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Graphic Organizers as a Tool for Teaching the Laws of Direct Current in University Physics: A Methodological Analysis

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A B S T R A C T

Direct-current circuits are a core topic of the university physics course, yet students often memorize formulas without forming a coherent model of current, voltage and resistance. Graphic organizers are widely recommended as a remedy, but in national methodological publications they are usually described without explicit links to learning objectives, typical misconceptions or assessment. To systematize and analyse a set of graphic organizers and interactive techniques for teaching the topic «Laws of Direct Current» and to align them with the levels of the revised Bloom taxonomy. A qualitative methodological (design-based) analysis was carried out on five techniques used in lectures and practical sessions at Bukhara State Technical University: the Fishbone diagram, the Sunflower case technique, the Concept Analysis table, the Chained Logical Sequence (matching) task and alternative two-group tests. Each technique was examined against four criteria: the targeted cognitive level, the misconception it addresses, the lesson phase and the form of assessment. The techniques were found to be complementary rather than interchangeable: matching tasks and concept tables support remembering and understanding, the Fishbone diagram supports causal analysis, and the Sunflower case supports application, analysis and evaluation in a realistic safety context. A lesson sequence, a Bloom alignment matrix, corrected answer keys and a worked physical solution of the case are proposed. Graphic organizers are most effective when they are selected for a specific cognitive goal and are explicitly directed at known DC misconceptions. Their effect on learning outcomes should be verified in a controlled pre-test/post-test study.

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1. Introduction

The effective organization of the educational process on the basis of modern pedagogical and information technologies is one of the central tasks of higher education reform in Uzbekistan. The aim of modern education is not only to transmit knowledge but also to develop students' interests, abilities and independent thinking [1, 2]. In engineering universities this task is particularly important for general physics, because physical concepts form the basis of all subsequent technical disciplines.

The topic «Laws of Direct Current» occupies a key place in the physics course. Direct current is an electric current whose magnitude and direction do not change over time; it is maintained in a closed circuit by a source of constant electromotive force (EMF). If the circuit is not branched, the current is the same in all its parts. The main laws of the topic are Ohm's law for a circuit segment and for a complete circuit, the Joule–Lenz law and Kirchhoff's rules for branched circuits. The topic has direct technical applications in electrometallurgy, transport, communications and automation.

At the same time, research in physics education shows that DC circuits are a source of persistent misconceptions. Students frequently believe that current is «used up» by a load, treat the battery as a source of constant current rather than constant EMF, and reason locally and sequentially about circuits instead of treating the circuit as a system [16, 17]. Such misconceptions are not removed by additional formula drill; they require tasks that make the structure of the concept visible.

Graphic organizers are visual representations that show relationships between concepts: concept maps, cause-and-effect (Fishbone) diagrams, Venn diagrams, clusters, tables and similar forms. Their theoretical basis goes back to Ausubel's idea of advance organizers [10] and to concept mapping [11]. Meta-analyses confirm that learning with concept and knowledge maps produces moderate positive effects on knowledge retention and transfer [12], and that graphic organizers are particularly helpful for students who have difficulties in learning [13]. In Uzbek methodological literature, interactive methods and graphic organizers are widely recommended for physics teaching [3, 4, 6–9]; however, they are usually presented as a list of techniques, with little attention to which cognitive objective each technique serves and how its effect can be assessed.

The aim of this study is to systematize and analyse a set of graphic organizers and interactive techniques for teaching the topic «Laws of Direct Current» in a technical university and to align them with learning objectives, typical misconceptions and assessment. The study addresses three questions: (1) which cognitive levels of the revised Bloom taxonomy [14] each technique supports; (2) which DC misconceptions each technique can address; (3) how the techniques can be combined in a single lesson sequence.

2. Materials and Methods

The study is a qualitative methodological (design-based) analysis. Its material consists of teaching resources developed and used by the author in lectures and practical sessions on general physics at the Department of Exact Sciences of Bukhara State Technical University: graphic organizers, case tasks, matching tasks and test banks on the topic «Laws of Direct Current» and related topics of electrostatics and electrolysis. No experimental comparison of student groups is reported in this paper; empirical verification is discussed as the next stage of research (Section 4.3).

