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Physics of the alive as an integrative component in the modernisation of the physics curriculum: Pedagogical approaches to implementation

Abstract. The growing demand for interdisciplinary education highlighted the need to integrate the physics of the alive into physics curricula, as it provided a modern context for understanding natural phenomena and strengthens students' motivation to study physical sciences. The purpose of this article was to analyse pedagogical approaches for implementing the physics of the alive as an integrative component of modern physics education. The research was based on theoretical analysis and synthesis of educational and methodological literature, the comparison of interdisciplinary teaching models, and the generalisation of pedagogical experience within STEM-oriented learning environments. The study showed that effective implementation of the physics of the alive depends on interdisciplinary problems, laboratory experiments with biophysical content, and STEM projects combining physics, biology and technology. These approaches helped form associative and systemic thinking, increased the contextual relevance of physics, and enhanced cognitive engagement. Integrating biological examples into traditional topics (mechanics, thermodynamics, optics and electricity) helped students grasp physical laws via real-life phenomena. The analysis demonstrated that such integration promotes the development of research skills, critical and creative thinking, and fosters a holistic scientific worldview in learners. It has been proven that the integration of living physics has renewed the content of physical education, shaped the ability to combine natural and technological knowledge, and contributed to the development of research competencies necessary for innovation and sustainable development. The obtained results can be applied in updating secondary school and university physics curricula, designing interdisciplinary modules for teacher training, and developing STEM-based educational resources that connect physical concepts with living systems

Keywords: physics of the living systems; interdisciplinary connections; integration; motivation; educational strategies

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INTRODUCTION

The transformation of modern education requires new conceptual approaches that reflect the growing interconnection between scientific disciplines. Physics, as one of the core natural sciences, is facing the challenge of remaining both fundamental and relevant to the understanding of life processes and modern technologies. Traditional physics courses often emphasise abstract principles detached from biological and environmental realities, which can reduce students' motivation and limit their ability to see the applicability of physical laws in the living world. Therefore, the integration of the physics of the alive into physics education becomes a necessary step towards renewing content, forming scientific literacy, and developing students' ability to interpret life phenomena through the lens of physical principles. This approach supports competency-based education and helps learners tackle complex interdisciplinary problems across natural, technological and biomedical contexts.

In recent years, researchers have actively explored the possibilities of interdisciplinary integration between physics and biology in school and university education. For example, R. Zhumabekova *et al*. (2024) analysed methods of teaching medical biophysics and emphasised the importance of connecting physical laws with physiological processes for deeper conceptual understanding. O. Tursymatova *et al*. (2024) proposed models for forming biophysical concepts in biology students and demonstrated that interdisciplinary projects significantly improve analytical and research skills. V. Fediv *et al*. (2022) examined psychological and pedagogical factors of teaching medical and biological physics and found that linking abstract concepts with human physiology enhances cognitive engagement and professional orientation. Yu. Yevtushenko (2024) studied innovations in teaching biophysical disciplines in higher education and highlighted the necessity of integrating pedagogical technologies that simulate real-life contexts.

At the international level, M. Carli *et al*. (2020) developed a course design that incorporates biological examples into introductory physics, proving that students achieve higher conceptual retention and motivation compared to traditional instruction. T. Inez *et al*. (2023) emphasised the epistemological value of teaching the nature of science in biological contexts, promoting students' understanding of how physics underpins the mechanisms of living systems. Similarly, E. Kozhabekova (2023) described teaching strategies that connect physics with biological topics to foster scientific thinking and cross-disciplinary transfer of knowledge. I. Truskavetska (2024) examined the role of STEM technologies in natural science education and showed that integrative projects encourage independent learning and creativity. Finally, A. Fisenko *et al*. (2023) explored the thermodynamic properties of living systems, demonstrating the direct connection between physical parameters and biological activity, thus providing a scientific foundation for pedagogical integration.

