowledge), and soon (in 1932) it was cancelled.

The country's leadership set the goal of educating physicists in the rather harsh conditions of that time who would be able to conduct research at a "world level".

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Роль измерений физических величин в общем курсе физики должна определяться следующими соображениями:

Существуют такие измерения, которые в теоретическом отношении никаких трудностей не представляют; для их понимания достаточно знания элементарного курса физики. При этом метод измерения и в особенности применяемые при этом приборы могут быть весьма сложны. Сюда относятся, например, измерения углов, длин, площадей, объемов, некоторых сил, веса, давления, времени, плотности и др. Нет надобности рассматривать эти измерения в общем курсе физики.

Затем существуют многочисленные измерения, которые в теоретическом отношении представляют нечто новое для знакомых только с элементарной физикой. Относительно таких измерений должны быть, в общем курсе физики, изложены теоретические основы, но без указания деталей метода и устройства инструментов. Сюда относится, например, метод измерения сил при помощи крутильных весов, которому посвящена эта глава, а также методы измерения силы тяжести (глава X).

Наконец, имеется ряд исторически важных измерений, которые ныне весьма редко или вовсе не повторяются и которые, конечно, должны быть рассмотрены в общем курсе физики. Сюда относятся, например, методы измерения средней плотности Земли (глава XI), скорости света и др.

§ 2. Однонитные крутильные весы или унифиляр. Этот важный прибор служит для измерения притягательных или отталкивательных сил, обнаруживающихся в различных случаях между телами (всемирное тяготение, притяжение и отталкивание между магнитами или наэлектризованными телами). На основании сказанного в § 1 нам нет надобности описывать современные унифиляры; нам важен только принцип их устройства. На рис. 127 изображен один из простейших видов унифиляра, иногда впрочем не представляющего особого прибора, но входящего, как часть, в состав других более сложных инструментов.

Существенная часть унифиляра — это горизонтальное, обыкновенно стержневидное тело, висящее на тонкой нити, прикрепленной над его центром тяжести. Нить может быть металлическая (из алюминия, серебра, платины), стеклянная или коконовая; иногда приготовляют нити кварцевые (предложены Boys'ом в Англии). Горизонтальное тело может быть весьма различно, смотря по тому, для каких измерений назначен унифиляр: это может быть легкий стерженек, снабженный на одном или обоих концах шариками, магнит, плоская продолговатая пластинка и т. д. Это тело может быть помещено внутри круглого или четырехугольного стеклянного ящика, а нить—внутри вертикальной трубки R, поставленной над круглым отверстием, вырезанным посреди крышки ящика. В этой крышке имеется обыкновеннно сбоку еще второе отверстие, служащее для ввода внутрь ящика другого тела (магнита, наэлектризованного шарика), отталкивательное действие которого на другое тело требуется измерить.

Рис. 127. Рис. 128.

Верхний конец нити прикреплен к центру крышки вертикальной трубки. Эта крышка вращается, причем угол вращения может быть измерен; кроме того, обыкновенно существует приспособление для поднимания или опускания всей нити. На рис. 128 изображена верхняя часть трубки одного из унифиляров. Нить прикреплена к стержню g, который может быть приподнят, опущен,

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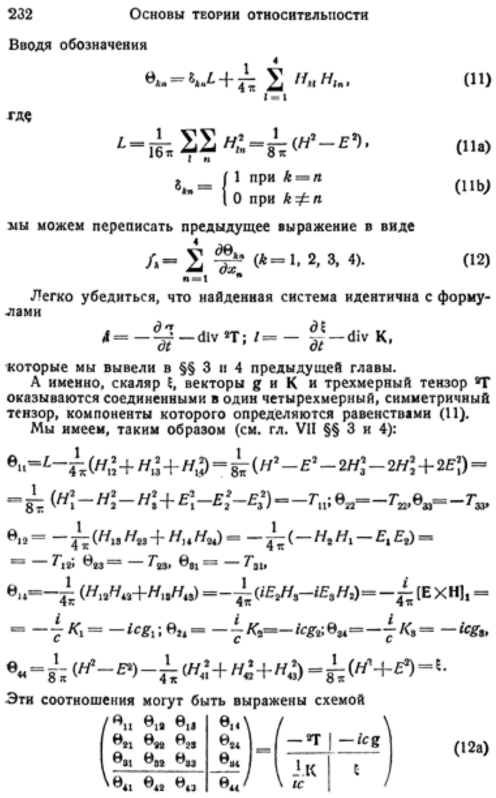
Fig 1. Page from Khvolson's textbook

