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Organizing The Teaching Process Of The Physics Course Based On Interdisciplinary Connections

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Abstract. This article focuses on enhancing the effectiveness of the teaching process on the basis of interdisciplinary connections, drawing on the work carried out at leading centers specializing in pedagogical research. It examines the definitions of interdisciplinary connections provided in the scientific and methodological works of prominent scholars. The concepts of interdisciplinary education and various didactic and methodological approaches are analyzed, and their application in teaching physics is explored. Based on the research findings, a definition of interdisciplinary connections and a schematic representation of how to organize the teaching process using these connections are provided.

The article highlights the information-methodological support for improving the effectiveness of teaching physics on the basis of interdisciplinary connections, as well as the ways in which "Natural Sciences" lessons integrate physics knowledge to foster interdisciplinarity. It underscores how the acquired knowledge helps students in future career choices, explores ways to increase the intensity of integration in the pedagogical process, and explains how to develop students' scientific awareness competencies by explaining physics concepts using related disciplines. The integration of physics with other natural and exact sciences is shown to increase students' cognitive activity and develop their physics-oriented thinking, thereby making the educational process more effective and engaging. Moreover, a mathematical analysis of the experimental work and the achieved effectiveness in improving the quality of physics education is provided.

Keywords: pedagogical research, teacher, student, interdisciplinary connections, interdisciplinary education, physics course, study materials, natural phenomena, educational process, objective, teaching based on interdisciplinary connections, process organization, experimental study, effectiveness.

Introduction. At leading international centers specializing in pedagogical research—such as the Network of International Education Associations (NIEA), the Inter-association Network on Campus Internationalization (INCI), the European Association for International Education (EAIE), NAFSA: Association of International Educators, and others—studies are being conducted on developing strategies, mechanisms, and methodological bases for improving physics education in schools. These studies focus on teaching physics in an interdisciplinary manner, modernizing the methodological and didactic foundations for developing students' physical thinking and creative cognitive activity.

Additionally, special attention is paid to the following aspects of interdisciplinary instruction: first, improving teachers' knowledge of related subjects; second, integrating the educational process into the pedagogical and psychological environment; and third, setting strategic and tactical objectives for developing students' free, independent thinking and their conscious attitude toward reality, engagement, and social activity.

Literature Review. The famous American book *Interdisciplinary Research: Process and Theory* presents the following hypothesis [1]: although integrative research and interdisciplinarity do not share identical boundaries, they have many important common points. Integration is likely the most critical step in the interdisciplinary research process and is required in all areas of life. The integration skills that learners acquire through interdisciplinary activities are more beneficial in real life, and it is emphasized that students will be better prepared to solve today's complex problems and participate in society as responsible members.

Another source, *Interdisciplinary Education (Literature Review and Landscape Analysis)*, notes that there is no single definition of the term "interdisciplinary education" accepted by all researchers and practitioners [2]. Applebee points out that there is very little consensus among scholars on the terms and definitions used to describe how various disciplines are interconnected, and there are few cross-references among authors who address problems in interdisciplinary research. The lack of consensus in the literature makes defining and implementing interdisciplinary education more difficult. Since many scholars argue that interdisciplinary education exists along a continuum of disciplinary integration, the discussion concludes with several continuums that further clarify the definition and implementation of interdisciplinary education. This literature examines two approaches to defining interdisciplinary education. The first focuses on the primary meaning of interdisciplinary education—i.e., describing what it is [3].

Newell (2013, p. 24) defines interdisciplinary education as "a process for answering a question, solving a problem, or addressing a topic." This definition has several key components: (a) interdisciplinary education is a process, (b) the justification for an interdisciplinary approach lies in the breadth or complexity of what is being studied, and (c) the intended outcome is a comprehensive understanding (Newell, 2013). It should be noted that interdisciplinary education neither simply merges disciplines nor is built upon them [4].

