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CLASSIFICATION OF ANALOGIES AS A METHODOLOGICAL FRAMEWORK FOR USE IN INSTRUCTION IN PHYSICS

In the article, the author provides a detailed description of the methodology used to collect and analyze research data, and the process of developing a classification system. The main part of this study is based on the results of a survey of physics teachers. The author also showed that the data collected during the survey were qualitatively analyzed using thematic analysis, and a comprehensive system of classification of analogies in physical education was developed. It is described that analogies in teaching physics can be divided into two main groups. These are subjective and intersubject analogies. That is, the development of a comprehensive system of classification of analogies that can be used in physics education is being considered in detail. The use of analogies is studied as a means to improve students' understanding of abstract scientific concepts, in particular, in the context of electromagnetism. The research uses a methodology for analyzing scientific literature based on various sources to identify and evaluate different approaches to analog thinking in physics education. The results of the study demonstrate that the analogy classification system can greatly simplify the explanation of complex scientific concepts, providing teachers with a valuable tool for improving pedagogical practices. In addition, the proposed classification system offers a framework for developing new analogies and improving existing ones, contributing to the development of more effective teaching methods. In general, the study emphasizes the importance of analogical thinking in physics education and offers practical findings that can be applied in the development of educational materials in various fields based on the use of analogies.

Keywords: physics education, analogies in physics, methodological value of analogies, educational process, problem-solving, systematization of knowledge, teaching effectiveness.

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Физикада оқытуға пайдалану үшін методологиялық негіз ретінде аналогияларды сыныптау

Мақалада автор зерттеу деректерін жинау және талдау үшін қолданылатын әдістеменің толық сипаттамасын береді. Бұл зерттеудің негізгі бөлігі физика мұғалімдерінің сауалнамасының нәтижелеріне негізделген. Сондай-ақ, автор сауалнама барысында жиналған мәліметтер тақырыптық талдауды қолдана отырып сапалы талданғанын және физикалық білім берудегі ұқсастықтарды жіктеудің кешенді жүйесі жасалғанын көрсетті. Физиканы оқытудағы ұқсастықтарды екі негізгі топқа бөлуге болатындығы сипатталған. Бұл субъективті және пәнаралық ұқсастықтар. Яғни, физика бойынша білім беруде қолдануға болатын ұқсастықтарды жіктеудің кешенді жүйесін әзірлеу егжей-тегжейлі қарастырылады. Аналогияларды қолдану студенттердің абстрактілі ғылыми ұғымдарды, атап айтқанда электромагнетизм контекстінде түсінуін жақсарту құралы ретінде зерттеледі. Зерттеу физика бойынша білім берудегі аналогтық ойлаудың әртүрлі тәсілдерін анықтау және бағалау үшін әртүрлі көздерге негізделген ғылыми әдебиеттерді талдау әдісін қолданады. Зерттеу нәтижелері аналогияны жіктеу жүйесі мұғалімдерге педагогикалық тәжірибені жақсартудың құнды құралын ұсына отырып, күрделі ғылыми тұжырымдамаларды түсіндіруді айтарлықтай жеңілдететінін көрсетеді. Сонымен қатар, ұсынылған жіктеу жүйесі оқытудың тиімдірек әдістерін дамытуға ықпал ете отырып, жаңа ұқсастықтарды әзірлеу және бұрыннан барларын жетілдіру үшін негіз ұсынады. Тұтастай алғанда, зерттеу физика бойынша білім берудегі аналогтық ойлаудың маңыздылығын көрсетеді және ұқсастықтарды қолдануға негізделген әртүрлі салаларда оқу материалдарын әзірлеуде қолдануға болатын практикалық тұжырымдарды ұсынады.

Түйін сөздер: физикалық білім беру, физикалық аналогиялар, аналогиялардың методологиялық мәні, білім беру процесі, мәселе шешу, білімді жүйелеу, оқыту әсерлілігі.

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Классификация аналогий как методологическая основа для использования в обучении физике

В статье автор предоставляет подробное описание методологии, используемой для сбора и анализа данных исследования. и процесс разработки системы классификации. Основная часть этого исследования основана на результатах опроса учителей физики. Также автор показал, что собранные в ходе опроса данные, были качественно проанализированы с использованием тематического анализа, и была разработана комплексная система классификации аналогий в физическом образовании. Описывается, что аналогии в обучении физике можно разделить на две основные группы. Это субъективные и межпредметные аналогии. То есть подробно рассматривается разработка комплексной системы классификации аналогий, которые могут быть использованы в образовании по физике. Использование аналогий изучается как средство для улучшения понимания студентами абстрактных научных концепций, в частности, в контексте электромагнетизма. В исследовании применяется методика анализа научной литературы, опирающаяся на различные источники для выявления и оценки различных подходов к аналоговому мышлению в образовании по физике. Результаты исследования демонстрируют, что система классификации аналогий может значительно упростить объяснение сложных научных концепций, предоставляя учителям ценный инструмент для улучшения педагогических практик. Кроме того, предложенная система классификации предлагает фреймворк для разработки новых аналогий и совершенствования существующих, способствуя развитию более эффективных методов преподавания. В целом, исследование подчеркивает значимость аналогического мышления в образовании по физике и предлагает практические находки, которые могут быть применены в разработке учебных материалов в различных областях, основанных на использовании аналогий.

Ключевые слова: физическое образование, аналогии в физике, методологическая ценность аналогий, образовательный процесс, решение проблем, систематизация знаний, эффективность преподавания.

Introduction

Currently, there is a growing need for effective methods of teaching physics, especially in light of the rapid development of technology and scientific discoveries. One way to improve the learning process is to use analogies as a pedagogical tool. The importance of using analogies lies in the fact that they help students better understand abstract scientific concepts, which is often a major obstacle in their study. In this article, we propose the development of an analogy classification system that can be used in teaching physics. This system provides teachers with a tool to develop new analogies and improve existing ones, which can lead to more effective teaching methods. Thus, this article is important and relevant as it can help teachers improve the quality of their teaching and give students the opportunity to better understand complex scientific concepts. Modeling of the processes under study has always played an important role in scientific reasoning and in discoveries since XVIII century. Analogies always have and always will help scientists understand, represent and explain natural phenomenon and structure of the world [1]. The functional utility of analogical approach in education and in conceptual changes has been emphasized by the researchers Treagust et al. According to them, the use of analogies during the education would contribute to better understanding of abstract scientific concepts [2]. Posner et al. also wrote that the use of analogies is one of the effective methods of overcoming difficulties in visualizing abstract concepts which contribute to conceptual understanding. Since it is the theoretical nature of the majority of notions and processes in physics that makes the subject difficult to understand [3]; we decided to adapt the analogy approach to simplify it in use during the educational activities of physics teachers. According to the research results of Bagno and Eylon [4] electromagnetism turned out to be the hardest branch of physics for students in universities and high school to understand because of the visualization challenges. The researchers also note that the concepts in this chapter are very abstract, most of the phenomena cannot be observed directly; only the consequences of these phenomena are obvious [5]; the course contains mainly theoretical concepts [6].