Deductive-theoretical method of teaching physics

And so Frenkel decided to make a textbook on electrodynamics based on his lectures at SPbPU. He first published it in Berlin in 1926-1927, and later (1934-1935) a slightly edited version was published in Russian. It was, one might say, a revolutionary textbook for both Russia and Europe, where the special theory of relativity was chosen as the initial premise and, for almost the first time, a deductive-theoretical, rather than an inductive-historical approach to the subject was proposed. One of the reviewers of the journal “Nature” wrote that Frenkel was looking for a way to put an end to the historical presentation of the doctrine of electricity, which is natural in the atmosphere of Leningrad. The deductive-theoretical approach to teaching is characterized by the presentation of physics from the general fundamental principles, and the usual questions of the general physics course are then considered as special cases of the general theory. Moreover, the emphasis is placed on the theory. Figure 2 shows a screenshot of Frenkel's textbook "Electrodynamics, Volume 1" in Russian, so that the difference with Khvolson can be seen.



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Вводя обозначения

$$\Theta_{kn} = \delta_{kn} L + \frac{1}{4\pi} \sum_{l=1}^{4} H_{kl} H_{ln}, \qquad (11)$$

где

$$L = \frac{1}{16\pi} \sum_l \sum_n H_{ln}^2 = \frac{1}{8\pi} (H^2 - E^2), \qquad (11a)$$

$$\delta_{kn} = \begin{cases} 1 \text{ при } k = n \\ 0 \text{ при } k \neq n \end{cases} \qquad (11b)$$

мы можем переписать предыдущее выражение в виде

$$f_k = \sum_{n=1}^{4} \frac{\partial \Theta_{kn}}{\partial x_n} \quad (k = 1, 2, 3, 4). \qquad (12)$$

Легко убедиться, что найденная система идентична с формулами

$$f = -\frac{\partial g}{\partial t} - \mathrm{div}\, {}^2\mathbf{T}; \quad l = -\frac{\partial \xi}{\partial t} - \mathrm{div}\, \mathbf{K},$$

которые мы вывели в §§ 3 и 4 предыдущей главы.

А именно, скаляр ξ, векторы $\mathbf{g}$ и $\mathbf{K}$ и трехмерный тензор ${}^2\mathbf{T}$ оказываются соединенными в один четырехмерный, симметричный тензор, компоненты которого определяются равенствами (11).

Мы имеем, таким образом (см. гл. VII §§ 3 и 4):

$$\Theta_{11} = L - \frac{1}{4\pi}(H_{12}^2 + H_{13}^2 + H_{14}^2) = \frac{1}{8\pi}(H^2 - E^2 - 2H_3^2 - 2H_2^2 + 2E_1^2) =$$

$$= \frac{1}{8\pi}(H_1^2 - H_2^2 - H_3^2 + E_1^2 - E_2^2 - E_3^2) = -T_{11}; \Theta_{22} = -T_{22}, \Theta_{33} = -T_{33},$$

$$\Theta_{12} = -\frac{1}{4\pi}(H_{13}H_{23} + H_{14}H_{24}) = -\frac{1}{4\pi}(-H_2 H_1 - E_1 E_2) =$$

$$= -T_{12}; \ \Theta_{23} = -T_{23}, \ \Theta_{31} = -T_{31},$$

$$\Theta_{14} = -\frac{1}{4\pi}(H_{12}H_{42} + H_{13}H_{43}) = -\frac{1}{4\pi}(iE_2H_3 - iE_3H_2) = -\frac{i}{4\pi}[\mathbf{E} \times \mathbf{H}]_1 =$$

$$= -\frac{i}{c}K_1 = -icg_1; \ \Theta_{24} = -\frac{i}{c}K_2 = -icg_2; \ \Theta_{34} = -\frac{i}{c}K_3 = -icg_3,$$

$$\Theta_{44} = \frac{1}{8\pi}(H^2 - E^2) - \frac{1}{4\pi}(H_{41}^2 + H_{42}^2 + H_{43}^2) = \frac{1}{8\pi}(H^2 + E^2) = \xi.$$

