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TEACHING STUDENTS TO SOLVE PROBLEMS ON DETERMINING THE ELECTRIC FIELD

The article presents a methodological approach to teaching students how to solve problems in electrostatics, illustrated by the example of determining the electric field for bodies of linear geometric shape. The proposed approach is based on three key components: (1) the analogy method, which allows the transfer of problem-solving strategies from mechanics (determination of the moment of inertia) to electrostatics; (2) the differentiation and integration method (DI method), structured as a clear step-by-step algorithm; and (3) the method of gradually increasing problem complexity, which reduces cognitive overload and supports the consistent development of problem-solving skills. Unlike traditional approaches that emphasize rote memorization of formulas, this study focuses on structured thinking, the integration of mathematical operations with their physical meaning, and interdisciplinary connections between different branches of physics.

The study involved 116 students of technical specialties. Testing was conducted to assess the effectiveness of the developed approach. The results showed that more than 80% of the students successfully completed the final tasks and demonstrated increased confidence in their knowledge and skills after the training. The findings verified the effectiveness of the proposed approach in developing problem-solving abilities, analytical thinking, and academic motivation.

The significance of the proposed approach lies in its universality and reproducibility across different higher educational institutions. The offered methodological approach can be readily adapted to the curricula of other universities, while the demonstrated instructional materials have simple structure and can be extended to different areas of physics where integral methods are applied and analogies with models already known to students can be constructed.

Key words: *teaching methods, problem solving, electric field, analogy method, differentiation and integration method, method of gradually increasing problem complexity.*

(статтю подано мовою оригіналу)

1. Introduction. Problem-solving in physics is an essential component in the development of professional competencies of future specialists in technical fields. It fosters analytical thinking, deepens the understanding of physical concepts and laws, and facilitates the formation of the skills necessary for establishing interdisciplinary connections.

One of the most challenging topics for students is the determination of the electric field produced by objects with complex geometrical shapes. The main reasons for this are insufficient training in mathematics and isolated teaching of the topic without relying on previously acquired knowledge [1] – [3]. At the same time, students have prior experience in solving problems to calculate the moment of inertia for bodies of analogous geometric shapes: a material point, a rod, a disk, a sphere, etc. [4]. The similarity of the underlying mathematical models provides grounds for employing the method of analogy, which enables the transfer of previously formed knowledge into a new learning context [5] – [6].

Recent publications show that effective teaching of solving physical problems requires a combination of traditional and modern pedagogical approaches. Researchers highlight several key aspects: the development of students' conceptual thinking [7]; student-centered, active learning methods that stimulate thinking and understanding [8]; integration of constructivist and active learning methods adapted to modern educational requirements [9]; development of critical thinking, modeling and argumentation in students [10]; emphasis on qualitative understanding of concepts rather than solely their mathematical application [1]; formation of a "physical" mode of reasoning through the constant comparison of models with real phenomena [11]; and the use of the method of analogies to transfer knowledge from one problem to another [5]. Thus, the analyzed sources imply the effectiveness of combining differentiation and integration, the use of analogies, and the gradually increasing problem complexity as key methods for forming a holistic strategy for solving physics problems.

The goal of this study is to develop and test a methodological approach to teaching students how to solve problems involving the determination of the electric field by utilizing knowledge gained from other areas of physics. The proposed approach integrates three methods: differentiation and integration, analogy, and the gradual increase in problem complexity.

2. Research methods. To achieve the aim of the study, a set of complementary methods was applied, focusing on investigating the features of the formation of students' skills in the process of solving physical problems in electrostatics.

Analogy method. This method was used to establish similarities between problems in mechanics familiar to students and new problems in electrostatics. Such an approach promoted cognitive activity and facilitated the assimilation of new concepts. In particular, the process of solving problems related to determining the electric field was explained through analogies with calculating the moment of inertia of bodies with similar geometrical shapes.

Differentiation and integration method (DI method). The generalized scheme of the DI method applied in electrostatics for the bodies of linear geometric shape includes the following steps:

1. Problem analysis
- Identify the physical quantity to be determined (e.g., the electric field value, the electric potential, etc.);
- Specify a body that can be considered linear (straight wire, arc, thin rod);
2. Choice of an elementary segment
- Divide the body into infinitesimal elements of length dl;
- Express the elementary charge dq in terms of dl;
3. Formulation of the expression for the elementary contribution
- Apply the corresponding law or equation to the chosen body element (depending on the problem statement);
4. Determination of geometrical relations
- Choose a coordinate system in which the integration limits for the object are simplified;
- Express all the variables involved in the law in terms of the one with respect to which integration is most convenient;
5. Compilation of the integral
- Write the total effect as the integral, considering the integration limits with respect to the length of the body;
6. Integration
- Calculate the integral;
- When necessary, apply trigonometric substitutions or exploit symmetry (e.g., one of the components may vanish due to symmetry);
7. Result analysis
- Verify the dimensional consistency;
- Verify the limiting cases, for example, when the rod length tends to infinity;
- Compare with known formulas (e.g., for an infinite wire, for a semicircular arc).