However, despite the potential benefits of using analogies in teaching physics, there is currently no systematic approach to their application in the classroom. This lack of organization can lead to inconsistent use and effectiveness of analogies in teaching. In order to address this issue, the purpose of this study is to develop a comprehensive classification system for analogies in physics education that can be applied at various stages of studying the educational material, at studying various issues of the section, at the school subject and in the intersubjective level.

To accomplish this goal, we will provide a brief review of the literature on the use of analogies in physics education and the challenges that students face in understanding the theoretical concepts in electromagnetism. We will then describe how our classification system can help teachers to select and apply analogies more effectively, in order to enhance students' understanding of abstract concepts in physics.

Hypothesis: Developing a comprehensive classification system for analogies in physics education will improve the effectiveness of using analogies in teaching abstract concepts in physics and enhance students' conceptual understanding.

Methodology

This study aims to develop a comprehensive classification system for analogies in physics education. In this section, we provide detailed information on the methods used to collect and analyze data for this research.

Sample Selection: We selected data on existing analogies from literature reviews conducted in the field of physics education. This information was used to further classify and analyze the analogies collected from our survey. Additionally, we selected a convenience sample of physics teachers from several schools and universities. The participants were chosen based on their experience in teaching electromagnetism, and their willingness to participate in the study.

Data Collection: The survey was created on the SurveyMonkey platform and a link to it was provided to the respondents. It was designed to gather information about the analogies used by physics teachers in their classrooms. The survey consisted of open-ended questions that asked the teachers to describe the analogies they used and their effectiveness in helping students to understand the concepts of electromagnetism. We received responses from 50 teachers (Appendix 1).

Data Analysis: The survey data was analyzed qualitatively using thematic analysis. We identified common themes and patterns in the responses provided by the teachers, and used these to develop a classification system for analogies in physics education.

The classification system was then validated through expert review. We asked a panel of experienced physics teachers to review the classification system and provide feedback on its validity and usefulness.

Overall, the methodology used in this study involved a combination of qualitative data collection and analysis methods. The results were used to develop a comprehensive classification system for analogies in physics education that can be applied by teachers to enhance students' understanding of abstract concepts in physics.

Results and Discussion

Based on the results of the survey, it became clear that the use of analogies in physics education is highly valued by teachers (Appendix 1). However, the lack of a systematic classification system for analogies has been identified as a significant obstacle. Thus, in order to address this issue, we decided to develop a comprehensive classification system for analogies in physics education. In this section, we will provide a detailed description of the methodology used to collect and analyze data for this research, and the process of developing the classification system. The main part of this study is based on the results of a survey of physics teachers (Appendix 1) in which they were asked about the analogies they use to teach the concept of electromagnetism. The data collected from the survey was analyzed qualitatively using thematic analysis, and a comprehensive classification system for analogies in physics education was developed. The following sections describe the development of this classification system in detail. Analogies in the instruction in physics can be divided in two main groups. They are subjective and inter-subject analogies. The full classification of analogies is shown below (Figure 1).