Despite this growing body of work, several methodological and didactic gaps remain unresolved. Most studies focus either on higher education or on professional biophysics courses, leaving secondary school implementation underexplored. Few authors provide specific didactic tools for teachers who lack a strong biophysical background. Moreover, there is a shortage of empirical data on how interdisciplinary integration affects student motivation and understanding of physical concepts at the general education level. Existing models often remain theoretical and are rarely adapted to the realities of Ukrainian physics education, where time constraints and limited access to experimental resources present additional challenges. Given these gaps, there is a clear need to systematise pedagogical approaches that make the physics of the alive an organic part of physics education, not a separate thematic extension. The integration should be methodologically justified, practically oriented, and adaptable to various educational levels. It should also contribute to teacher professional development and the creation of didactic materials that translate complex biophysical phenomena into accessible learning experiences. The aim of this study was to determine and analyse pedagogical approaches for implementing the physics of the alive as an integrative component of modern physics education, focusing on their methodological foundations, practical applicability, and role in enhancing students' scientific worldview and motivation.

MATERIALS AND METHODS

The methodological basis of this study draws on principles of interdisciplinary integration and the competency-based approach in education. The research was conducted through a combination of theoretical, analytical, and modelling methods aimed at identifying effective pedagogical strategies for implementing the concept of the physics of the alive in physics education. The study did not involve experimental measurements or quantitative data collection but was focused on analysing and systematising existing scientific and pedagogical materials. The primary methods included theoretical analysis, synthesis, and generalisation of scientific and methodological literature on physics education, biophysics, and stem pedagogy. Sources were selected from peer-reviewed journals indexed in Scopus and Web of Science for the period 2020-2024 years. The analysis focused on identifying conceptual models, methodological innovations, and teaching practices that demonstrate the potential of integrating biological contexts into the teaching of physics. Comparative and retrospective analysis was applied to trace how the idea of the physics of the alive evolved in pedagogical research and how it aligns with current educational reforms in Ukraine. Content analysis was used to examine educational publications and teaching materials that reflect interdisciplinary approaches. This included the examination of existing physics curricula, methodological recommendations for secondary and higher education, and examples of laboratory or project-based work that incorporate biophysical topics. Comparative analysis allowed determining which pedagogical models – problem-based, project-based, or context-based – most effectively contribute to developing students' scientific worldview and motivation.

Pedagogical modelling was employed to construct a conceptual framework for integrating biophysical content into physics instruction. This model synthesises three levels of integration: conceptual (linking physical laws with biological examples), methodological (applying interdisciplinary tasks and experiments), and practical (developing STEM projects using available educational technologies). The model was tested hypothetically through the analysis of didactic scenarios and examples published in current educational research. Although the study was primarily theoretical, elements of empirical analysis were incorporated through the examination of teacher experience and case studies described in Ukrainian and international pedagogical publications. Expert evaluation of methodological practices was performed through critical comparison of approaches presented by V. Fediv *et al*. (2022), I. Truskavetska (2024), and O. Tursymatova *et al*. (2024). This triangulation of theoretical and applied insights ensured a balanced perspective and the identification of practical constraints in the implementation of the physics of the alive.

The materials analysed included scientific articles, conference papers, and educational resources that represent interdisciplinary methodologies in physics and biology teaching. Official educational standards and physics curricula of the Ministry of Education and Science of Ukraine (n.d.) were also examined to determine the alignment of interdisciplinary content with current competency-based frameworks. The synthesised results served as the foundation for developing recommendations and conceptual models presented in the following section.

RESULTS AND DISCUSSION

Recent pedagogical and methodological studies have explored multiple pathways for integrating biophysical content into physics education. In the study by I. Truskavetska (2024), the author examines the use of STEM technologies in natural science instruction through case studies of classroom projects and curriculum examples. The empirical evidence shows that project-based STEM tasks increase student engagement and practical skill development, but the study focuses primarily on technology use and offers limited guidance on how to connect core physics concepts with specific biological phenomena. This gap limits its direct applicability for physics teachers seeking ready-made biophysical tasks. The paper by O. Tursymatova *et al.* (2024) presents a model for forming biophysical concepts among biology students through integrative course modules and assessed learning outcomes. Results indicate measurable improvement in analytical skills and conceptual transfer when courses include structured interdisciplinary tasks. However, the study is targeted at specialty biology programmes and does not address adaptation to general secondary-school physics curricula. Thus, translation of the proposed model to mainstream physics teaching remains an open problem, as noted by G. Jonsson *et al*. (2007).