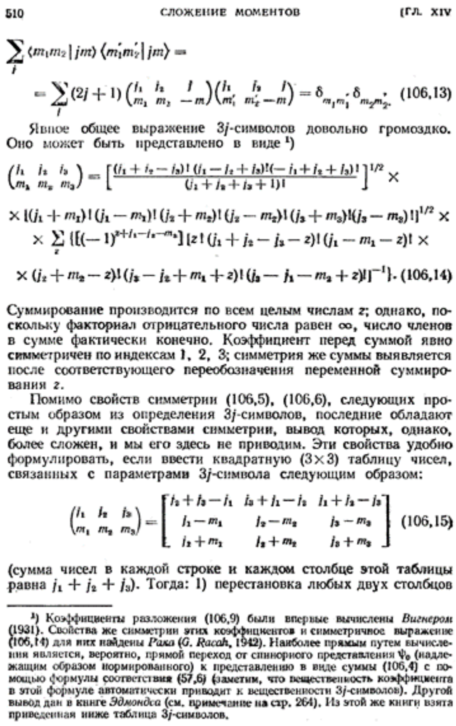
Эти соотношения могут быть выражены схемой

$$\left(\begin{array}{ccc|c} \Theta_{11} & \Theta_{12} & \Theta_{13} & \Theta_{14} \\ \Theta_{21} & \Theta_{22} & \Theta_{23} & \Theta_{24} \\ \Theta_{31} & \Theta_{32} & \Theta_{33} & \Theta_{34} \\ \hline \Theta_{41} & \Theta_{42} & \Theta_{43} & \Theta_{44} \end{array}\right) = \left(\begin{array}{c|c} -{}^2\mathbf{T} & -ic\mathbf{g} \\ \hline \frac{1}{ic}\mathbf{K} & \xi \end{array}\right) \qquad (12a)$$

Fig.2 Page from Frenkel's textbook

And this deductive-theoretical method began to be used in full force in the so-called "Bible of theoretical physics" – "The Course of Theoretical Physics" by Lev Davidovich Landau and his student Evgeny Mikhailovich Lifshitz. This course was conceived as a five-volume set at the very end of the 1920s, and turned into a ten-volume set in the 1970s. This course was conceived by Landau and Matvey Petrovich Bronshtein (who worked part-time at SPbPU), and they began working on it together. As is known, in 1931 Landau had a falling out with Ioffe and left for Kharkov, and Landau and Bronstein worked on the course independently – one in St. Petersburg, the other in Kharkov. But Bronstein was arrested in 1937 and shot at the beginning of 1938, and Landau continued to work on the first volumes together with Lifshitz and Pyatigorsky.

There is a lot to say about this course, it has become a standard textbook and has spread its influence on the teaching of physics at all levels. Suffice it to say that it has been translated into dozens of languages, and a total of about a million copies have been sold (if you count all the copies in different countries) – which is a record for such a special textbook. After this course, the mass transition from inductive-historical to deductive-theoretical presentation of physics began. To make it clear how far this course is from any description of experiments that was accepted in physics courses before it, we can cite the following fact: in the first edition of "Statistical Physics" (this is the 5th volume of the Course, but historically it was this volume that was published first in 1938 before Landau's arrest) the only (!) experimental numerical value mentioned is the Boltzmann constant. That is, for the entire large volume there is only one reference to an experimental value, and everything else is one theory and formulas without any experimental values. Figure 3 shows a screenshot from the Landau and Lifshitz Course.



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$$\sum_j \langle m_1 m_2 | jm\rangle \langle m_1' m_2' | jm\rangle =$$

$$= \sum_j (2j+1) \begin{pmatrix} j_1 & j_2 & j \\ m_1 & m_2 & -m \end{pmatrix} \begin{pmatrix} j_1 & j_2 & j \\ m_1' & m_2' & -m \end{pmatrix} = \delta_{m_1 m_1'} \delta_{m_2 m_2'}. \quad (106,13)$$