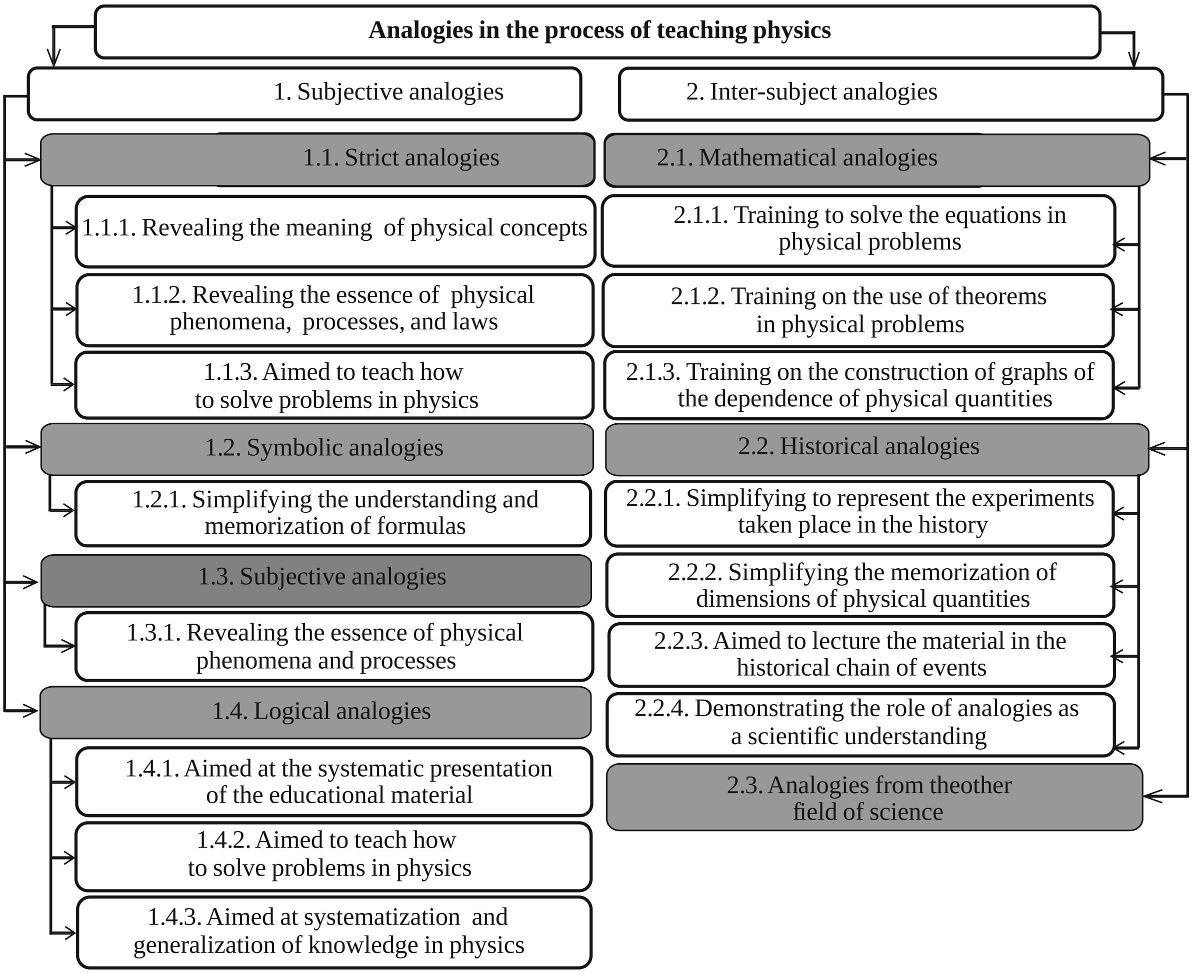


Figure 1 - Analogies in the process of teaching physics

Subjective Analogies. Let's consider the first group of physical analogies. The implementation of subjective analogies allows us to organize the integration of physical knowledge, as well as to establish links between some branches of physics. Physical analogies demonstrate the internal unity of physical nature of all these seemingly diverse processes. The sense of the links and similarities between various physical phenomena contributes to the formation of a holistic worldview and the natural-scientific picture of the world.

By the nature of the transferred features, subject analogies can be divided into strict, symbolic, subject, and logical.

Strict Analogies. Using strict analogies in the process of teaching physics is a teaching method by which the essence of physical phenomena, processes, laws, and concepts is revealed and mastered through the comparison and use of established similarities between the properties of the physical phenomena (processes) under consideration.

Depending on the purpose of the application, a strict analogy can be used:

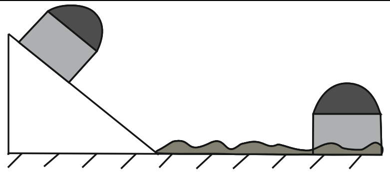
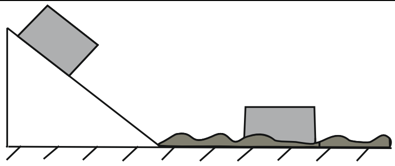
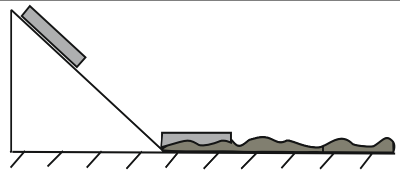
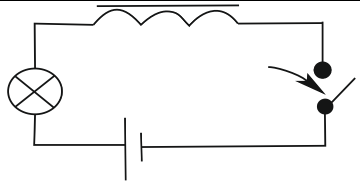
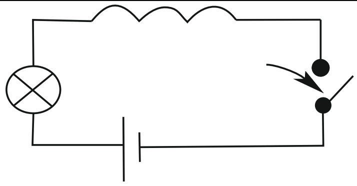
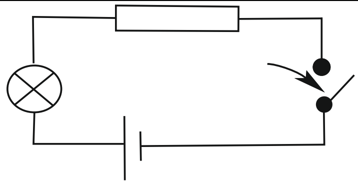
1. To reveal the physical meaning of physical concepts.

2. Revealing and mastering the essence of physical phenomena, processes, laws.

3. For training in solving problems in physics.

Consider how to reveal the physical meaning of the concept using the analogy method, using the example of the concept of conductor inductance. To do this, you need to consider mass as a measure of the inertia of the body concerning the change in body speed, and inductance as a measure of the inertia of the conductor concerning the change in current strength in German. You can reveal the physical meaning of inductance by performing a task to establish an analogy between two processes: process (time) of motion of bodies of different mass and process (time) of lamp burning after key opening (Table 1).

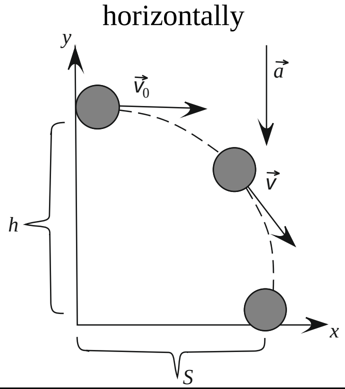
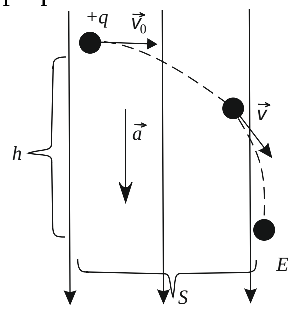
Table 1- Task to establish analogies

 Sandbox	 Emptybox	 Board (bottom of the box)
 Coil with core	 Coil without core	 Conductor

A heavy body is more inert than a light one and will move for a longer time before stopping. Similarly, a circuit with higher inductance will cause a lamp to burn longer after it is turned off. The method of strict analogy can be used to explain physical phenomena and laws, such as the interaction of two linear conductors with current being similar to the interaction of fixed-point charges. This allows trainees to independently hypothesize and explain observed processes in Ampere's experiments.

Analogies can be used to solve physical problems, such as comparing the motion of a body in gravitational and electrostatic fields. In both cases, a downward force acts and causes the body or particle to move in two dimensions: uniformly in the horizontal direction and equally accelerated in the vertical direction. Calculating kinematic characteristics is done the same way due to the established analogy. (Table 2).

Table 2- Analogies in solving physical problems

Set of initial conditions		Similar kinematic characteristics
Motion in the gravitational field with acceleration: $F = mg;\ a = g$	Movement in electrostatic field with acceleration: $F = ma :\Rightarrow a = \frac{E_q}{m}$	
Movement of a body thrown horizontally  	Motion of the particle flying perpendicular to the field  	$S = \upsilon_0 t$ $h = \frac{at^2}{2}$ $\upsilon = \sqrt{\upsilon_0^2 + (gt)^2}$

Symbolic Analogies. Using symbolic analogies in the process of teaching physics is a method aimed at simplifying the processes of understanding and memorizing educational material (in most cases, formulas) through the establishment of physically justified analogies between the symbolic representation of various elements of educational material, as well as through the use of additional associations. Symbolic analogies can include graphic, abstract, verbal, and other generalized images of an object. Let us show using the example of studying the foundations of electromagnetism how this type of analogy can be used. Many expressions of "memorizers" of formulas in physics are known (Table 3).