The analysis was based on the following content of the topic. Ohm's law for a homogeneous segment of a circuit and for a complete circuit with a source of EMF ε and internal resistance r:

$$\mathbf{I = U / R,} \qquad \mathbf{\varepsilon = IR + Ir,} \qquad \mathbf{I = \varepsilon / (R + r)} \tag{1}$$

the resistance of a conductor of length l and cross-sectional area S made of a material with resistivity ρ, and the Joule–Lenz law for the heat released by a current:

$$\mathbf{R = \rho l / S,} \qquad \mathbf{Q = I^2Rt} \tag{2}$$

as well as Kirchhoff's rules for nodes and loops of branched circuits. A simple circuit with a source, a lamp and a rheostat (Fig. 2) was used as the basic visual model throughout the topic.

Five techniques were selected for analysis:

1) **Fishbone diagram** (Ishikawa cause-and-effect diagram [15]) for the question «Why does an electric current arise in a conductor?»;

2) **Sunflower technique** — a case-based organizer in which the central problem is surrounded by «petals» (sub-questions) and «leaves» (processes and preventive measures);
3) **Concept Analysis table**, in which students write the meaning of key terms before and after the lesson;
4) **Chained Logical Sequence task** — matching physical quantities, their symbols and SI units written on the board in random order;
5) **Alternative two-group tests**, in which each question is answered by choosing the correct statement from two columns of answers (group A and group B) that contain both correct answers and distractors.

Each technique was analysed using four criteria: (a) the cognitive levels of the revised Bloom taxonomy that it primarily and secondarily supports [14]; (b) the DC misconceptions it can expose or correct, based on physics education research [16, 17]; (c) the lesson phase in which it is most appropriate (activation, presentation of new material, consolidation, application, assessment); (d) the form and criteria of assessment. The physical correctness of all tasks and answer keys was checked against the content described in Section 2.2.

3. Results

The Fishbone diagram (Fig. 1) turns the question «Why does an electric current arise in a conductor?» into a structured causal model. The upper bones show the necessary causes — free charge carriers, an electric field created by a source of EMF, and a closed circuit. The lower bones show the evidence and consequences — directed motion of charges, measurable quantities connected by Ohm's law, and the thermal, magnetic and chemical effects of current. The tail formulates the conclusion: a current exists only when a closed circuit, free charge carriers and a current source are present simultaneously.

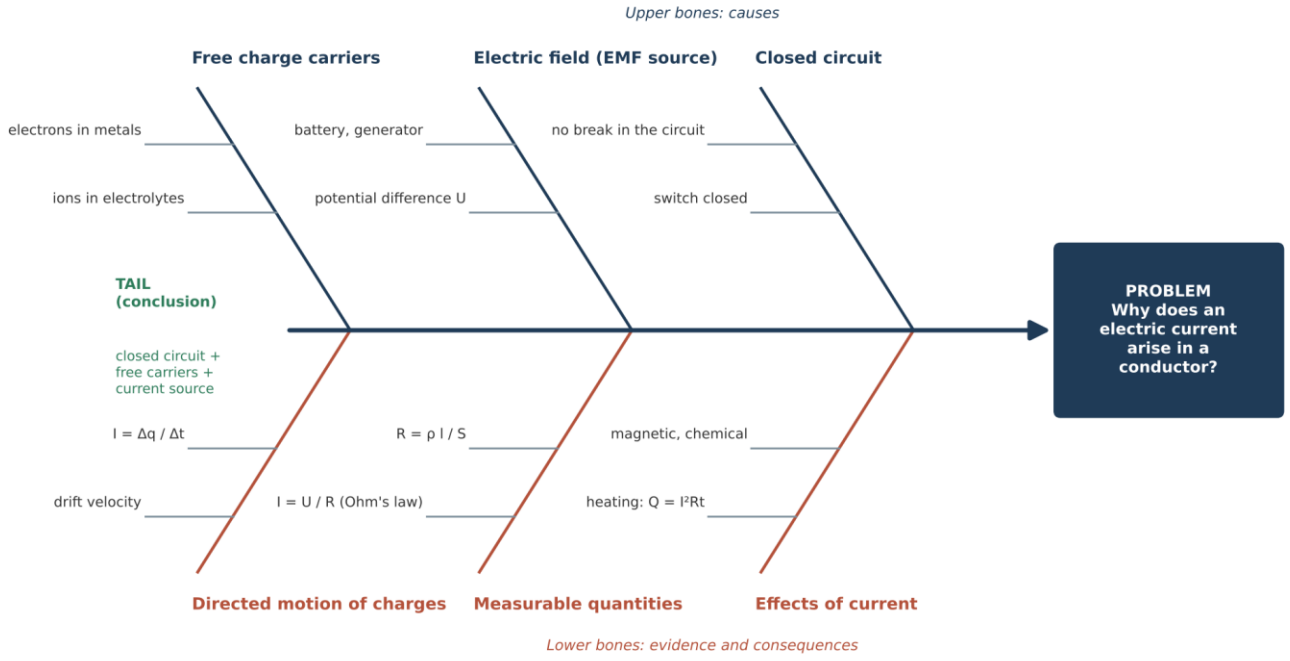


Figure 1. Fishbone diagram «Why does an electric current arise in a conductor?»