Moser K. M., Ivy, J., & Hopper, L. M., in Harrison, E., Hurd, & K. Brinegar (Eds.), (2020), rely on the elements of this definition in their research on interdisciplinary education to describe it as "developing a fundamental understanding beyond the scope of a single discipline," involving two or more disciplines [5].

Drake and Berns (2004) offer a similar definition: "an interdisciplinary approach devotes equal attention to two or more disciplines and involves a thorough understanding of concepts from the chosen fields" [6].

Finally, Boix Mansilla (2005, p. 16) provides the following definition of interdisciplinary education: "the capacity to integrate knowledge and modes of thinking from two or more disciplines to produce a cognitive advancement—e.g., to explain a phenomenon, solve a problem, create a product, or raise a new question—in ways that would have been impossible through a single disciplinary lens" [7].

Although these definitions use slightly different language, they all share commonalities pointing to an emerging consensus. First, interdisciplinary education requires disciplines as foundational concepts and content. Second, it must draw on multiple disciplines as part of its main direction (i.e., more than one perspective must be in focus). Third, interdisciplinary education should involve a clear integration of disciplines so that students solve a problem, answer a question, explain a phenomenon, or create a new product [8].

Methods. It is well known that the physics course forms students' initial scientific understanding of the natural world. Before starting physics lessons, students have already become familiar with basic natural phenomena in subjects such as nature study (elementary science) and geography—disciplines included in the natural sciences. Therefore, it is advisable to begin teaching physics by applying elements of physical theory to phenomena that are already familiar to students. As a result, opportunities increase for developing students' thinking skills and shaping a scientific worldview about nature.

The study materials in the subjects being taught are selected and unified around common physical concepts. Presenting the learning content based on this principle offers distinct advantages. First, it creates conditions for using the deductive method in teaching physics. Second, choosing study materials in this way increases the significance of fundamental physical theories. Consequently, students learn to determine the causes of various phenomena based on theoretical knowledge, which, in turn, heightens their interest in the subject. The following measures can be considered feasible:

1) Enhancing information and methodological support for increasing the effectiveness of teaching physics based on interdisciplinary connections and for improving the continuity of physics knowledge learned through "Natural Sciences" lessons.

2) Demonstrating that, through teaching physics on an interdisciplinary basis, the knowledge students acquire will assist them in choosing future careers.

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3) Developing recommendations to increase the intensity of integration of the structural components of interdisciplinary teaching in the pedagogical process.

4) Identifying ways to foster scientific awareness competencies in students through the teaching of physics and refining the didactic structure for improving the effectiveness of physics instruction on the basis of natural science integration.

Results. The principle of linking theoretical knowledge to practical skills is based on the philosophical doctrine of the unity of theory and practice in the process of cognition. Applying this principle is one of the main tasks of physics education in general secondary schools. Along with imparting deep knowledge in the field of physics, instruction should also enable students to understand physical concepts and laws and to perceive their interconnectedness.

Above all, it is necessary to awaken in the student a level of attentiveness and curiosity that allows them to “see” the physics in all natural phenomena around them. In other words, students should arrive at the firm realization that “physics is at every step.” Most importantly, such awareness should be nurtured in the earliest stages of learning physics.

Teaching physics through interdisciplinary connections is of vital importance because physics advances our understanding of the true nature of phenomena. It is through linking physics to other natural sciences and related subjects that this can be accomplished. However, interdisciplinary connections do not arise automatically in the learning process. This is a multifaceted issue that can only be addressed with a clear set of objectives.

Interdisciplinary learning is based on combining knowledge, theories, and methodologies from various subjects to study the lesson objectives. It is advisable to set tasks for students aligned with these lesson objectives. Such a task is essentially a problem that needs to be solved with a specific purpose in mind. Therefore, it is a situation in which students are expected to work in a way the teacher anticipates. The teacher acts with a certain didactic intention, embedding knowledge and skills into the specific activity comprising the task. Hence, a task encompasses all the activities the teacher implements to create conditions for student learning.

When revealing the content of different types and forms of interdisciplinary connections, teachers can also determine the extent to which students have mastered other subjects and ensure that the material being studied is deeply and fully understood. Below is a recommended schematic representation of how this process can be carried out (Figure 1).