Table 3 - Examples of symbolic analogies

Formulas	Mnemonic analogies
$F = k\frac{q_1 q_2}{r^2}$	To memorize the physical quantities included in the formula of Coulomb's Law: the rooster's cry: “cuckoo” - “cuckoorekoo”: $q_1(ku), k(ka), r(re), q_2(ku)$
$U = IR$	Ohm's Law “Virgins Are Rare” Volts=Amps x Resistance
$c = 299.792.458 m\sec^{-1}$	Speed of light: 11 The phrase “We guarantee certainly, clearly referring to this light mnemonic.” Represents the speed of light in meters per second through the number of letters in each word: 299,792,458
R, M, I, V, U, X, G	*R* - Radio waves, *M* - Microwaves, *I* - Infrared, *V* - Visible light, *U* - Ultraviolet, *X* - X-Rays, *G* - Gamma Rays. The order of increasing frequency or decreasing wavelength of electromagnetic waves can be remembered with the phrase: Roman Men Invented Very Unusual X-Ray Guns
The symbol E (EMF) was used to designate voltages.	The phrase ELI the ICE man as a reminder that: For an inductive (*L*) circuit, the EMF (*E*) is ahead of the current (*I*) While for a capacitive circuit (*C*), the current (*I*) is ahead of the EMF (*E*). EMF - electromotive force

It is also possible to simplify the memorization of formulas by establishing symbolic analogies between formulas that have a similar physical meaning. For example, body density is the mass of a body in a unit volume ($\rho = \frac{\Delta m}{\Delta V}$). Similarly, a formula for calculating the bulk density of electric or magnetic fields can be derived and stored. The bulk density of the electric (magnetic) field is the energy of the field in unit volume ($u = \frac{\Delta W}{\Delta V}$). In turn, the formulas for calculating the bulk density of electric and magnetic fields are very similar: ($u_{el} = \frac{1}{2}\varepsilon\varepsilon_0 E^2$) and ($u_{el} = \frac{1}{2}\mu\mu_0 H^2$). Symbolic analogies in formulas help to quickly remember them. Visual comparisons of the mathematical apparatus of physics are effective for generalizing concepts, theories, and methods and can be used as a pedagogical tool to improve students' understanding of the material. [7].

Model Analogies. Using model analogies in physics teaching reveals the essence of physical phenomena through virtual and physical models that reflect analogous processes. The mechanical model for explaining electrical circuit processes remains relevant, with the ball rolling under gravity analogous to electric charges moving in a circuit. Virtual models are popular, such as a slide showing the silicon crystal structure used to explain semiconductor conductivity. (Figure 2.1).

All elements of the slide are fixed, except for the electrons, which are free to move on the surface of the interactive panel. In the preparation of this slide, there are objects under each electron that act as holes. To increase the visibility of the material under study, the electrons on the slide are shown in blue and the holes in green.

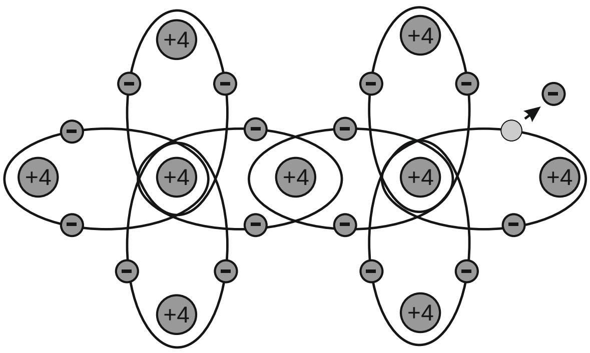


Figure 2.1 - A model for explaining the mechanism of conduction of semiconductors (example 1)

By moving one of the electrons shown on the slide, one can demonstrate and explain how individual bonds break when silicon is heated and how some electrons leave their atoms and become free. Further, in order to explain the nature of hole conduction, it is also necessary to demonstrate a continuous process in which one of the electrons that provide the bonding of the atoms jumps to the site of the hole formed and restores the covalent bond at that site, and a new hole is formed at the site where the electron jumped. In this way, the teacher can use a slide to explain how the hole moves through the crystal (Figure 2.2).

Logical Analogies. Logical analogies are used in teaching physics to help students master the essence of physical phenomena, processes, laws, and concepts in a logical order. This allows for comparison and analysis of already learned elements of the physical knowledge s ystem. The analogy method can be implemented at different stages of the learning process, such as studying educational material, training in solving physical problems, and systematizing and generalizing knowledge. The use of logical analogies in presenting educational material can be done through parallel or serial analogy, depending on the purpose of the application. In training students to solve physical problems, the analogy is expressed in the ability to apply known methods or algorithms to unfamiliar physical situations by analogy with familiar ones. It is important to teach students not just to solve problems, but also to understand the essence of the methods used as separate tools for problem-solving. (Table 4)

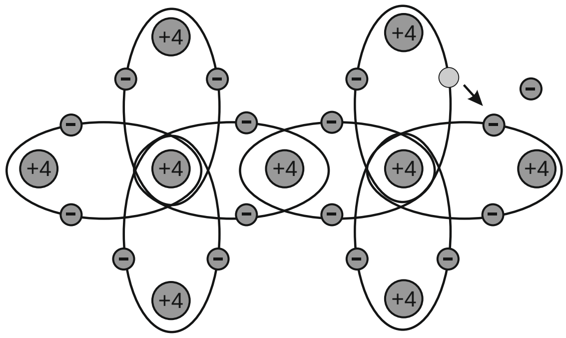
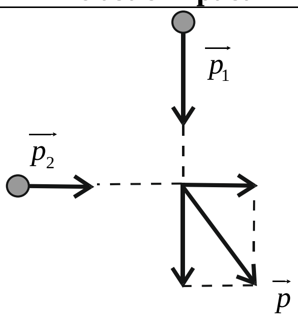
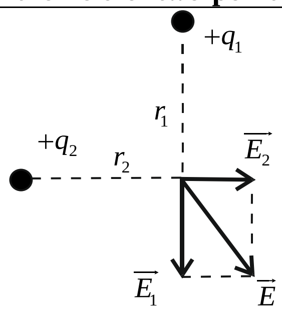