The analysis shows that the diagram primarily supports *understanding* and *analysis*: students must distinguish causes from consequences and justify each bone. It also directly addresses the misconception that a source «pushes out» a fixed current regardless of the circuit, because the closed circuit and the resistance appear as separate necessary elements.

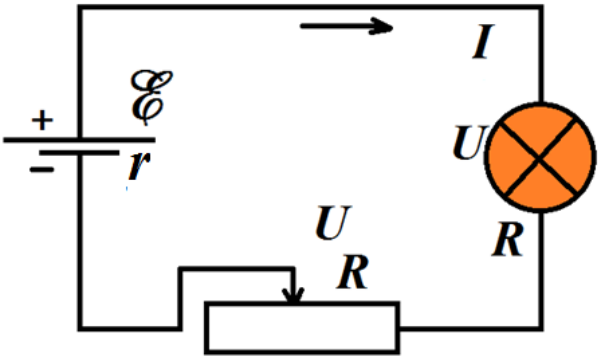


Figure 2. Basic circuit used throughout the topic: source of EMF ε with internal resistance r, lamp and rheostat.

The Sunflower technique was applied to a realistic case [4]: *a journalist bought the cheapest electric heater on the market, which had a very short and thin power cord; on the second day of use the cord caught fire and nearly caused a serious fire.* The central question is «Why did the cord of the heater catch fire?». The petals guide the analysis (Fig. 3), and the two leaves require students to name the physical processes and to propose preventive measures.

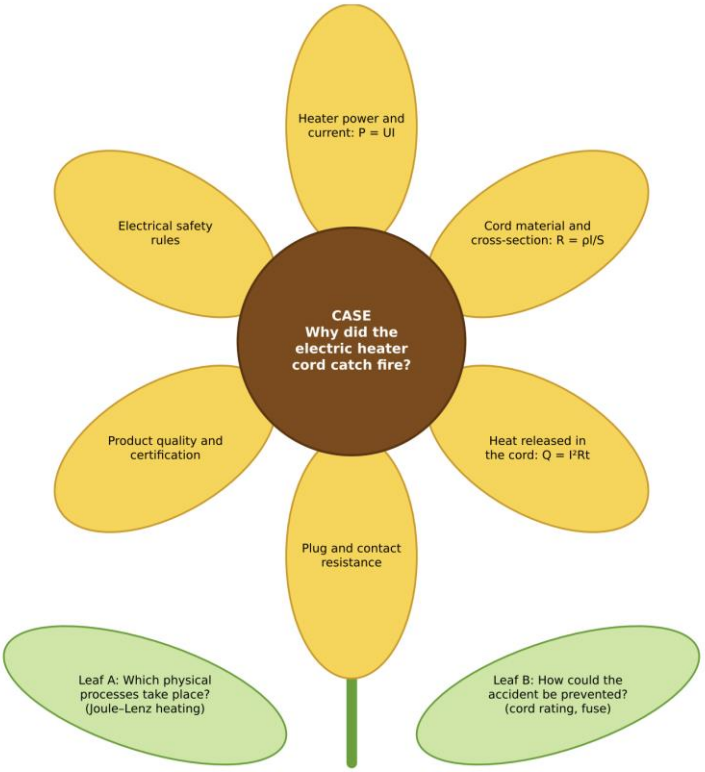


Figure 3. Sunflower organizer for the heater case.

A model solution was developed to make the assessment of the case objective. For a heater with power P = 2000 W connected to a 220 V network, the current is $I = P/U \approx 9.1$ A. The same current flows through the cord, since the circuit is not branched. For a copper cord ($\rho = 1.7 \cdot 10^{-8}$ Ω·m) with a total conductor length of 3 m and an undersized cross-section of 0.35 mm^2, formula (2) gives $R \approx 0.15$ Ω and a heating power of $I^2R \approx 12$ W distributed along the thin cord, compared with about 4 W for a properly rated 1.0 mm^2 cord. A poor contact in the plug with a resistance of only 0.3 Ω releases about 25 W in a volume of a few cubic centimetres. Because the heat is released continuously while the heat dissipation is small, the insulation

overheats and ignites. The short cord also encourages the use of extension leads and additional contacts, which increases the total contact resistance.