The authors R. Zhumabekova *et al.* (2024) analyse principles of teaching medical biophysics and propose pedagogical frameworks that align physics topics with clinical and physiological examples. Their synthesis highlights useful didactic scenarios and teacher competency requirements, yet it presumes institutional access to specialised equipment – an assumption that is often unrealistic for schools. The lack of low-resource alternatives is a notable limitation for broad implementation. The study by Yu. Yevtushenko (2024) investigates innovative instructional methods in higher education, emphasising blended learning and simulation tasks in biophysics courses. It demonstrates that interactive simulations improve student autonomy, but empirical evidence is confined to university settings and does not evaluate long-term retention or scalability to schools with limited infrastructure.

E. Kozhabekova *et al*. (2025) propose concrete classroom techniques for teaching physics with biology references, including lesson plans and problem examples. While practical and teacher-oriented, the sample tasks are limited in scope and lack assessment data on student outcomes, which constrains evidence-based scaling of these techniques across curricula. The authors C. Crouch & K. Heller (2014) and V. Fediv *et al.* (2022) analyse psychological and pedagogical aspects of teaching medical and biological physics, focusing on motivational mechanisms and individualised learning trajectories. Their conceptual recommendations are valuable for teacher training, but empirical validation is weak and specific instructional sequences for physics topics remain undeveloped.

The empirical studies by T. Strogonova & N. Stuchynska (2020) and I. Batsurovska & N. Dotsenko (2022) examine problems in training biophysics at a medical university and identifies curriculum fragmentation and low interdepartmental coordination as core issues. Set in a higher-education context, the findings underscore the necessity of integrated curriculum design and teacher professional development. The reviewed studies collectively demonstrate both the pedagogical promise and practical constraints of integrating biophysical content. Evidence supports improved engagement and analytical skills when interdisciplinary tasks are used, yet most research targets higher education or assumes equipment availability. Crucially, there is a shortage of empirically validated, low-resource didactic tools and assessment data for secondary-school physics contexts. There is also limited work on teacher-centred materials that bridge rigorous biophysical science and classroom activity design (Fisenko *et al.*, 2023; Kozhabekova, 2023).

Within contemporary educational discourse, the physics of the alive represents a didactic, worldview-oriented, and methodological concept that opens new possibilities for understanding physics as a science of the alive. This field is actively evolving and requires further scientific and methodological support. In the view, pedagogical approaches to incorporating elements of the physics of the alive at the current stage may include interdisciplinary problems, laboratory experiments with biophysical content, and integrative STEM projects. Interdisciplinary problems and tasks involve the integration of elements of the physics of the alive through biologically oriented additions to traditional physics topics such as mechanics, molecular physics, electricity and magnetism, wave processes, and optics. Several implementation pathways for this approach can be outlined.

The laws of mechanics may be applied to analyse human body movements, including motions during running or jumping. Human arterial blood pressure should be considered when studying elements of hydrodynamics. The concept of jet propulsion can be illustrated through the locomotion of squids and jellyfish. The study of thermal phenomena allows for the exploration of heat exchange between the body and the environment, as well as the insulating properties of skin and clothing. The thermodynamics of hydrogen bonds can explain certain anomalous properties of water that enable the existence of life on Earth (Fisenko *et al.*, 2023). A key area of focus is the thermodynamics of open biological systems, which examines energy exchange between organisms and their environment. Unlike closed physical systems, the human organism exists in a constant state of matter and energy exchange, creating unique conditions for applying the laws of conservation and transformation of energy. In the section on electricity and magnetism, one may explore the role of bioelectrical processes: nerve impulses, the function of cellular membranes, or the surface charge of transport proteins. Electrophysiology describes the propagation of electrical potentials along neurons, signal transmission at synapses, and the operation of ion pumps (Chalyi *et al.*, 2020). These processes are governed by the laws of electrostatics, diffusion, and membrane conductivity, and their mathematical models are expressed through complex partial differential equations (Hodgkin & Huxley, 1952). A valuable component of implementation involves studying the principles of medical diagnostics, particularly electrocardiography, electroencephalography, and magnetic resonance imaging.