Figure 2.2 - A model for explaining the mechanism of conduction of semiconductors (example 2)

Table 4 - Examples of analogies at the stage of training in solving physical problems

Determine total momentum of balls after inelastic impact	**Determine the intensity at the specified point of the field of two-point charges**
	
$\left\|\vec{p}\right\| = \sqrt{\left\|\vec{p_1}\right\|^2 + \left\|\vec{p_2}\right\|^2}$, $\vec{p_1} = m_1\vec{\upsilon_1}; \vec{p_2} = m_2\vec{\upsilon_2}$	$\left\|\vec{E}\right\| = \sqrt{\left\|\vec{E_1}\right\|^2 + \left\|\vec{E_2}\right\|^2}$, $\left\|\vec{E_1}\right\| = \frac{1}{4\pi\varepsilon_0} \cdot \frac{\left\|q_1\right\|}{r_1^2}$, $\left\|\vec{E_2}\right\| = \frac{1}{4\pi\varepsilon_0} \cdot \frac{\left\|q_2\right\|}{r_2^2}$

The use of logical analogy can be implemented at the stage of systematization and generalization of knowledge. To organize the systematization and synthesis of knowledge, it is convenient to use the table. Filling in the table allows you to systematically present and repeat the training material (Table 5). The work with the developed table differs from the traditional filling of tables in that it contains graphic material selected based on analogies, as well as questions and tasks that allow establishing analogies between the studied elements of the physical knowledge system, repeating and systematizing them, as well as summarizing the wording of basic principles and algorithms.

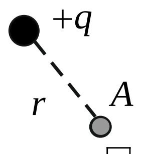
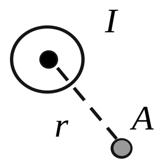
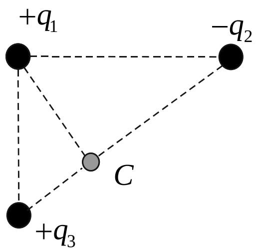
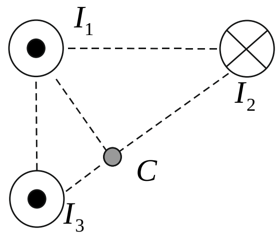
Inter-Subject Analogies. The second group of physical analogies is inter-subject analogies (Figure 1). Physics, which is originally a science, describing all the processes that surround us cannot exist separately from other sciences. After all, the concepts of physics and its laws underlie natural science [8].

For example, electromagnetic interaction underlies chemical transformations [9]. Even in bio-medicine, there are studies defining the spinal cord as a natural antenna of incident electromagnetic waves [10]. The use of inter-subject analogies makes the learning process interesting and creative, promotes the integration of knowledge and the development of the child's personality [11].

A distinctive feature of inter-subject analogy from other species is that it allows you to adapt the material of exact sciences by various objects from the humanitarian field and everyday life.

According to the content, inter-subject analogies can be divided into mathematical, historical, analogies from other fields of science.

Table 5 - Table fragment for systematization and generalization of knowledge through the establishment of analogies

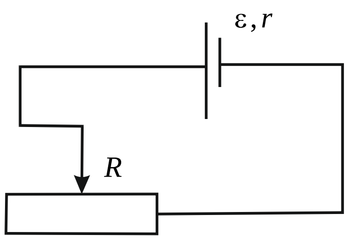
Questions and tasks	Electrostatic field	Magnetic field
- plot the force lines of the fields and compare them; - write down the formula to calculate the force characteristic of the field and depict its vector at the specified point; - analyze and compare the physical flush of the force characteristic of the field for both cases;	 $\vec{E} = \square \cdot \frac{\square}{\square}$	 $\vec{B} = \square \cdot \frac{\square}{\square}$
- write down the principle of superposition of fields in general form; - determine the resulting direction of the intensity vector (induction) at the specified point; - formulate a common algorithm for finding the resulting vector of the power characteristic for both cases; - come up with a formulation of the superposition principle suitable for both types of fields	 $\vec{E} = \square + \square + \square$	 $\vec{B} = \square + \square + \square$

Mathematical Analogies. Using mathematical analogies in the process of teaching physics is a teaching method aimed at forming the ability to apply the mathematical apparatus in the field of physical knowledge through the establishment of analogies between physical expressions, quantities, and mathematical equations, variables, coefficients for variables; between physical situations in tasks and geometric problems. Mathematical analogies find their application in some cases:

1. In solving the equation or system of equations obtained during the solution of physical problems;
2. When performing geometric constructions and applying theorems to search for an unknown physical quantity specified in the requirements of a physical task;
3. In the graphical representation of functional dependence of physical quantities.

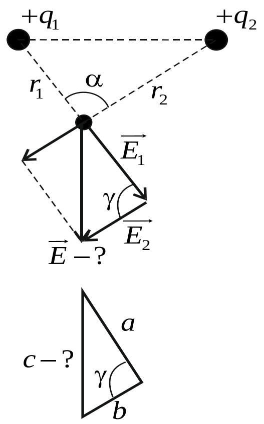
Consider the possibilities of implementing mathematical analogies using the example of solving a problem (Table 6).

Table 6 - Solving the problem through the establishment of mathematical analogies

Task condition	Progress in solving the problem
The figure shows the electrical diagram. Determine at what value of external resistance the useful power is $P_{net} = 4W$? 	Usable power: $P_{net} = I^2 R$, where *I* – is determined from the Ohm's law $I = \frac{\varepsilon}{R+r}$. Then for R we get the equation: $R^2 + \frac{2r-\varepsilon}{P_{net}} \cdot R + r^2 = 0$ The obtained equation is similar to the square equation of the form: $ax^2 + bx + c = 0$ We establish mathematical analogies: unknown is *R*; variable *a* = 1; variable *b* is an expression $\frac{2r-\varepsilon^2}{P_{net}}$; variable *c* is r^2. Solving the square equation if the discriminate is greater than zero: $x_{1,2} = \frac{-b \pm \sqrt{b^2-4ac}}{2a}$ We get two values for the resistance, of which we choose a positive one

As practice shows, students experience difficulties at the stage of solving the equations obtained in the problem. However, after establishing mathematical analogies, students independently solve equations relative to unknown physical quantities. Consider an example of the implementation of mathematical analogies when applying geometric theorems in solutions to physical problems. Solving superposition problems for finding the field strength of two-point charges at the said point is usually reduced to constructing a vector triangle (Table 7).