The application of this method allowed students to work with realistic models of physical objects, accounting for their geometrical shapes and the distribution of physical quantities. This provided the formation of analytical skills and an understanding of the universality of the method for both mechanics and electrostatics.

Gradually increasing complexity. This method involved a step-by-step complication of the learning material and problem tasks. Such an approach prevented cognitive overload, built students’ confidence, and facilitated the progressive development of students’ advanced problem-solving skills.

Testing. Control tests were used to assess the level of knowledge and skills acquired. Standardized tasks provided objective quantitative indicators of student achievement.

2.1 Organization of the study

The study was conducted during the spring semester of 2025 at the National Technical University of Ukraine “Igor Sikorsky Kyiv Polytechnic Institute”. A total of 116 students from the Institute of Aerospace Technologies, who studied the discipline “General Physics. Part 2”, section “Electrostatics”, participated. The experiment was conducted within the framework of the regular educational process, which ensured natural conditions for testing the effectiveness of the developed methodology.

2.1.1 Participants. The sample consisted of first-year students who had already completed the basic sections of “General Physics. Part 1. Mechanics”. All the participants had approximately the same level of prior training, allowing for reliable comparisons within a homogeneous group.

2.1.2 Educational environment. Classes were conducted in a blended format, combining modern distance learning technologies (including Zoom Meetings, PowerPoint presentations, Google Workspace for Education and the certified distance learning platform based on Moodle www.physics.zfftt.kpi.ua) with face-to-face practical trainings. The use of these resources provided interactivity, flexibility in course organization, and opportunities for continuous monitoring of learning outcomes.

2.1.3 Structure of practical lessons. Practical lessons followed a unified structure consisting of six stages:

1. Organizational stage – creating a working atmosphere, activating prior knowledge, and setting learning objectives;
2. Homework review – analyzing completed exercises and clarifying difficult aspects;
3. Work with new material – presentation of main theoretical principles; methodological recommendations for problem-solving using the three main stages of solution:
- Physical stage: analysis of phenomena, identification of laws/equations, concise record of the problem data in SI units, construction of schemes and figures;
- Mathematical stage: compilation and solution of equations, application of the differentiation and integration method, use of analogies and other techniques, numerical calculations;
- Analytical stage: verification of units, evaluation of the adequacy of results, comparison with reference data, and search for alternative solutions; demonstration of examples of problem-solving with a gradual increase in complexity;
4. Guided independent work – solving three problems of varying complexity with step-by-step lecturer’s support;
5. Homework – three medium-difficulty problems and one advanced-level problem, and a preparatory task for the next lesson;

6. Final stage – generalization of the material, evaluation of the level of knowledge and skills acquired, and analysis of group performance.

2.1.4 Methodological approaches. The following didactic strategies were employed during the lessons:

- gradually increasing task complexity through the introduction of new geometrical elements;
- application of analogies from mechanics (e.g., explaining the DI method in electrostatics through analogies with the calculation of the moment of inertia);
- use of tests to assess comprehension of the material;
- questionnaires to identify the learning motivation and difficulties experienced by students.

These approaches aimed to develop students' ability to solve physics problems using integral methods, foster analytical thinking, and enhance motivation for learning.

3. Results

To evaluate the effectiveness of the implemented approach, tests were used to assess the level of acquired knowledge and skills. The results demonstrate that appropriately selected teaching methods enhance students' academic performance and motivation while contributing to the development of stable skills in applying physical knowledge across diverse learning situations.

3.1 Methods of data collection and processing

To evaluate the effectiveness of the proposed teaching methodology, data collection through the knowledge testing (quantitative analysis of results),

- https://physics.zfftt.kpi.ua/mod/quiz/view.php?id=1100,
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and statistical processing of the obtained indicators were employed. The tests included various types of tasks: closed (multiple-choice), open (short-answer), matching, sequencing, and numerical problem-solving tasks. The test assignments were divided into three blocks:

- Diagnostic (D1–D5): evaluation of students' mastery of the differentiation and integration method (DI method);
- Theoretical (E1–E5): evaluation of students' understanding of key concepts in electrostatics related to the determination of the electric field vector $\boldsymbol{E}$;
- Generalized (Z1–Z10): evaluation of students' practical skills in applying the DI method to solve problems regarding the determination of the electric field.