Явное общее выражение $3j$-символов довольно громоздко. Оно может быть представлено в виде [1])

$$\begin{pmatrix} j_1 & j_2 & j_3 \\ m_1 & m_2 & m_3 \end{pmatrix} = \left[\frac{(j_1+j_2-j_3)!\,(j_1-j_2+j_3)!\,(-j_1+j_2+j_3)!}{(j_1+j_2+j_3+1)!}\right]^{1/2} \times$$

$$\times [(j_1+m_1)!\,(j_1-m_1)!\,(j_2+m_2)!\,(j_2-m_2)!\,(j_3+m_3)!\,(j_3-m_3)!]^{1/2} \times$$

$$\times \sum_z \{[(-1)^{z+j_1-j_2-m_3}] [z!\,(j_1+j_2-j_3-z)!\,(j_1-m_1-z)! \times$$

$$\times (j_2+m_2-z)!\,(j_3-j_2+m_1+z)!\,(j_3-j_1-m_2+z)!]^{-1}\}. \quad (106,14)$$

Суммирование производится по всем целым числам z; однако, поскольку факториал отрицательного числа равен ∞, число членов в сумме фактически конечно. Коэффициент перед суммой явно симметричен по индексам 1, 2, 3; симметрия же суммы выявляется после соответствующего переобозначения переменной суммирования z.

Помимо свойств симметрии (106,5), (106,6), следующих простым образом из определения $3j$-символов, последние обладают еще и другими свойствами симметрии, вывод которых, однако, более сложен, и мы его здесь не приводим. Эти свойства удобно формулировать, если ввести квадратную (3×3) таблицу чисел, связанных с параметрами $3j$-символа следующим образом:

$$\begin{pmatrix} j_1 & j_2 & j_3 \\ m_1 & m_2 & m_3 \end{pmatrix} = \begin{bmatrix} j_2+j_3-j_1 & j_3+j_1-j_2 & j_1+j_2-j_3 \\ j_1-m_1 & j_2-m_2 & j_3-m_3 \\ j_1+m_1 & j_2+m_2 & j_3+m_3 \end{bmatrix} \quad (106,15)$$

(сумма чисел в каждой строке и каждом столбце этой таблицы равна $j_1+j_2+j_3$). Тогда: 1) перестановка любых двух столбцов

[1]) Коэффициенты разложения (106,9) были впервые вычислены *Вигнером* (1931). Свойства же симметрии этих коэффициентов и симметричное выражение (106,14) для них найдены *Рака* (*G. Racah*, 1942). Наиболее прямым путем вычисления является, вероятно, прямой переход от спинорного представления ψ_0 (надлежащим образом нормированного) к представлению в виде суммы (106,4) с помощью формулы соответствия (57,6) (заметим, что вещественность коэффициента в этой формуле автоматически приводит к вещественности $3j$-символов). Другой вывод дан в книге *Эдмондса* (см. примечание на стр. 264). Из этой же книги взята приведенная ниже таблица $3j$-символов.

Fig.3 Landau and Lifshitz Course Page

Landau had somewhat radical views on teaching. Landau once advised a graduate student that "one should think less about the basics. The main thing to master is the technique of work, and an understanding of the subtleties will come later". Why he said this – if you think about it, this statement doesn't seem so strange. Landau believed that canonical textbooks created the idea that the current triumph of science was achieved through the discovery of first principles, and this is unlikely to help students correctly prioritize solutions to modern problems. This attitude, Landau believes, distorts the role of outstanding people and "foundational" research, confusing talented students and distracting them from regular studies and exercises that allow them to master the subtleties of the craft. If they were just disciplined enough in their studies, they could have reached the forefront of science. And one of the tasks set before Landau was how, under fairly harsh conditions, to educate at least a handful of professional theorists who would be able to conduct research at a "world level". Landau, by the way, suggested taking a "theoretical minimum," consisting of 9 exams, including mathematical apparatus (2 exams) and all the main sections of theoretical physics (the remaining 7). Hundreds of physicists attempted to pass these exams during Landau's lifetime, but only 43 of them (during Landau's lifetime) passed them in full, and of these, about a dozen were honored to work directly with Landau for quite a long time. And yet the influence of this small group of scientists (as well as their own students) on Soviet and Russian physics was enormous.