Table 7- Mathematical analogies in solving the physical problem

Analogy between the physical situation and the geometric problem	Applying the cosine theorem for a vector triangle
	We establish mathematical analogies: - the known side of triangle a - is the $\vec{E_1}$ in the vector triangle; - the known side of triangle b - is the $\vec{E_2}$ in the vector triangle; unknown side of triangle - is E in vector triangle; Let's write down the cosine theorem: $c^2 = a^2 + b^2 - 2ab\cos\gamma$ Apply the cosine theorem for a vector triangle: $\lvert\vec{E}\rvert^2 = \lvert\vec{E}_1\rvert^2 + \lvert\vec{E}_2\rvert^2 - 2\lvert\vec{E}_1\rvert\lvert\vec{E}_2\rvert\cos\gamma$, where $\lvert\vec{E}_1\rvert = \frac{1}{4\pi\varepsilon_0}\cdot\frac{\lvert q_1\rvert}{r_1^2}$, $\lvert\vec{E}_2\rvert = \frac{1}{4\pi\varepsilon_0}\cdot\frac{\lvert q_2\rvert}{r_2^2}$

To find the modulus of the resulting field strength, it is convenient to refer to a similar problem in geometry: two sides of the triangle and the angle between them are known, you need to determine the side opposite the known angle. To determine the unknown side, use the cosine theorem. Establishing analogies between the physical situation in the problem and the geometric problem simplifies the process of applying the cosine theorem for a vector triangle.

The graphical representation of the functional dependence of physical quantities is also simplified through the establishment of mathematical analogies. For example, to build the dependence of the electric field potential of a point stationary charge on the distance $\varphi = \frac{kq}{r}$, it is important to pay attention to the trainees that this function is a function of inverse proportionality $y = \frac{k}{x}$. Accordingly, $\varphi(r)$ is the function $y(x)$, $r$is the argument x, kq is the proportional coefficient. Thus, knowing the properties of the inverse proportionality function, learners, after establishing mathematical analogies, will be able to independently plot the function $\varphi(r)$.

The mathematical apparatus of analogies in physics is rightfully considered the most common. For first-year students of technical universities, many examples of the use of mathematical apparatus as a method of analogy can be shown. There are many works showing how the same mathematical theory can be used to describe physical phenomena of different nature. James Clerk Maxwell and Lord Kelvin used an analogy method to study the wave phenomena in elastic theory and electromagnetism. They established that the elastic displacements are analogous to the displacements of the current introduced by Maxwell in his electromagnetic equations. Especially that both of the waves in elastic theory and the electromagnetism are transverse. Maxwell assumed that the aether, that is always was in a stress state, would only transmit transverse waves. In his point of view his equations could only be valid if the absolute system of the objects located in aether. However, with the advent of the theory of relativity, the scientific world abandoned the ideas of the aether to fill all the space between us, but that still didn't invalidate the wave's motion. The most important idea here is the transverse propagation of the wave, which contradicts the propagation of waves in a liquid, for example, where they can propagate only longitudinally. This formal analogy frequently becomes a complete mathematical equivalence, allowing the same equations to be employed to solve problems in both areas [12].

If Maxwell and Kelvin showed that the wave equation and related mathematical developments can be used to describe the propagation of elastic and electromagnetic waves, Fresnel's equations are a classic example of the analogy between transverse waves and light waves. George Green in the nineteenth century used analogies to obtain the reflection coefficients of sound waves and light waves before the advent of the electromagnetic theory of light [13].

The other example of analogies in science is the definition of light formulated in 1660 by Robert Hooke as a vibrational displacement of the medium, through which it propagates at a final speed and the comparison of this phenomenon with the stress-strain relationships, establishes the elastic behavior of solid bodies (1635-1703). August Jean Fresnel showed that if light were a transverse wave, it would be possible to develop a theory that takes into account the polarization of light (1778-1827). Subsequently, in 1815, Brewster discovered the law that regulated the polarization of light.

Researchers Carcione and Cavallini, showed the analogy in the time-space and wave-number (or slowness)-frequency domains [14].

Historical Analogies. "Historical analogies" is a teaching method in physics based on using analogies between educational and historical materials to form a scientific worldview. It is based on the principle of historicism, which allows for the use of analogies based on the common and special properties of phenomena. Examples include reproducing historical experiments and memorizing the units of physical quantities named after scientists such as Joule (J), Coulomb (C), Ampere (A), and Ohm (Ω). Analogies that help to remember the dimension of physical quantities named after scientists can be distinguished into a separate group of historical analogies. The sequence of presenting educational material in physics can follow a historical sequence to systematize the flow of information.

Analogies from Other Fields of Science. The use of analogies between different fields of science can improve our understanding of physical processes. James Clerk Maxwell himself used the analogy of fluid mechanics to explain the electromagnetic waves. Similarly, analogies can help us understand the properties of electromagnetic waves by studying the laws of incompressible fluid waves in hydrodynamics. Analogies can also be used in medicine to describe the rate of spread of a particular disease, where an outbreak of infection can be compared to the spread of a charged particle. For example, the book "An Integrated, Quantitative Introduction to the Natural Sciences" demonstrates analogies between formulas in the mechanics of motion with drag, first-order chemical kinetics, and electrical circuits, as well as exponential growth of bacteria. [15] In this example, we can conclude that the bacteria choose to grow exponentially over time, instead of decaying.

Our study aims to summarize the existing methods of analogy briefly to assist teachers in explaining physics to students. We can use analogies in various scientific fields, and apply mathematical solutions. Wave propagation and induction can also be observed in sociology and everyday life, and they always have a cause and effect relationship. Similarly, in electromagnetism, there is always an initial charge for a field, and induction requires a field. Such comparisons help us describe natural phenomena around us using electromagnetism.