The case therefore requires students to *apply* formulas (1)–(2), to *analyse* where heat is released, and to *evaluate* product quality and safety rules (cord rating, fuses or circuit breakers, certified products). This is the only technique in the set that reaches the evaluation level in an authentic context.

In the original materials the Concept Analysis table was used with nanomaterial terms. For the DC topic it was adapted as shown in Table 1. Students complete the right-hand column at the beginning of the lesson (diagnosis of prior knowledge) and revise it at the end (reflection), so that changes in their understanding become visible.

Table 1. Concept Analysis table for the topic «Laws of Direct Current» (reference answers)

Concept	Reference meaning
Direct current	Current whose magnitude and direction do not change over time
Electromotive force (EMF)	Work of external (non-electrostatic) forces in moving a unit positive charge around the closed circuit
Internal resistance	Resistance of the source itself; causes the terminal voltage to fall as the current increases
Short circuit	Connection with $R \approx 0$; the current reaches its maximum $I = \varepsilon/r$
Joule heat	Heat released by a current in a conductor, $Q = I^2Rt$
Node (junction)	Point where three or more conductors meet; the sum of currents entering equals the sum leaving (Kirchhoff's first rule)

Source: Author's own development based on the results of scientific research

In this task the teacher writes physical quantities, their symbols and their units on the board in random order, and students reconstruct the correct chains [3, 6]. The analysis of the original task showed that it lacked a verified key and contained an incorrect unit symbol for electrical conductance. Table 2 gives the corrected key.

Table 2. Key to the Chained Logical Sequence task

Physical quantity	Symbol	SI unit
Current	I	ampere (A)
Voltage	U	volt (V)
Resistance	R	ohm (Ω)
Resistivity	ρ	ohm·metre (Ω·m)
Internal resistance	r	ohm (Ω)
Electrical conductance	G	siemens (S)
Conductivity	σ	siemens per metre (S/m)
Electromotive force	ε	volt (V)
Amount of heat	Q	joule (J)
Time	t	second (s)
Temperature coefficient of resistance	α	kelvin^{-1} (K^{-1})

Source: Author's own development based on the results of scientific research

The task supports the *remembering* and *understanding* levels and is suitable for quick consolidation. Its limitation is that correct matching does not guarantee correct reasoning about circuits; therefore it should be followed by tasks of higher cognitive levels.

The test bank contains sets of ten questions on Coulomb's law, electric field lines, electric potential and Faraday's laws of electrolysis. For each question the student chooses the correct answer from two columns (A and B) that also contain distractors. The analysis showed that the bank is well suited for checking definitions and formulas, but in the original form it did not include an answer key linking question numbers

to correct answers, and the numbering of the Faraday questions did not start from 1. Table 3 gives a verified key for the Coulomb's law set as an example.

Table 3. Verified answer key for the test «Coulomb's law. Dielectric permittivity»

No.	Question (abridged)	Correct answer
1	Unit of electric charge in SI	coulomb (C): charge passing through a conductor cross-section in 1 s at a current of 1 A
2	Coulomb's law	force between two point charges is proportional to the product of the charges and inversely proportional to the square of the distance
3	Coulomb's law in a medium (SI)	$F = q_1q_2 / (4\pi\varepsilon_0\varepsilon r^2)$
4	Coulomb's law in vacuum (SI)	$F = q_1q_2 / (4\pi\varepsilon_0 r^2)$
5	Relative permittivity of a medium	shows how many times the interaction force in the medium is smaller than in vacuum
6	Absolute permittivity	product of the electric constant and the relative permittivity, $\varepsilon_a = \varepsilon_0\varepsilon$
7	Electric constant	ε_0 — permittivity of vacuum
8	Numerical value of ε_0	$1/(36\pi\cdot10^9) \approx 8.85\cdot10^{-12}$ F/m
9	Unit of ε_0	F/m (equivalently $C^2/(N\cdot m^2)$)
10	Unit of relative permittivity	dimensionless quantity

Source: Author's own development based on the results of scientific research

For the Faraday set, the key values were also verified: the Faraday constant $F = 9.65\cdot10^7$ C/kmol, the Avogadro number $N_A = 6.02\cdot10^{26}$ kmol^{-1}, and the elementary charge $e = F/N_A \approx 1.6\cdot10^{-19}$ C; the first law is $m = kq = kIt$, and the second law is $k = (1/F)\cdot(A/n)$, where A is the molar (atomic) mass and n the valency.