It cannot be denied that in those difficult times there was also obscurantism of the type like this: on December 3, 1948, the President of the USSR Academy of Sciences S. I. Vavilov and the Minister of Higher Education S. V. Kaftanov sent a letter to the Central Committee of the All-Union Communist Party (Bolsheviks) with a request for permission to convene an All-Union Conference of Heads of Physics Departments of Universities and Higher Education Institutions with the participation of the Physics and Mathematics Department of the Academy of Sciences. Here is a quote from this letter: "The USSR Ministry of Higher Education and the USSR Academy of Sciences believe that there are serious shortcomings in the teaching of physics in higher education institutions, as well as in the field of scientific research. The physics course is taught in many higher education institutions in complete isolation from dialectical materialism. Lenin's brilliant work "Materialism and Empiriocriticism" is still far from being fully used by physics teachers in their presentation of the course... Idealistic philosophical conclusions from modern theoretical physics (quantum mechanics and the theory of relativity) pose a particularly serious danger to students…" It's good that in August 1949, the first Soviet atomic bomb was successfully tested at the Semipalatinsk test site, and the physicists were left alone. But it seems that the main problem in teaching physics was not this attempt to impose a doctrine from above, but the fact that the physicists themselves, including the founders of this new physics, had difficulties in trying to explain this new physics. It was even more unclear how to teach it.

A very interesting view from the outside (I mean Western researchers) on the influence of this course on the teaching of physics throughout the world is contained in [16]. The author writes that the Course, more than any other textbook of the second half of the last century, did more to undermine traditional ideas about how physical canons are created. Here is another quote from Landau, showing that it was important for him to teach the correct research methods: "The method is more important than the discovery, because the correct research method will lead to new, even more valuable discoveries." As already noted, it was after this course that the transition from inductive-historical to deductive-theoretical presentation of physics began. Namely, in many textbooks it has become fashionable to begin the presentation of mechanics with the theory of relativity, the presentation of electromagnetism with Maxwell's equations, the presentation of thermodynamics and statistical physics with the Gibbs distribution, etc.

Reverse rotation and current state

In the late 60s and 70s, a return to the inductive-historical approach began and classical textbooks on general physics were created, which are widely used and are now used in almost all universities. These are the textbooks of Dmitry Vasilyevich Sivukhin (General Course of Physics (in 5 volumes), 1975-1989), Igor Vladimirovich Savelyev (Course of General Physics (in 3 volumes (now in 5 volumes)), 1961-1970), Igor Evgenievich Irodov (Course of Physics (in 5 books), 1975-2001), Alexey Nikolaevich Matveyev (Course of General Physics (in 5 volumes), 1976-1989). The years in brackets in the previous sentence are the years of publication of the first editions of the corresponding courses - the years are different, since different volumes were published for the first time, as a rule, in different years; between the first editions of the first and last volumes of the course, as a rule, many years passed (Savelyev initially had a course in 3 volumes, but then it also became in five).

Since the early 90s, many physics textbooks have been published, many of them were published by local publishers, but their quality, unfortunately, often left much to be desired. In the 2000s, this process intensified and the situation worsened [17], firstly, by the introduction of new Federal State Educational Standards [18], which led to a decrease in classroom workload (FSES-3 in particular), and secondly, the introduction of the Unified State Exam in schools lowered the level of school preparation (and in our reality, it is no secret that in many schools in senior classes teachers are forced to prepare schoolchildren specifically for passing the Unified State Exam). Therefore, the issue of teaching physics in universities became acute. And the Scientific and Methodological Council for Physics of the Ministry of Education and Science of the Russian Federation was created [19]. One of the main goals of the Council is to examine educational literature and determine the content of physics courses and courses on the Concept of Modern Natural Science. The Council's base university was our SPbPU - i.e. it was there (but not only there, of course) that both manuscripts and published manuals were sent for review by universities and various publishing houses. One of the main methodologists of this Council was the deputy head of the physics department Nikolai Mikhailovich Kozhevnikov. He has many works on the methodology of teaching physics, he was an opponent of the deductive-theoretical method and a supporter of the inductive-historical approach. The council was formed in 2002, but after the deaths of Alferov and Kozhevnikov, its activities somehow faded away, and now it does not exist, but there is the Coordinating Council for the field of education "Mathematical and Natural Sciences" [20]. And now the question of how to teach physics correctly is again acute.

Conclusion. So which method is better?

So what approach is best to use for teaching physics at a university? The author's opinion is that it is best to use a mixed approach that combines the deductive-theoretical approach with the historical-inductive approach. In this way, students will gain a clear understanding of the specifics of physics and will be able to connect practice with theory. This approach will help participants in the process to get more benefit from teaching physics. No matter how much the author respects Landau, in my opinion, the level of current first-year students does not allow the use of the deductive-theoretical method. The author's experience of giving lectures on general physics at four universities tells him that, of course, the course material still needs to be coordinated to some extent with both the level of the students and the direction of their training (and even within one university - SPbPU - the author gave different courses of lectures on general physics for different areas of study).

