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TEACHING THE TOPIC "NUCLEAR COMPOSITION: ELECTRIC AND BARYON CHARGES" USING THE BRAINSTORMING METHOD

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ABSTRACT

This article examines the teaching of the topic "Nuclear Composition: Electric and Baryon Charges" through modern pedagogical technologies. The study aimed to present this conceptually demanding area of physics in an understandable, engaging, and effective manner through the brainstorming method. The role of interactive learning in teaching elements of nuclear and particle physics, developing independent reasoning, and increasing classroom participation was analyzed from scientific and methodological perspectives. The pilot work involved first-year students in the Medical Physics program. The topic was taught through a traditional approach and through brainstorming, after which student achievement was assessed descriptively. The reported mastery rate was 69% for the traditional approach and 78% for brainstorming. The number of students receiving the highest grade increased, while the number receiving the lowest passing grade decreased. These findings suggest that structured idea generation, peer explanation, and teacher-guided verification may support a deeper understanding of the atomic nucleus, electric charge, quark composition, and baryon number. Because the sample was small and the design did not include randomization or inferential testing, the results should be interpreted as preliminary methodological evidence rather than a definitive causal estimate.

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Keywords: *atomic nucleus, proton, neutron, electric charge, baryon charge, brainstorming, interactive method, pedagogical technology, nuclear physics.*



Introduction

At present, modernizing the education system and widely introducing innovative pedagogical technologies into the learning process are among the priority directions of educational development. The use of modern methods in teaching the natural sciences, including physics, is particularly important for improving learning outcomes. Physics is a fundamental discipline that explains natural phenomena and processes on a scientific basis and therefore plays a major role in shaping students' scientific worldview. Physics education research emphasizes that students need opportunities to connect formal representations with reasoning, discussion, and conceptual reconstruction rather than relying only on passive reception of information [2,3]. Consequently, physics education must not only ensure the acquisition of theoretical knowledge but also develop students' ability to think independently, analyze problematic situations, and draw scientifically justified conclusions.

The selected topic is difficult because it requires students to distinguish several related but non-identical levels of description. At the nuclear level, protons and neutrons are nucleons; at the subnuclear

level, they are baryons composed of quarks. Electric charge describes electromagnetic interaction, whereas baryon number is a separate additive quantum number used to classify baryonic matter. Contemporary particle-physics references classify ordinary baryons as three-quark states and organize the spin-1/2 octet and spin-3/2 decuplet according to quark content and quantum numbers [1]. Students may memorize these diagrams without understanding why a proton has charge +e, a neutron has zero net charge, or why both have baryon number one. A discussion-based lesson can expose these partial models and help the teacher connect macroscopic matter, atoms, nuclei, nucleons, and quarks within one coherent explanatory hierarchy.

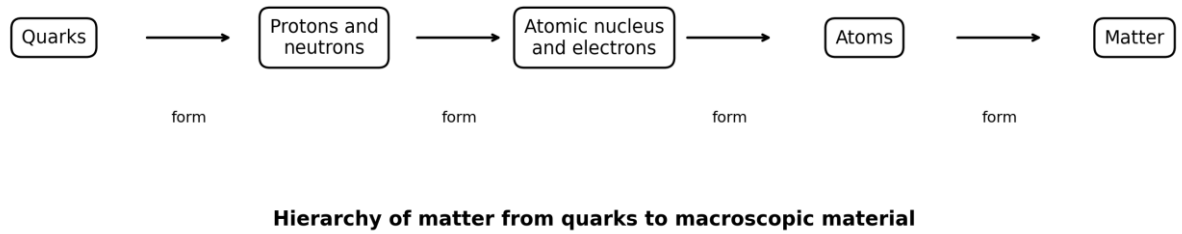


Figure 1. The hierarchical organization of matter from quarks to macroscopic material.

Using the brainstorming method to teach the topic "Nuclear Composition: Electric and Baryon Charges" helps students examine complex physical concepts through active verbalization and peer interaction. Students are not only recipients of prepared information but participants who propose explanations, compare alternatives, and revise their reasoning. Problem-based questions and open discussion encourage them to consider the composition of the atomic nucleus, the properties of protons and neutrons, the physical meaning of electric charge, and the conservation of baryon number. This movement from passive reception toward constructive and interactive engagement is consistent with the ICAP framework and established principles of physics education research [2,3,9].