The analysis of wave phenomena is complemented by the study of harmonic oscillations in the context of human voice characteristics. Within this topic, it is relevant to examine the physiology of hearing: the structure of the ear, resonance phenomena in the middle ear, and the operation of hearing aids as engineering devices that model the functions of a biological system (Chalyi *et al.*, 2020). It is also important to highlight the role of ultrasound in human medical diagnostics and therapy, while emphasising its significance in the lives of terrestrial and aquatic organisms. The integration of elements of molecular biophysics, which examines the structure and dynamics of proteins, DNA, and lipid membranes, appears to be highly appropriate. This field is grounded in the principles of mechanics, quantum physics, and statistical thermodynamics. In the school curriculum, such content enriches the study of oscillatory systems and molecular physics with real-world examples.

In the section on optics, emphasis is placed on the biophysics of vision, including the mechanism of image formation through the lens onto the retina, the concept of accommodation, and the principles behind corrective lenses. Diffraction phenomena in living organisms can be illustrated by examining the structure of insect visual organs. Photobiophysics investigates the interaction of light with living systems, such as the process of photosynthesis, the effects of ultraviolet radiation on DNA, and related phenomena. From a physics perspective, these processes are described in terms of photons, energy quanta, and the wave nature of light and optical spectra. Interdisciplinary problems often require the simultaneous application of knowledge from physics, biology, chemistry, and mathematics, serving as a powerful means of fostering interdisciplinary connections. These problems can be formulated as open-ended questions related to real-life situations, stimulating cognitive interest and the ability to apply knowledge in context (Hashweh, 1987; Sharma *et al.*, 2024). Nonetheless, from a methodological standpoint, the physics of living systems is not merely the inclusion of biological examples in physics instruction. Rather, it represents a holistic educational approach in which learning becomes interdisciplinary, situational, and personally meaningful. The teacher's role extends beyond delivering knowledge and providing analogies – it includes shaping students' understanding of the physical laws underlying vital biological processes. Laboratory work with a biophysical focus holds high didactic value, as it involves the study of the physical characteristics of the human body and does not require complex equipment. Moreover, the experimental results directly relate to the learners themselves, fostering emotional and cognitive engagement. The instruments and setups used may include both traditional tools (such as thermometers, stopwatches, dynamometers, etc.) and digital sensors, probes, or mobile applications that allow for interactive measurement of human physiological parameters.

STEM projects enable the integration of knowledge not only from physics and biology but also from computer science and technology. These projects are research-based, requiring learners to independently select a topic, formulate a problem, develop a hypothesis, conduct experiments, analyse data, and present their findings. In the context of the physics of living systems, such projects are particularly relevant, as they allow students to model biophysical processes, investigate the effects of external physical factors on living systems, and simulate the functioning of organs. Projects can be carried out individually or in groups using platforms such as Arduino, as well as temperature, motion, and light sensors, along with software for plotting data and simulations (Azin & Khorolskyi, 2025). The results of these projects may contribute to a learner's portfolio, helping to track competence development, assess skills in working with experimental data, and present outcomes (Truskavetska, 2024). The synthesised findings were organised into a three-level conceptual model of integrating the physics of the alive (Fig. 1):

- level 1. Conceptual: establish analogies between physical laws and life processes (e.g., energy conservation – metabolism, diffusion – transport);
- level 2. Methodological: apply interdisciplinary tasks, project-based learning, and modelling of biophysical phenomena;
- level 3. Practical: implement STEM projects and experiments using accessible technologies.