In this scheme, during the teaching process based on interdisciplinary connections, students are first provided with interdisciplinary knowledge. After that, each student is assigned a task. As they work on completing this task, new knowledge, skills, and competencies are formed and developed alongside their cognitive activity. As a result, when studying various subjects in an integrated manner, students gain deeper and broader knowledge compared to focusing on a single discipline, thus ensuring continuity, quality, and effectiveness in education.

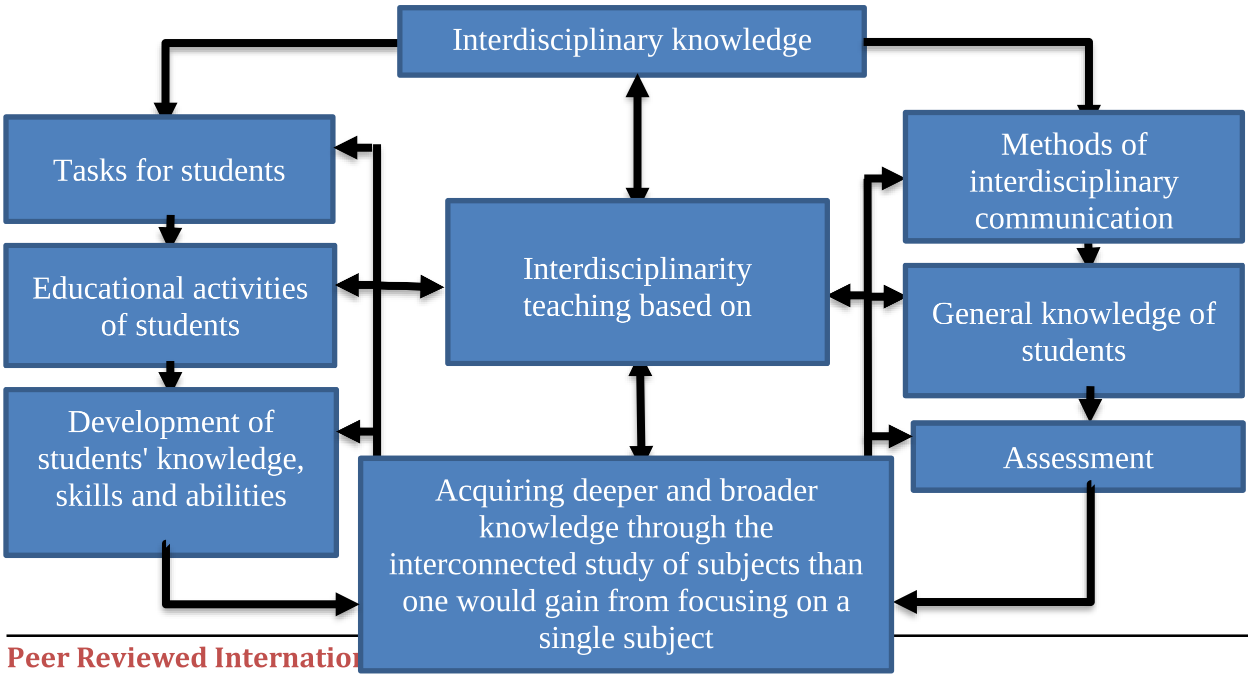

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Figure 1. The scheme of organizing the teaching process based on interdisciplinarity

In order to teach on the basis of interdisciplinary connections, the teacher themselves must have interdisciplinary knowledge. Implementing these connections involves the following: using computer and information technologies to teach physics, fostering interdisciplinary links through interactive methods, and helping students form a holistic understanding of the universe. In education, interdisciplinary connections lead to the development of independent thinking, initiative, the thorough and conscious assimilation of knowledge, and the growth of creative thinking. They also reveal how well students have mastered other subjects and ensure a full and deep understanding of the content being studied. Therefore, when teaching physics, it is necessary to organize lessons around interdisciplinary connections, develop corresponding lesson plans, and continuously devise and implement new teaching methods. During lessons, it becomes possible to assess students' knowledge not only of physics but also of other subjects they have studied. Consequently, students' knowledge becomes not only subject-specific but also generalized, providing opportunities to transfer and apply that knowledge to new contexts and real-world situations.