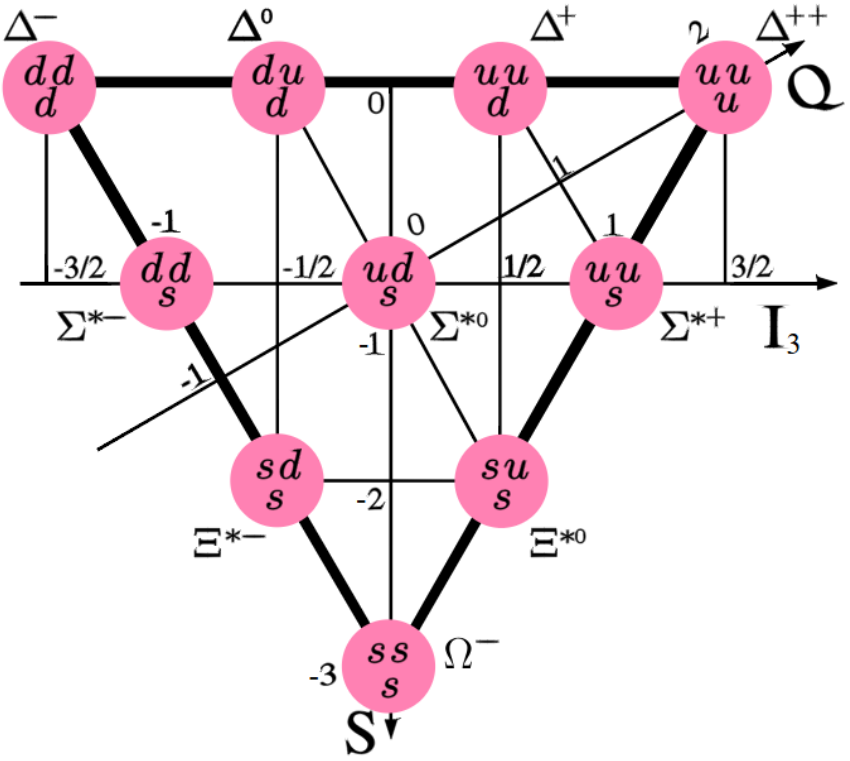


Figure 2. Baryons with spin 3/2 composed of combinations of three u, d, or s quarks: the uds baryon decuplet.

Educational research consistently indicates that well-designed active learning can outperform uninterrupted lecture-based instruction in science and physics courses [4-8]. A major advantage of brainstorming is that it encourages students to generate and communicate ideas before the teacher supplies a final explanation. Every student can contribute an initial model, question, or hypothesis, which strengthens confidence, improves scientific communication, and develops collaborative problem solving. The method is particularly useful when the topic contains abstract entities that cannot be observed directly, because discussion makes students' assumptions visible and allows misconceptions to be addressed during the lesson.

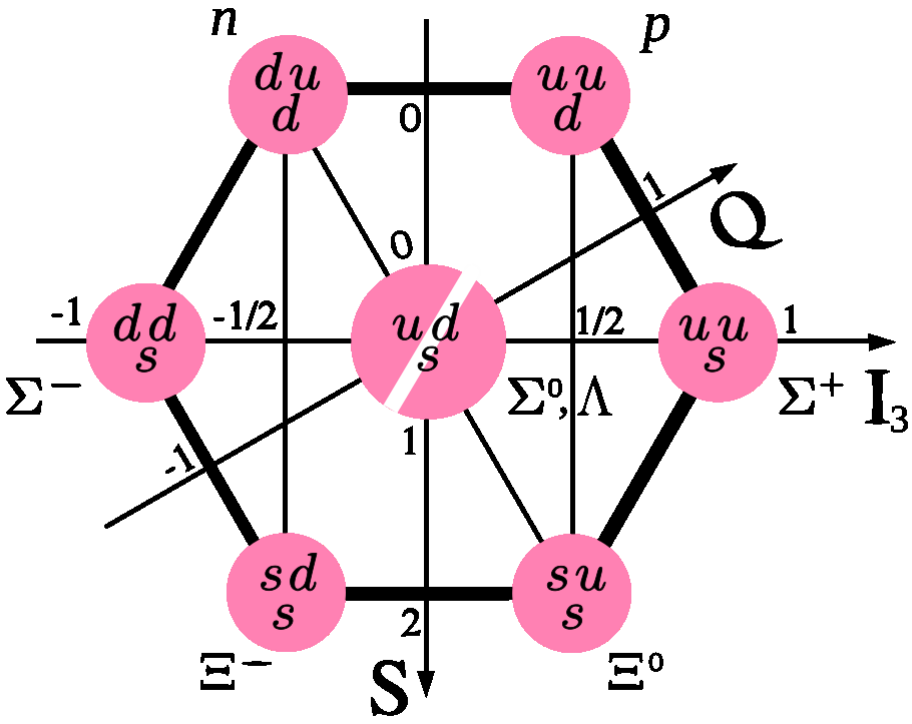


Figure 3. Baryons with spin 1/2 composed of combinations of three u, d, or s quarks: the uds baryon octet.