Table 4 summarizes the cognitive levels supported by each technique. The matrix shows that no single technique covers the full range of objectives, while together they span all six levels.

Table 4. Alignment of techniques with the revised Bloom taxonomy (● primary, ○ secondary)

Technique	Remember	Understand	Apply	Analyse	Evaluate	Create
Chained Logical Sequence	●	●	○			
Concept Analysis table	●	●		○		
Alternative two-group tests	●	●	○	○		
Fishbone diagram		●		●	○	○
Sunflower case		○	●	●	●	○

Source: Author's own development based on the results of scientific research

Table 5. Typical misconceptions and the techniques that address them

Misconception	Correct idea	Technique
Current is «used up» by the load	In an unbranched circuit the current is the same in all parts	Fishbone; Sunflower (current in the cord equals the heater current)
A battery supplies a constant current	A source has a constant EMF; the current depends on $R + r$	Fishbone; tests on Ohm's law for a complete circuit
Local, sequential reasoning about circuits	A change in any element changes the current in the whole	Circuit model (Fig. 2); Kirchhoff tasks

Misconception	Correct idea	Technique
	circuit	
Confusing potential and potential difference	Voltage is the potential difference between two points	Alternative tests (potential set)

Source: Author's own development based on the results of scientific research

Table 6. Combination of techniques within one lecture and practical session

Lesson phase	Technique	Time, min	Expected result
Activation of prior knowledge	Concept Analysis table (first column)	5	Diagnosis of initial ideas
Presentation of new material	Fishbone diagram built jointly with students	25–30	Causal model of current
Consolidation	Chained Logical Sequence	10	Quantities, symbols and units
Application (practical session)	Sunflower case with calculation	25	Use of formulas (1)–(2) in a real situation
Assessment and reflection	Alternative tests; Concept table revisited	10–15	Feedback for student and teacher

Source: Author's own development based on the results of scientific research

4. Discussion

The analysis shows that the techniques differ substantially in their cognitive function. Matching tasks, concept tables and alternative tests mainly operate at the levels of remembering and understanding; they are efficient for consolidation and quick feedback but cannot by themselves develop circuit reasoning. The Fishbone diagram and the Sunflower case require students to construct causal explanations and to apply laws to a new situation, which corresponds to the conditions under which graphic organizers have shown the strongest effects in meta-analyses — active construction rather than passive viewing of a ready-made map [12, 13].

A second finding is that the value of an organizer depends on its physical content. A visually attractive diagram that does not target a known misconception adds little to understanding. When the Fishbone diagram explicitly separates the closed circuit, the source of EMF and the resistance, and when the Sunflower case requires students to recognise that the current in the cord equals the current in the heater, the organizers directly confront the «current is used up» and «constant current source» misconceptions described in physics education research [16, 17].

- Select each organizer for a specific objective from Table 4, and combine techniques of different levels within one lesson (Table 6).
- Prepare and verify answer keys and assessment criteria in advance; for case tasks, a model solution with numerical estimates makes assessment objective.
- Use organizers as tasks that students build themselves, not only as finished schemes shown by the teacher.
- Use authentic safety contexts (overheating of cords, fuses, short circuit) to connect the laws of direct current with engineering practice.

This paper presents a methodological analysis and does not report quantitative evidence of the effect of the techniques on student achievement. The next stage should be a quasi-experimental study with experimental and control groups, a pre-test and a post-test based on a validated instrument such as the DIRECT concept test [17] or the alternative tests described above, and calculation of the normalized gain g = (post − pre) /

(100 − pre) [18]. Student questionnaires on interest and perceived difficulty would complement the achievement data.

5. Conclusion

Graphic organizers and interactive techniques can make the abstract concepts of the topic «Laws of Direct Current» — current, voltage, resistance, EMF and Joule heat — visible and logically connected. The analysis of five techniques used at Bukhara State Technical University shows that they are complementary: matching tasks, concept tables and alternative tests support remembering and understanding, the Fishbone diagram supports causal analysis, and the Sunflower case supports application, analysis and evaluation in an authentic safety context. Their effectiveness increases when each technique is chosen for a specific cognitive objective, directed at a known misconception and supported by verified answer keys. The proposed alignment matrix, lesson sequence and model solutions can be used directly by physics teachers, while the effect of the approach on learning outcomes should be confirmed by a controlled empirical study.

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