Hence, when organizing learning activities, it is important to plan lessons that draw on knowledge of everyday life and technology, information obtained from the internet and communication technologies, observed natural phenomena and processes, and the knowledge gained in subjects such as natural sciences, mathematics, information technology, and computer science. In other words, organizing interdisciplinary teaching is a key factor in achieving high-quality education. Implementing interdisciplinary teaching in physics simplifies the interconnection of materials from related subjects, enables students to acquire systematic and robust knowledge, skills, and competencies, fosters ideas for creating new technologies, and facilitates progress toward a higher level of educating well-rounded individuals.

Within the school physics curriculum, increasing students' interest in physics, shaping the idea of applying their knowledge in production technologies, developing cognitive abilities, modern knowledge, skills, and competencies, and supporting students in their future career choices are all crucial goals.

Taking into account that physics is taught beginning in the 7th grade in schools—while prior to this, students acquire foundational knowledge of nature (including elementary physics) from the "Natural Sciences" textbook—experimental studies have confirmed the changes in mastery and knowledge levels in physics among students in both the experimental and control groups. Seventh-grade classes in general secondary schools were chosen for the experimental phase. A total of 1,012 students from general education schools in Tashkent city, Namangan region, and Fergana region participated in the experimental work (see Table 1).

Table 1

Analysis of the Initial Results (in Numbers and Percentages) of the Experimental Study on Improving the Methodology of Teaching the Physics Course Based on Interdisciplinary Connections

Groups	Number of students	Mastery results (in %)			
		excellent	good	satisfactory	unsatisfactory
Experimental groups	528	47 / 9	143 / 27	243 / 46	95 / 18
Control groups	484	39 / 8	126 / 26	227 / 47	92 / 19

According to the results of the experiment, it was found that the differences between the knowledge, skills and abilities of the students in the experimental group involved in the research

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process compared to the students in the control group are not significant. This diagram looks like this (Figure 2).