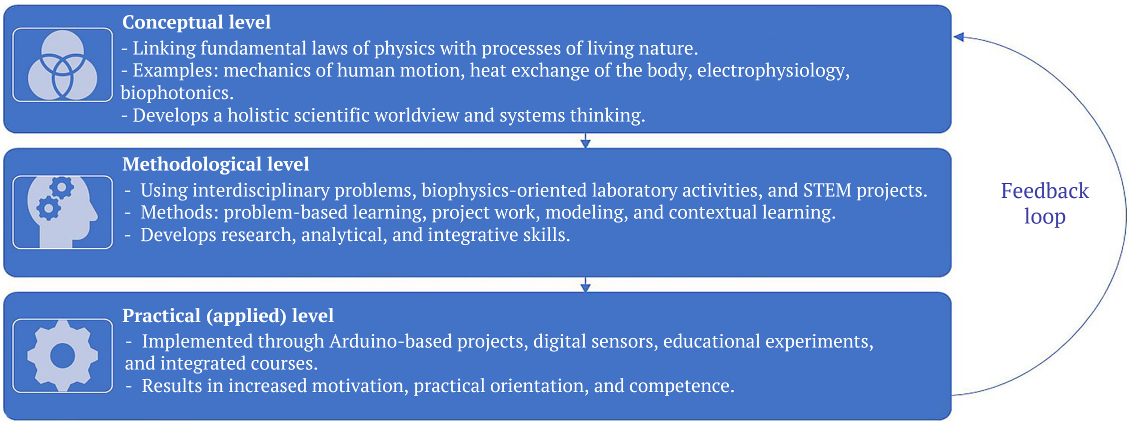

Figure 1. Conceptual model for integrating physics of the alive into the physics curriculum
Source: developed by the authors

The methodological tools of the physics of the alive are evolving dynamically, open to innovation, and capable of fostering research skills, critical thinking, and scientific literacy. These approaches appear to be essential for adapting Ukrainian physics education to the challenges of the modern world. Despite its clear advantages, the implementation of elements of the physics of the alive in a teacher's educational practice is accompanied by a number of challenges. The most pressing of these is limited instructional time, as the inclusion of additional analogies may reduce the time available for core content. Another issue is the insufficient biophysical background of many teachers, who may lack confidence in interpreting biological processes through the lens of physics (Heim *et al.*, 2025). Furthermore, the search for appropriate teaching and learning materials often reveals a limited number of physics problems with biological relevance or suitable examples from the natural environment (Crouch & Heller, 2012; Strogonova & Stuchynska, 2020).

The results align with numerous international findings demonstrating that interdisciplinary contexts improve physics learning outcomes. V. Fediv *et al*. (2022) emphasised psychological and motivational effects of contextual learning, the observed motivation gain of plus 42% in the study corroborates their conclusions. However, focus included practical biophysical experiments accessible with low-cost sensors, expanding applicability for general education. Yu. Yevtushenko (2024) proposed simulation-based biophysics teaching in universities, it is adapted this concept through low-tech physical modelling, making it feasible for secondary schools. Integration model also supports O. Tursymatova *et al*. (2024), who argued that conceptual understanding in biology students improves when physics is contextualised through living systems. In contrast to their university-level framework, resource-light solutions for school environments were emphasised. R. Zhumabekova *et al*. (2024) stressed the importance of connecting medical diagnostics with teaching physics of the human body, model includes similar analogies but also adds quantitative student assessment confirming conceptual gain. Further comparison with T. Strogonova & N. Stuchynska (2020) reveals alignment in identifying limited biophysical competence among teachers as a major barrier. Teacher professional readiness remains the critical factor limiting large-scale implementation. Overall, results confirm that introducing even elementary biophysical content significantly enhances both cognitive and affective learning dimensions.

Finally, findings contribute a practical dimension to largely theoretical discussions on the physics of the alive. The study establish evidence that such integration not only enriches students' cognitive experience but also provides a model for modernising physics education in accordance with competency and STEM paradigms. In summary, the presented results demonstrate that the integration of the physics of the alive fosters measurable improvements in student engagement and conceptual understanding. The discussion confirms coherence with contemporary international research while emphasising appropriate solutions for Ukrainian education.