3.2 Diagnostic tasks

Diagnostic tasks (D1–D5) were designed to verify students' mastery of the differentiation and integration method (DI method). The results demonstrated a high level of mastery over the basic steps of the DI method. The highest percentages of correct answers were obtained for determining the integration variable (96%), integration limits (92%), and the first step in calculating the electric field of a distributed charge (87%) – questions D3–D5. This indicates confident use of the problem-solving algorithm. However, the lowest results were observed in tasks related to the fundamental principles of the method (D1 – 68% and D2 – 74%), indicating insufficient understanding of the theoretical underpinnings. Therefore, additional attention should be given to the mathematical foundations of differentiation and integration and their connection with physical meaning to ensure more holistic learning.

3.3 Theoretical tasks

The average rate of correct answers was 73%. The results of testing indicate that students generally developed a solid understanding of the concept of electric field and its determination for various types of charged bodies. High scores were obtained for identifying relevant parameters for calculating the field due to a point charge (E1 – 92%), the field due to a long charged wire (E5 – 90%), and the direction of the field due to a positive charge (E3 – 81%). At the same time, lower performance was observed in tasks requiring deeper comprehension and spatial thinking: approximately one-third of the students struggled with tasks related to the superposition principle (E2 – 73% of correct answers), and only 30% answered without error when determining the direction of the field due to an infinite charged plane in different spatial regions. These results suggest an adequate grasp of fundamental electrostatics concepts while highlighting the need for additional practice in understanding spatial orientation.

3.4 Generalized tasks

The results of the testing on the generalized tasks are presented in Table 1. They indicate that students have mastered well the initial stages of applying the DI method – algorithmization, dividing the body into elements and recording elementary quantities. However, difficulties arise when visualizing, performing mathematical operations and interpreting the obtained expressions.

The level of students' mastery of the material according to the generalized scheme of the DI method is shown in Fig. 1.

3.5 Summary of results of students' mastery of the proposed approach

The obtained results demonstrate that students:

- successfully mastered the fundamental theoretical principles of electrostatics and the DI method;
- confidently performed the basic algorithmic steps;
- were able to apply knowledge in standard situations.

Table 1

Results of tasks Z1–Z10

Task	% Correct Answers	Main Difficulties
Z1 (select the sequence of steps of the DI method algorithm)	97%	–
Z2 (select the elements into which a charged linear body should be divided)	97%	–
Z3 (select formulas for calculating the charge of an element)	90%	Determining linear charge density
Z4 (select the figure with correct notation of physical quantities related to the problem)	61%	Locating dE
Z5 (select the correct formula for dE using the most convenient integration variable)	66%	Transforming formulas using the integration variable
Z6 (select the correct formulas for the projections of dE)	66%	Gaps in trigonometry knowledge
Z7 (select the limits of integration)	62%	Failure to relate integration limits to the chosen coordinate system
Z8 (select the correct steps and results of integration for the components of vector E)	60%	Integration of trigonometric functions
Z9 (obtain the formula for the final result of E)	63%	Determining the magnitude of the vector
Z10 (determine the direction of vector E)	60%	Spatial orientation