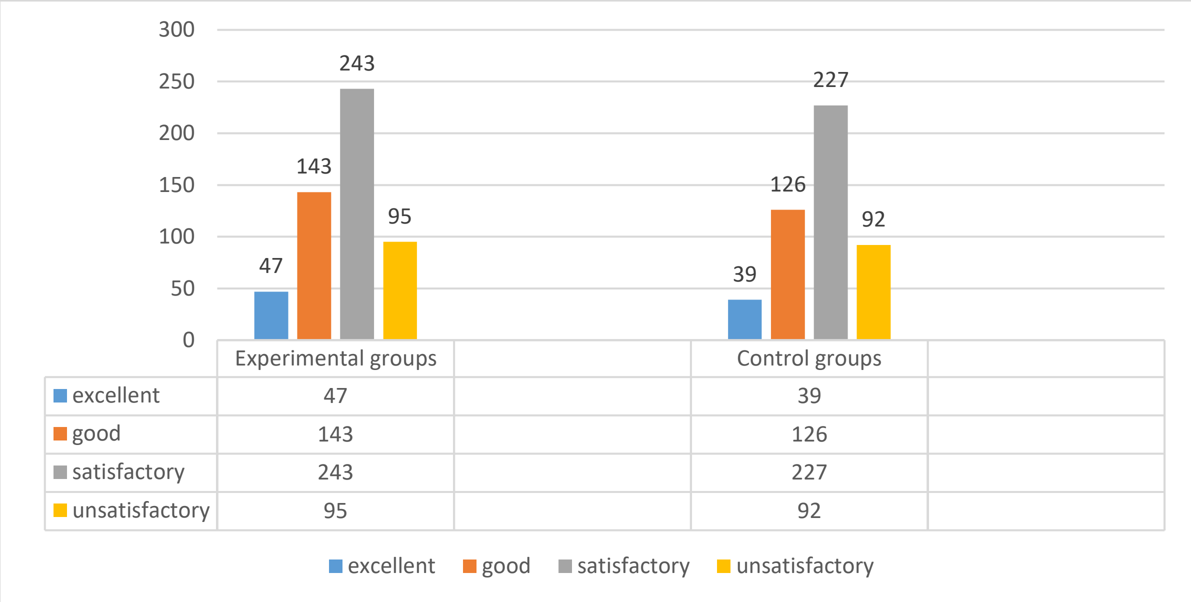

Figure 2. Initial diagram for improving the teaching methodology of the physics course on the basis of interdisciplinarity

As can be seen from the diagram, the excellent and good indicators in the experimental group are not significantly different from the indicators of the control group. In Table 2, the level of students' mastery is defined as an excellent indicator with 5 points, a good indicator with 4 points, a satisfactory indicator with 3 points, and an unsatisfactory indicator with 2 points. The excellent and good scores in the experimental group are higher than those of the control group.

Table 2

The final analysis of the results of the experiment on the improvement of the teaching methodology of the physics course on the basis of interdisciplinarity

(in numbers and percentages)

Groups	Number of students	Mastery results (in %)			
		excellent	good	satisfactory	unsatisfactory
Experimental groups	528	164 31	222 42	84 16	58 11
Control groups	484	44 9	126 26	232 48	82 17

In the diagram (Figure 3), it took the following form.

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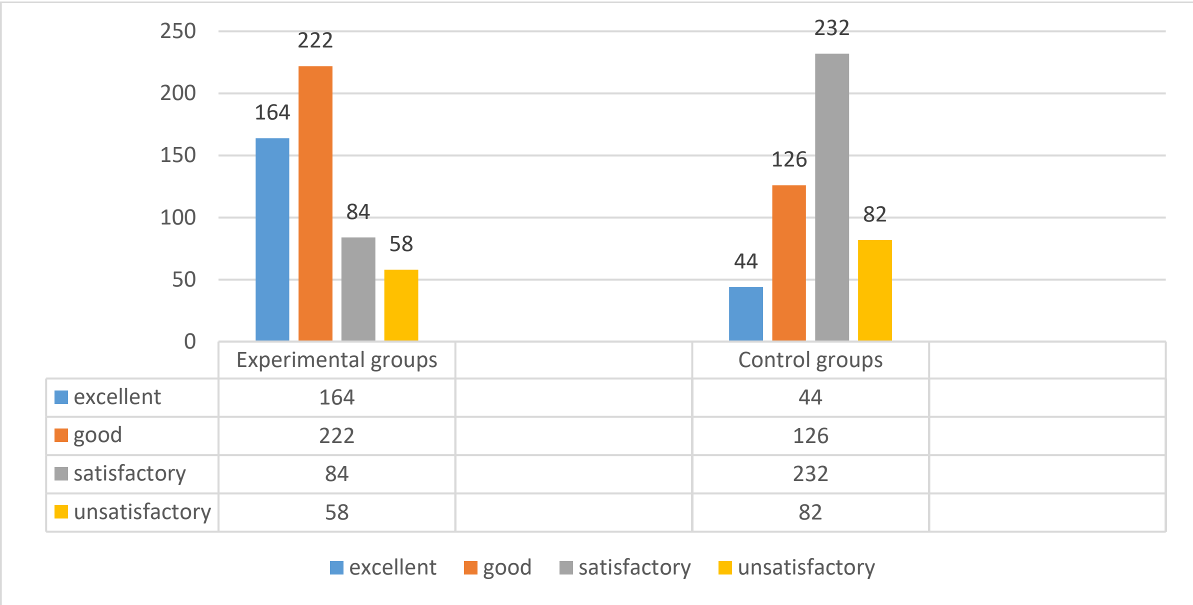

Figure 3. The final diagram on the improvement of the teaching methodology of the physics course based on interdisciplinary communication