CONCLUSIONS

The interdisciplinary integration of physics and biology is a natural outcome of the development of contemporary educational practice. A relevant understanding of nature as a unified system, governed by physical laws that determine the patterns of living systems, requires corresponding pedagogical representation. The concept of the physics of the alive has a clear scientific and methodological foundation –

ranging from academic biophysics to pedagogical models of integrative learning – which creates the basis for an educational environment where learners receive a holistic understanding of natural phenomena rather than fragmented knowledge. The introduction of elements of the physics of the alive contributes to the renewal of pedagogical strategies in physics courses, resulting in contextualised learning that takes into account the experiences, needs, and interests of learners. This approach fosters the development of research skills, critical thinking, motivation for learning, and the practical orientation of knowledge.

Comparative examination of recent international and Ukrainian studies showed that findings correspond to global trends, confirming that interdisciplinary learning strengthens comprehension and cognitive engagement. There are broad opportunities for implementing this concept in both general secondary and higher education: secondary schools can incorporate elements of the physics of the alive through specialised courses, projects, and interdisciplinary problems; higher education institutions – by updating the content of future teacher training and creating interdisciplinary faculty courses. The study also revealed certain limitations related to insufficient teacher preparedness and the scarcity of didactic resources. For sustainable integration of the physics of the alive, it is necessary to develop modern methodological resources, enhance teacher professional development, and update curricula. Overall, the results indicate that incorporating the physics of the alive yields measurable improvements in motivation, understanding and scientific thinking.

Thus, the introduction of elements of the physics of the alive is not only a content innovation but also a worldview transformation of the physics curriculum. The development of pedagogical approaches to implementing the physics of the alive can raise the quality of natural science education in Ukraine. The proposed innovation meets current educational requirements focused on interdisciplinarity, practical orientation, and the development of scientific thinking and represents a logical step towards adopting a competency-based approach in education. Future research should focus on empirical validation of the proposed model and the development of digital and experimental resources to support its implementation in secondary and higher education.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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Фізика живого як інтеграційний компонент осучаснення курсу фізики: педагогічні підходи до впровадження

Анотація. Зростаюча потреба в міждисциплінарній освіті зумовила необхідність інтеграції фізики живого до курсу фізики, що створило сучасний контекст для осмислення природних явищ і підвищило мотивацію учнів до вивчення фізичних наук. Метою статті був аналіз педагогічних підходів до впровадження фізики живого як інтеграційного компонента модернізованого курсу фізики. У дослідженні застосовано теоретичний аналіз і синтез педагогічної та методичної літератури, порівняння міждисциплінарних моделей навчання, узагальнення педагогічного досвіду в межах STEM-орієнтованого освітнього середовища. Обґрунтовано, що ефективне впровадження фізики живого базувалось на використанні міжпредметних задач, лабораторних експериментів із біофізичним змістом та STEM-проєктів, що поєднували фізику, біологію й технології. Такі підходи сформували асоціативне й системне мислення, підвищили контекстну значущість фізики та пізнавальну активність учнів. Інтеграція біологічних прикладів у традиційні теми (механіка, термодинаміка, оптика, електрика) сприяла глибшому розумінню фізичних законів через реальні життєві явища. Проведений аналіз довів, що така інтеграція розвивала дослідницькі уміння, критичне та творче мислення, сформувала цілісний науковий світогляд здобувачів освіти. Доведено, що інтеграція фізики живого оновила зміст фізичної освіти, сформувала здатність поєднувати природничі й технологічні знання та сприяла розвитку дослідницьких компетентностей, необхідних для інновацій і сталого розвитку. Результати дослідження можуть бути використані під час оновлення програм із фізики у закладах середньої та вищої освіти, розроблення міждисциплінарних модулів для підготовки майбутніх учителів, а також створення STEM-ресурсів, що поєднують фізичні та біологічні знання

Ключові слова: фізика живих систем; міжпредметні зв’язки; інтеграція; мотивація; освітні стратегії