This article analyzes the pedagogical potential of the brainstorming method in teaching the topic "Nuclear Composition: Electric and Baryon Charges." It also considers the theoretical and practical aspects of using interactive methods and substantiates their importance for developing students' knowledge, skills, and competencies. The main objective is to demonstrate the advantages of brainstorming in teaching complex concepts of nuclear physics and to develop methodological recommendations aimed at increasing the effectiveness of physics education.

Methodology

Brainstorming is a structured idea-generation method used to stimulate divergent thinking and collaborative problem solving. Its central principle is to generate a broad range of ideas before evaluating them. During the initial phase, criticism is postponed, unusual ideas are welcomed, and participants are encouraged to develop or combine the contributions of others. Reviews and experimental studies show that the quality of the procedure depends on clear rules, balanced participation, opportunities for individual reflection, and a separate stage for evaluating ideas [12-15]. In an educational setting, the teacher therefore acts as a facilitator during idea generation and as a scientific moderator during the subsequent verification stage.

The brainstorming method corresponds closely to competency-based education because it combines conceptual knowledge with communication, information processing, argumentation, and problem-solving competencies. The ICAP framework predicts that interactive and constructive engagement should produce stronger learning than active manipulation alone or passive listening [9]. In

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the present topic, students were expected not merely to name particles but to explain relationships among quark charge, nucleon charge, baryon number, nuclear composition, and conservation laws.

Pedagogical Design of the Lesson

The lesson can be organized in five sequential stages. First, the teacher presents a diagnostic prompt such as "What particles constitute the nucleus, and what determines their electric and baryon charges?" Students write brief individual responses so that less vocal participants also formulate an initial idea. Second, the class generates possible explanations without immediate criticism. Third, the teacher groups the ideas into categories: nuclear composition, electric charge, quark structure, and conservation laws. Fourth, the class tests each category against accepted scientific models, using the quark charges u = +2/3e and d,s = -1/3e to reconstruct the proton and neutron charges. The baryon octet and decuplet diagrams are then used to compare spin states and quark combinations. Finally, students produce a concise written explanation or concept map showing the hierarchy from quarks to matter. This sequence preserves the creative stage of brainstorming while ensuring that scientifically inaccurate ideas are explicitly corrected.

The post-lesson assessment used the same intended learning outcomes for both instructional approaches and classified performance according to grades 5, 4, and 3. The reported percentages and grade frequencies were summarized descriptively. Because the available dataset does not report a pre-test, random assignment, confidence intervals, or measures of variance, no inferential claim is made about statistical significance. For a stronger design, future work should use equivalent comparison groups, a validated concept test, common scoring rubrics, and pre-test/post-test analysis.

Results

The study was conducted among first-year students of the 70530507 Medical Physics program in group FIZ-MAG-TF-UZ-2401. The available summary reports 26 student results for the traditional instructional condition and 26 student results for the brainstorming condition. Because the source dataset does not clarify whether these were two independent groups or repeated observations of the same cohort, the comparison is treated as descriptive. At the end of the lesson, assessment tasks were administered to evaluate students' knowledge, and the grade distributions were summarized.

In the lessons organized through the traditional method, the reported mastery rate was 69%. In the lessons organized through brainstorming, students participated actively and expressed their views freely regarding the topic. As a result, the reported mastery rate increased to 78%. The results are presented in Table 1.

Table 1

Student Achievement Indicators

Assessment category	Traditional method	Brainstorming method
Students receiving grade "5"	6 students	10 students
Students receiving grade "4"	8 students	9 students
Students receiving grade "3"	12 students	7 students
Total number of students	26 students	26 students
Mastery rate	69%	78%

Discussion

As shown in Table 1, the distribution of grades shifted in a favorable direction under the brainstorming condition. The number of students receiving grade 5 increased from 6 to 10, whereas the number receiving grade 3 decreased from 12 to 7. The reported mastery rate increased by 9 percentage points, from 69% to 78%. These descriptive changes are compatible with a broader body of research showing that interactive engagement, peer instruction, and active learning can improve conceptual performance in physics and other STEM disciplines [4-8].