From Figure 3, it can be seen that the number of students in the experimental group achieving "excellent" and "good" scores is higher than in the control group. Each of the drawn diagrams shows that one can hypothesize that they were obtained from primary populations (datasets) with a normal statistical distribution. Next, the data from Table 2 are subjected to a mathematical and statistical analysis. The statistical assessment indicators for the experimental groups are aligned with the corresponding indicators and student numbers of the control groups, and statistical grouped variation series are formed. Additionally, "excellent" is assigned a score of 5 points, "good" 4 points, "satisfactory" 3 points, and "unsatisfactory" 2 points.

Based on the experimental studies, the number of students in the experimental groups is $n = 528$, and in the control groups $m = 484$. After the mathematical analysis, it was determined that, following the experiment, the average level of mastery increased by 13.2. This fully confirms the idea that, in the final stage of the scientific-pedagogical experiment, teaching physics on the basis of interdisciplinary connections led to a difference (13.2 points) in the indicators expressing the level of students' (7^{th}grade) knowledge, skills, and competencies compared to the initial stage. In turn, this result serves as a clear indication that the intended objectives of organizing the scientific-pedagogical experiment were achieved.

Discussions. Observations of students' work in the experimental classes indicate that their curiosity, cognitive abilities, creative independence, and skills in finding the most optimal solutions have all increased. Emphasizing this fact is important, as it proves that, in the process of teaching physics through an interdisciplinary approach, each student's initiative and independence are nurtured, contributing to the growth of their thinking abilities.

A lesson organized on the basis of interdisciplinary connections is a learning process aimed at engaging students in activities at the level the teacher expects. Based on the lesson's objectives, the teacher acts with a didactic intention, embedding knowledge and skills into the specific activities that constitute interdisciplinary connections. In addition, this method includes optimal measures implemented by the teacher to create conditions that will lead students toward effective learning and the overall objectives of the lesson.

Interdisciplinary connections constitute a didactic principle that requires cognitive actions to encourage the pursuit of knowledge, unification of concepts, recognition of differences and similarities, and identification of cause-and-effect relationships relevant to the lesson's objectives. These connections motivate students to engage in non-standard thinking when solving problems.

The results of the experimental study show that teaching based on interdisciplinary connections and applying modern pedagogical technologies in the learning process deepen students' theoretical knowledge of physics by integrating ideas and knowledge from other subjects, reinforce their practical skills and abilities, and, most importantly, foster the growth of their independent thinking [9-15]. Interdisciplinary research often faces significant challenges that can hinder its effectiveness—namely, situations in which similar concepts or data are subject to different interpretations in various disciplines. Careful coordination is required when generalizing knowledge acquired from other subjects.

Conclusion. Interdisciplinary connections demonstrate that they serve as a primary source of scientific knowledge and stimulate the development of learners' growing cognitive abilities by shaping their initial knowledge and skills in various subjects. Interdisciplinary connections integrate knowledge, theories, and methodologies from different subjects to explore complex issues. By uniting concepts from physics, mathematics, chemistry, natural science, and biology, students can gain a more comprehensive understanding of the topic being studied.

When conducting lessons on the basis of interdisciplinary connections, it is necessary to structure classroom activities according to specific goals and objectives, the nature of the material to be learned, and the students' level of preparedness. It is crucial for the teacher to consider the available opportunities for showing the interrelationships between physics and other subjects, as well as for drawing on students' existing knowledge of one subject during lessons in another. Only then can students gain a full and deep understanding of the material under study.

Providing instruction within a single subject area may limit the teacher's methodological and creative approach. Naturally, the extent to which these recommended strategies are implemented and their effectiveness depend on the teacher's expertise, knowledge of related disciplines, and overall professional qualifications. In interdisciplinary teaching, no changes are made to the number of hours allotted in the curriculum. Rather, success comes from the use of innovative technologies in class, incorporating "relevant" knowledge from other subjects based on lesson objectives, and focusing on organizing students' independent learning and homework assignments.

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