Conclusion

We conducted a pilot study in a high school in Almaty to evaluate the effectiveness of the developed classification system for analogies in physics education. The sample consisted of 50 11th grade students studying electromagnetism, divided into experimental and control groups. The results showed that the experimental group performed significantly better on the post-test than the control group (mean score 85% vs 75%, $t = 2.6$, $p < 0.05$). This suggests that the classification system for analogies in physics education can enhance students' understanding of abstract concepts. The use of analogies helped students develop a deeper understanding of theoretical concepts and made the learning process more enjoyable and engaging. Further research is needed to confirm these findings and explore the potential of the classification system in other contexts.

Our work has shown that the use of analogies in physics education can help students better understand abstract concepts and make the learning process more enjoyable and engaging. Furthermore, our classification of analogies represents a systematic approach to using analogies at different stages of education, which can overcome some limitations in the use of this method.

Further research can be conducted to identify other possible applications of our analogy classification in different contexts, as well as develop more effective methods of combining analogies with other teaching methods to achieve better results. We hope that the results of our research will be applied in teaching practice and contribute to improving the effectiveness of physics education.

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Appendix 1
Data Collection Survey and Responses

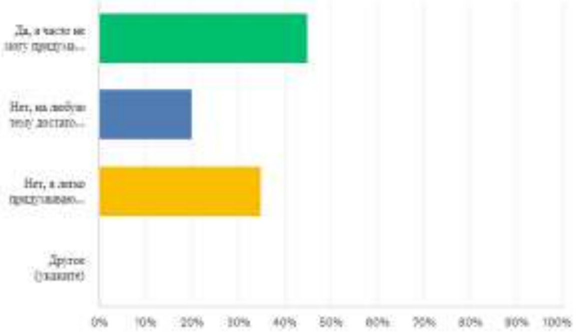
1. Do you experience difficulty when you need to provide an analogy from life or from the material covered when explaining a new topic? (*Испытываете ли вы затруднение, когда необходимо привести аналогию из жизни или из пройденного материала во время объяснения новой темы?*)

a) yes, I often struggle to come up with an analogy to explain new material. (*да, я часто не могу придумать аналогию, чтобы объяснить новый материал*);

b) no, there are plenty of analogies and comparisons available online for almost any topic (*нет, на любую тему достаточно приведено аналогий и сравнений в интернете*);

c) no, I find it easy to come up with analogies to explain complex processes encountered in physics (*нет, я легко придумываю аналогию для объяснения сложных в понимании процессов, с которыми приходится сталкиваться в физике*);

d) other (please specify) (*другое (укажите)*).



2. If there was a resource that collected all of the analogies invented by physics teachers, would you use it? (*если бы существовал ресурс, в котором были собраны все придуманные учителями физики аналогии, вы бы пользовались им?*)

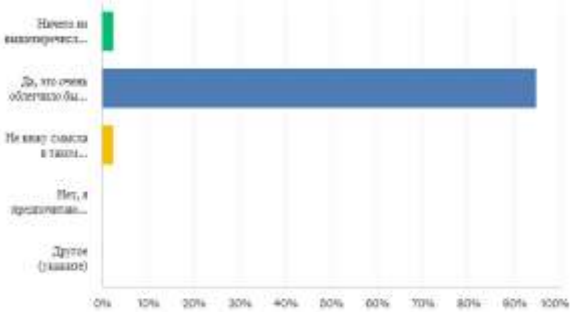
a) no one of the below (*ничего из нижеперечисленного*);

b) yes, it would greatly facilitate my work (*да, это очень облегчило бы мне работу*);

c) I don't see the point in such a resource, as theoretical material in textbooks is sufficient for explaining the material (*не вижу смысла в таком ресурсе, для объяснения материала достаточно теоретического материала в учебниках*);

d) no, I prefer to come up with analogies myself as needed (*нет, я предпочитаю сама придумывать аналогии по мере необходимости*);

e) other (please specify) (*другое (укажите)*).

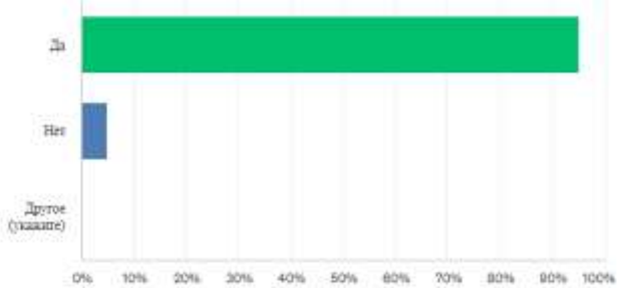


3. If you had your own collection of analogies, would you like to share it with other physics teachers? (*Если бы у вас была своя коллекция аналогий, вы хотели бы поделиться с ним с остальными учителями физики?*)

a) yes (*да*);

b) no (*нет*);

c) other (please specify) (*другое (укажите)*)



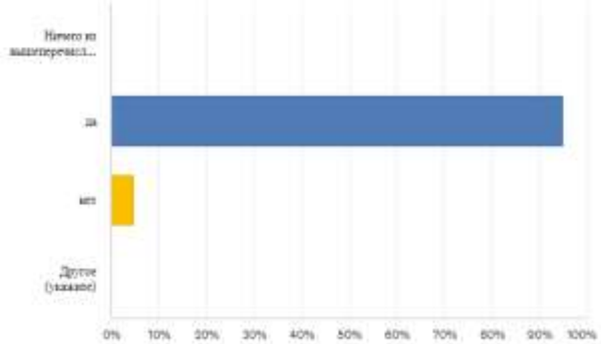
4. Do you believe that the ability to use analogy in physics is an important professional skill for a physics teacher? (*Считаете ли вы, что умение использовать методы аналогии в физике является важным профессиональным навыком для учителя физики?*)

a) no one of the below (*ничего из нижеперечисленного*);

b) yes (*да*);

c) no (*нет*);

d) other (please specify) (*другое (укажите)*).