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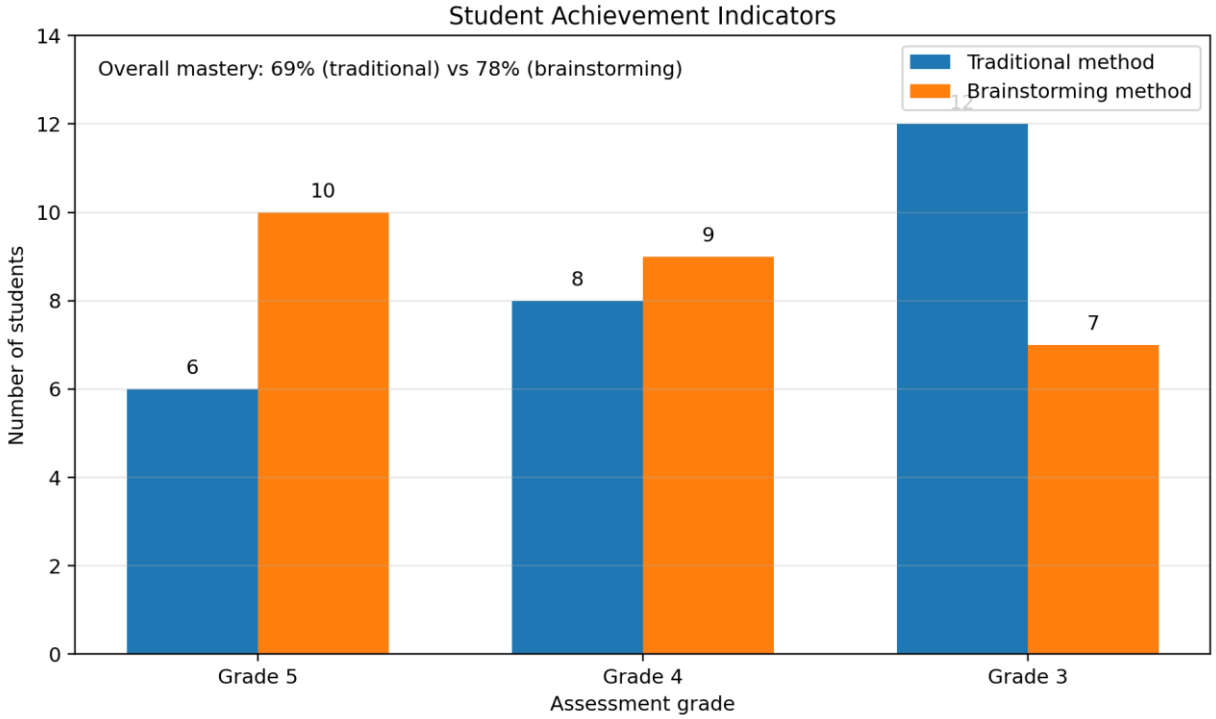


Chart 1. Distribution of students' grades under the traditional and brainstorming methods.

The chart-based analysis suggests that brainstorming can function as a pedagogical tool for increasing participation and making student thinking visible. Its value is not simply that students speak more; rather, the method requires them to retrieve prior knowledge, articulate a model, compare it with peer explanations, and revise it after scientific verification. Studies of active classrooms have shown that students may feel that they learn less when an activity is cognitively demanding even when their measured learning is greater [10]. This finding is relevant to nuclear physics, where productive difficulty and conceptual conflict may be necessary for replacing intuitive but incorrect models with scientifically coherent explanations.

The findings also have implications for inclusive classroom participation. A brainstorming lesson can create multiple entry points: students may contribute a definition, a calculation, a diagram, an analogy, or a question. When participation is carefully structured, active learning can reduce achievement disparities and increase access to disciplinary reasoning [11]. However, unstructured group brainstorming may allow dominant students to control discussion or may produce many ideas without sufficient evaluation. Combining brief individual idea generation with group discussion, teacher categorization, and evidence-based verification is therefore preferable to an unrestricted discussion [12-15].

Limitations and Directions for Further Research

The pilot has several limitations. The available summary reports 26 student results for each instructional condition but does not clarify whether these represent independent groups or repeated observations of the same cohort. Baseline equivalence was therefore not established. The study also did not report item-level assessment results, reliability estimates, delayed retention, or effect sizes. Consequently, the observed difference should not be interpreted as proof that brainstorming alone caused the improvement. A subsequent study should include at least two comparable classes, pre- and post-instruction concept measures, a delayed test, transparent scoring criteria, and observation of implementation fidelity. Qualitative analysis of students' explanations would also help determine whether they can distinguish electric charge from baryon number and correctly derive proton and neutron charge from quark composition.

Conclusion

The pilot work conducted with first-year Medical Physics students indicates that the brainstorming method is a promising approach for teaching nuclear composition, electric charge, and baryon number.

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The reported mastery rate increased from 69% under the traditional approach to 78% under brainstorming, accompanied by a shift toward higher grades. The method offers a structured way to reveal prior conceptions, stimulate peer explanation, and connect quark-level models with the properties of protons, neutrons, nuclei, and matter. Its educational value depends on separating idea generation from scientific evaluation and ensuring that every student participates. Because the evidence is preliminary, broader controlled studies are needed before firm causal conclusions are drawn. Nevertheless, the approach is suitable for further use and investigation in conceptually demanding physics courses.

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