Regarding the lectures themselves - what practices do I personally consider useful? At the very beginning of the lecture, you need to very briefly, but remind what was in the previous lecture. Very useful, in my opinion, are the so-called Rules of the

American Sergeant: 1) tell the audience what you want to tell them about – i.e. tell the plan of the lecture; 2) tell the audience everything that you wanted to tell them – i.e. actually tell the material of the lecture; 3) tell the audience what you just told them about – i.e. sum up at the end. Both in lectures and in practical classes, it is advisable to try to give examples of various phenomena whose physical explanation corresponds to the topic of the classes. Such examples can be found in many classical physics textbooks, as well as in various popular science publications, Internet channels - now there are many interesting videos on the Internet on various physical topics. Students should see that physics is everywhere and explains a lot of phenomena around us. A mandatory part of lectures is answering questions - both during the break and after the end of the lectures, and afterwards (via the Internet). In general, maintaining regular contact with students is very important – even though it sometimes takes a lot of time.

In my opinion, lecture demonstrations play a very important role in the course. They are used to visualize physical phenomena and laws and allow students to understand the concepts more deeply and apply them to real-life situations. In addition, demonstrations make the learning process more interesting and memorable by transferring abstract concepts into a visual mode. In turn, this helps students better absorb the material and improve their understanding of physics. The Physics Department at SPbPU [21] has a very good demonstration room, and the author tries to show all the demonstrations of this room in his lectures. In extreme cases, computer modeling of some experiment is acceptable (see, for example, [22]), but physical demonstrations are always preferable to computer ones.

It is very important to analyze your lectures, striving to improve your teaching skills. To do this, you need to record them (audio or video). To reduce the analysis time, you can avoid watching/listening to your entire lecture (although this is also very useful), and use a system for transcribing audio and video into text, for example [23] (the works [23]-[28] have been written about the IT infrastructure of SPbPU that we are creating, which helps to conduct classes effectively). A very useful tool for teachers to analyze their own lectures is Teaching Assistant [29]. This system allows you to create a lesson notes, calculate various metrics (distribution of conversation, methodological techniques, sociological techniques, speech rate, emotional modality), etc. The interface for loading a lesson into the system is shown in Figure 4.

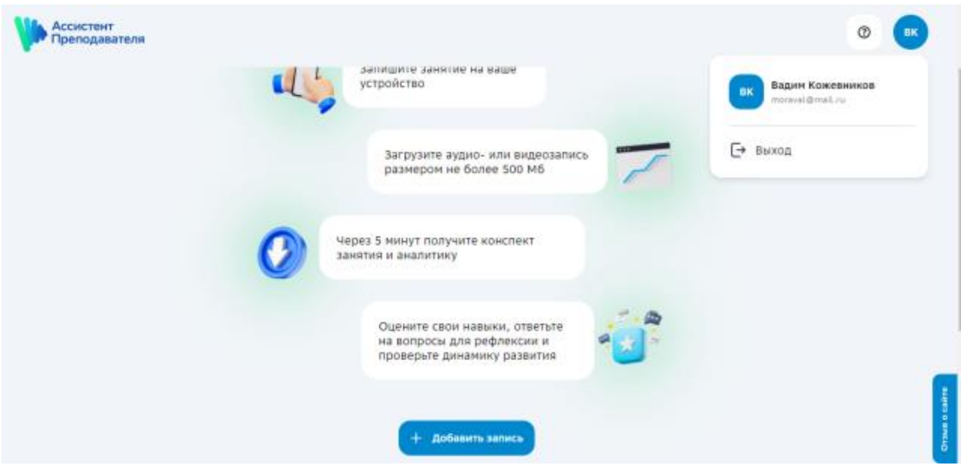

Fig 4. Teaching Assistant

Training on a VR public speaking simulator is very useful. SPbPU has a professional development program that uses such a simulator [30]. The VR simulator creates a room with listeners, which can be used to track the dynamics of the speech. Using the device, you can rehearse a speech, try out a prepared presentation. The program evaluates the performance on criteria such as eye contact and audience interaction, use of filler words.

The main thing that is very important for a teacher, in my opinion, is to love his job and be able to interest the student in his subject.

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