5. If there were competitions for physics teachers to present interesting analogies, would you like to participate? (*Если бы проводились олимпиады для учителей физики на представление интересных аналогий, хотели бы вы в нем поучаствовать?*)

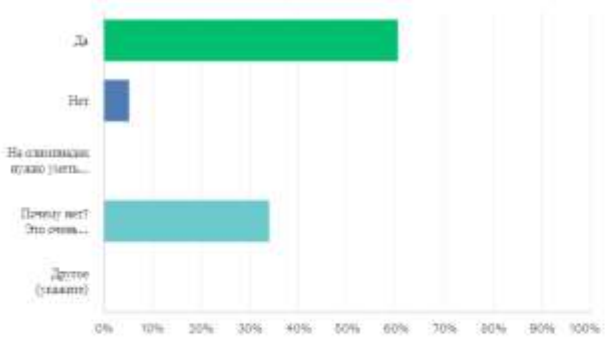
a) yes (*да*);

b) no (*нет*);

c) Competitions should test the ability to solve problems of increased difficulty, so I don't see the point in other competitions (*на олимпиадах нужно уметь решать задачи повышенной трудности, я считаю, что нет смысла в других олимпиадах*).

d) why not? It's very interesting and useful! The ability to creatively present material is the highest skill of a teacher. It's not enough for a teacher to simply know the material well, they need to be able to explain it. Such competitions are necessary for physics teachers (*почему нет? Это очень интересно и полезно! Умение креативно подать материал - это высшее мастерство учителя. Не достаточно учителю* *просто хорошо знать материал, нужно уметь его объяснить. Такие олимпиады необходимы для учителей физики*);

e) other (please specify) (*другое (укажите)*);



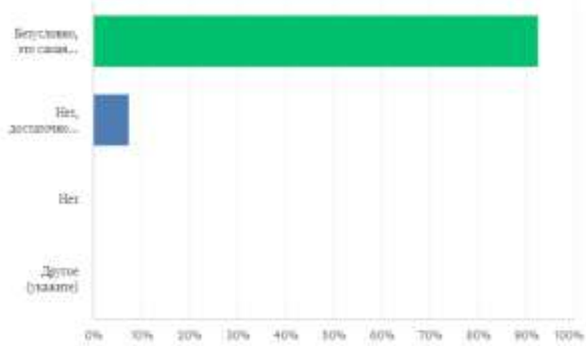
6. Do you believe that the analogy method is effective in summarizing and reviewing the material covered? (*Считаете ли вы, что метод аналогии является эффективным на этапе обобщения и повторения пройденного материала?*)

a) absolutely, it is the best way to summarize the material (*безусловно, это самая лучшая методика обобщения материала*);

b) no, it is enough for students to know the formulas and be able to apply them to solve problems. Using analogies is a waste of time (*нет, достаточно того, что учащиеся знают формулы и умеют их применять для решения задач. Приведение аналогий - трата времени*);

c) no (*нет*);

d) other (please specify) (*другое (укажите)*).



7. Which of the following types of analogy do you use in practice? (*Какие из нижеперечисленных видов аналогии вы применяете на практике?*)

a) during the explanation of material, I try to draw a parallel between implicit processes and processes that are understandable to students (for example, electric current in a circuit can be associated with the flow of water) (*наэтапеобъясненияматериалаяповозможностистараюсьпровестипараллельмеждунеявнымипроцессамии процессами, понятные учащимся (например, ток в цепи я ассоциирую с потоком воды)*);

b) when introducing new formulas, we always try to find something common with known formulas (for example, the force of gravity and Coulomb's law) (*в новых формулах мы с детьми всегда пытаемся найти что-то общее с известными формулами (например сила гравитации и закон Кулона)*);

c) I suggest to students that they can derive a formula based on the dimensional analysis of a physical quantity (for example, specific heat capacity *C*: if the dimension of C is $\frac{J}{kg \cdot C^{\circ}}$, then $C = \frac{Q}{m \cdot \Delta t}$) (*я подсказываю учащимся, что можно восстановить формулу, глядя на размерность постоянной величины (например удельная теплоемкость C: если у C размерность Дж/кг*градус Цельсия, то* $C = \frac{Q}{m \cdot \Delta t}$);

d) we look for similarities between formulas and words with our students (for example, $Q = U \cdot I \cdot t$ sounds like the English word "quit" (*мы с учащимися ищем сходство формул и слов (например:* $Q = U \cdot I \cdot t$ *похоже на английское слово quit)*);

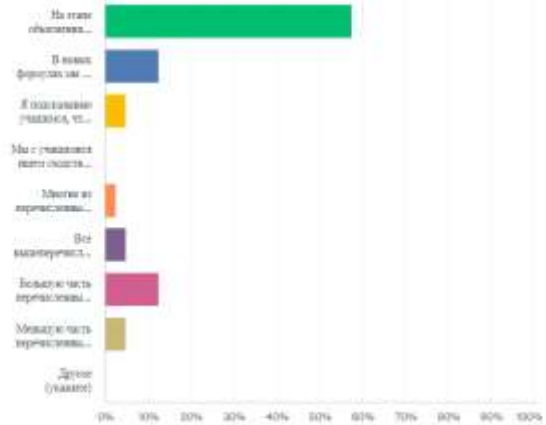
e) many of the listed types of analogy have not been applied by me, and I will gladly apply them in the future (*многие из перечисленных видов аналогии мною не применялись, и я с удовольствием буду применять их в дальнейшем*);

f) I use all of the listed analogies in my work (*все вышеперечисленные аналогии я применяю в своей работе*);

g) I use most of the listed analogies in practice (*большую часть перечисленных аналогий я применяю на практике*);

h) I use some of the listed analogies in practice (*меньшую часть перечисленных аналогий я применяю на практике*);

i) other (please specify)(*другое (укажите)*).



Appendix 2
Table of Individual Student Data and Mean Post-Test Scores, along with Statistical Analysis Results by Group

Experimental group		Control group	
Student	Score	Student	Score
1	67	1	57
2	72	2	74
3	90	3	80
4	78	4	52
5	59	5	66
6	71	6	59
7	86	7	78
8	69	8	49
9	58	9	64
10	88	10	72
11	64	11	68
12	80	12	55
13	61	13	73
14	84	14	61
15	60	15	58
16	75	16	77
17	68	17	53
18	79	18	48
19	63	19	70
20	74	20	50
21	62	21	76
22	82	22	60
23	70	23	67
24	76	24	62
25	66	25	56
Mean Score (%)	85	75	

Group	MeanPost-TestScore (%)	StandardDeviation	t-value	p-value
Experimental	85	3,6	2,6	<0.05
Control	75	4,2	-	-