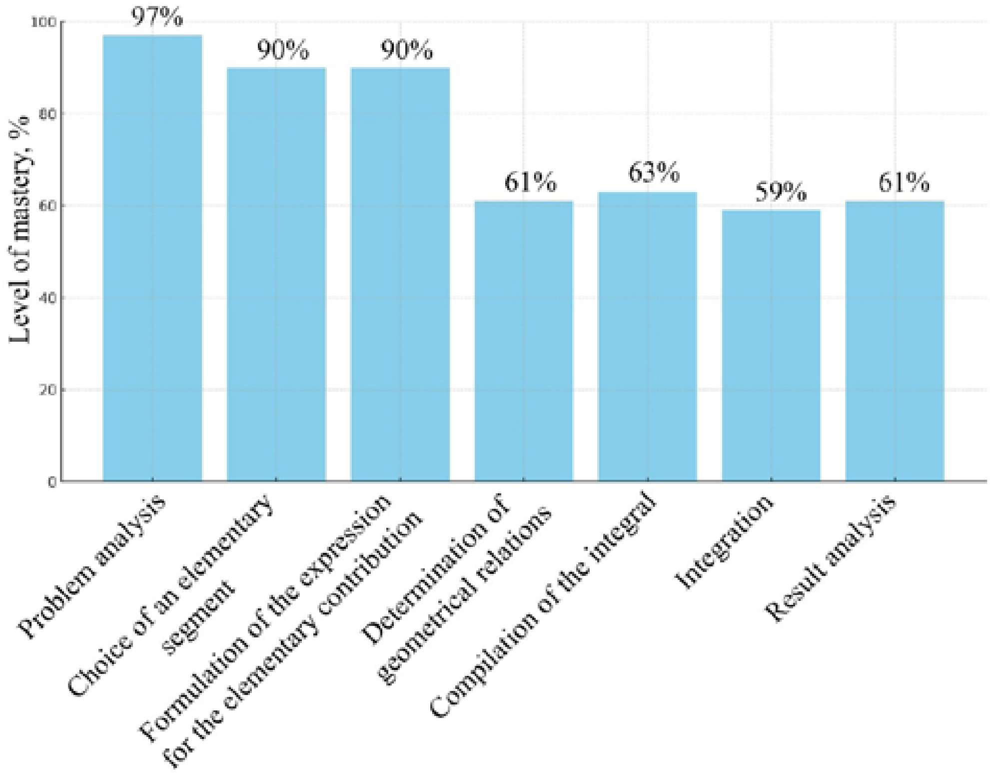

Fig. 1. Diagram of students’ mastery of the DI method

At the same time, the following difficulties remained characteristic:

- incomplete understanding of the theoretical principles of differentiation and integration (D1 and D2);
- insufficient spatial thinking (E1 and E2);
- difficulties with the mathematical processing of intermediate results (Z7–Z9).

Overall, the findings confirm the effectiveness of the proposed methodological approach. Further development of the approach should focus on practicing the complete algorithm of differentiation and integration, enhancing spatial thinking, and relating mathematical operations with their physical meaning to ensure comprehensive learning.

4. Conclusions. This article proposes a methodological approach to teaching students how to solve problems on determining electric field, based on the use of the analogy method, the differentiation–integration method, and the method of gradually increasing problem complexity. The results of investigation demonstrate the effectiveness of the developed methodology: more than 80% of students successfully completed final tasks, indicating a sufficient level of theoretical mastery and the formation of practical skills. Analysis of the test results shows that students have acquired basic algorithmic steps and fundamental concepts of electrostatics, but experienced difficulties with spatial thinking and processing of intermediate results. The proposed approach promotes the development of analytical thinking, formation of interdisciplinary connections, and increased student motivation.

The significance of the proposed approach lies in its universality and reproducibility across different educational institutions. Its core components – analogy, the DI method, and the step-by-step increase in problem complexity – are independent of the specific features of any particular university. The implementation requires only the following:

- a basic mechanics course that has already been completed by students;
- an electrostatics course within which the tasks are practiced;
- standard didactic materials (algorithm checklists, diagrams, and problems of varying complexities).

The proposed methodological approach can be readily adapted to the curricula of other universities because of its simple structure and the availability of clear instructional materials. A promising direction for further research is the adaptation of the proposed methodological approach to other branches of physics where integral methods are applied and analogies with models already known to students can be constructed, as well as the broader use of digital resources to support the development of students' spatial thinking.

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Ф. М. Гарєєва, М. В. Чурсанова, Д. В. Савченко, Т. В. Матвєєва, О. В. Дрозденко. Навчання студентів розв’язуванню задач на знаходження напруженості електричного поля

У статті описано методичний підхід до методики навчання студентів розв’язанню задач з електростатики на прикладі визначення напруженості електричного поля для тіл лінійної геометричної форми. Запропонований підхід ґрунтується на трьох ключових елементах: (1) метод аналогії, який дає змогу переносити стратегії розв’язування задач із механіки (момент інерції) в електростатику; (2) метод диференціювання та інтегрування (метод ДІ), структурований як чіткий покроковий алгоритм; (3) поступове ускладнення завдань, що зменшує когнітивне перевантаження та підтримує послідовний розвиток умінь. На відміну від традиційних підходів, що надають перевагу механічному заучуванню формул, у роботі акцентується увага на структурованому мисленні, інтеграції математичних операцій із їх фізичним змістом та міждисциплінарних зв’язках між розділами фізики.

Дослідження охопило 116 студентів технічних спеціальностей. Для оцінювання ефективності розробленого підходу використано метод тестування. Результати показали, що понад 80% студентів успішно виконали підсумкові завдання, продемонстрували зростання впевненості у власних знаннях та навичках. Отримані результати підтверджують ефективність запропонованого підходу у розвитку навичок розв’язування задач, аналітичного мислення та підвищенні навчальної мотивації.

Значущість запропонованого підходу полягає в його універсальності та можливості відтворення в інших закладах вищої освіти. Представлений методичний підхід може бути легко адаптованим до навчальних програм університетів, а продемонстровані чіткі інструктивні матеріали мають просту структуру та можуть бути поширені на інші розділи фізики, де застосовуються інтегральні методи та можлива побудова аналогій з уже відомими студентам моделями.

Ключові слова: *методи навчання, розв’язування задач, напруженість електричного поля, метод аналогії, метод диференціювання та інтегрування, метод поступового нарощування складності.*

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