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NEUROPHYSIOLOGICAL BASES OF LEARNING AND MEMORISATION IN STUDENTS OF DIFFERENT AGE GROUPS AND THEIR CONSIDERATION IN THE EDUCATIONAL PROCESS

НЕЙРОФІЗІОЛОГІЧНІ ОСНОВИ НАВЧАННЯ І ЗАПАМ'ЯТОВУВАННЯ В УЧНІВ РІЗНИХ ВІКОВИХ ГРУП ТА ЇХ УРАХУВАННЯ В ОСВІТНЬОМУ ПРОЦЕСІ

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АНОТАЦІЯ

У статті досліджено нейрофізіологічні основи навчання і запам'ятовування в учнів різних вікових груп та обґрунтовано їхнє врахування в освітньому процесі. Актуальність роботи зумовлена сучасними освітніми вимогами до міждисциплінарного підходу, що поєднує педагогіку, психологію та нейронауки для підвищення ефективності навчання. Метою дослідження є систематизація сучасних даних про вікові особливості мозку, пам'яті та уваги, а також розроблення практичних рекомендацій щодо адаптації методів навчання до цих особливостей у різних вікових групах.

Наголошено, що молодші школярі ефективніше засвоюють навчальний матеріал через інтерактивні ігрові та образні методи, що забезпечують активне залучення уваги та повторення матеріалу. Обгрунтовано, що у підлітковому віці оптимальними є проєктна діяльність, проблемно-орієнтоване навчання та групові дискусії, які стимулюють розвиток виконавчих функцій і когнітивної гнучкості. Старшокласники демонструють високу ефективність при самостійних дослідницьких проектах, інтегрованих завданнях і критичному аналізі матеріалу, що сприяє формуванню метапізнавальних стратегій і саморегульованого навчання.

Доведено, що результативність навчання біології визначається мірою відповідності використовуваних педагогічних методів віковим, когнітивним та психофізіологічним особливостям учнів. Установлено, що впровадження нейрофізіологічних знань у методичну систему навчання біології надає можливість науково обґрунтовано конструювати зміст і логіку освітнього процесу, диференціювати навчальне навантаження відповідно до функціональних можливостей учнів та формувати психологічно комфортне, когнітивно збалансоване освітнє середовище, спрямоване на розвиток навичок саморегуляції та внутрішньої навчальної мотивації. Підкреслено, що реалізація міждисциплінарного підходу, що інтегрує досягнення *нейрофізіології, когнітивної психології та сучасної дидактики, постає методологічно обґрунтованим і перспективним вектором модернізації освітньої практики. Такий підхід забезпечує підвищення якості біологічної освіти, розвиток метапізнавальних умінь і формування готовності учнів до навчання впродовж життя в умовах трансформації соціокультурного простору.*

Ключові слова: *нейрофізіологія навчання, вікові особливості учнів, когнітивний розвиток, методика навчання біології, освітній процес.*

Introduction. Modern education stands at the crossroads of pedagogy, psychology and neuroscience, creating new requirements for understanding the mechanisms of learning and memory as complex psychophysiological processes. Despite a significant amount of research in the field of cognitive psychology and pedagogical technologies, there is a significant gap between fundamental data on brain functioning and its systematic implementation in educational practice. In particular, learning and memorisation processes are realised through the complex interaction of neural networks, synaptic plasticity, attention modulation and motivational systems, which change throughout ontogenesis. Despite this, traditional pedagogical approaches do not always take into account the age-related neurophysiological differences of students, which can lead to ineffective learning strategies, cognitive overload, and uneven development of learning competencies. Neuropedagogy and educational neuroscience offer integrated learning models based on empirical data that take into account the individual neurocognitive profiles of students of different age groups. However, practical recommendations for adapting teaching technologies to the age-related characteristics of neurofunctioning remain insufficiently tested in real educational settings. This highlights the urgent need for a systematic scientific analysis of memory and learning mechanisms through the prism of neurophysiology, as well as for the formation of theoretical, methodological and applied foundations for their implementation in pedagogical practice. The interdisciplinary integration of pedagogy with neurophysiology and cognitive sciences is becoming increasingly relevant, due to the need for a scientifically sound understanding of the mechanisms of learning and memory. Scientists emphasise that age differences in brain function, neuroplasticity and the development of executive functions are of fundamental importance for the effectiveness of educational strategies, but these patterns are still not sufficiently systematically taken into account in pedagogical practice [1; 5]. As a result, the educational process often remains focused on uniform approaches that do not correspond to the neurophysiological capabilities of students of different age groups. At the same time, empirical data indicate a significant gap between the achievements of educational neuroscience and the level of their practical implementation in the teacher training system [5;

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6]. This limits the ability of teachers to consciously adapt teaching methods to the age and individual cognitive characteristics of students, which is especially important in the context of increasing academic workload and more complex educational tasks. Therefore, scientific research into the neurophysiological foundations of learning and memory in students of different age groups is relevant given the need to align pedagogical approaches with the biological mechanisms of brain development. A systematic understanding of the results of modern neuroscientific research and their pedagogical interpretation create the basis for the development of scientifically sound and individualised educational strategies that meet modern requirements for the quality of education and professional training of teaching staff.

The purpose of the article is to study the neurophysiological basis of learning and memorisation in students of different age groups and to justify practical approaches to their consideration in the educational process. To achieve this goal, the following tasks have been set: to systematise data on the age-related characteristics of the brain, memory and attention; to identify effective pedagogical conditions and teaching methods that take into account the age and cognitive characteristics of students.

Methods of the research. The study used a combination of complementary methods. The analytical component involved reviewing scientific sources on neurophysiology, cognitive psychology, and pedagogy in order to identify age-related characteristics of brain functioning, memory development, and attention. The practice-oriented component involved systematic observation and analysis of the learning activities of students of different age groups in biology lessons, in particular during interactive, problem-oriented and research tasks.

The results and discussion. The biological basis of learning and memory is determined by the complex interaction of structural and functional elements of the central nervous system, which ensure the encoding, consolidation and reproduction of information. The hippocampal complex plays a leading role in the formation of declarative memory, integrating sensory signals and their initial encoding, while long-term knowledge retention is associated with the reorganisation of neural networks in the neocortex. The prefrontal cortex regulates attention, working memory, and executive functions necessary for purposeful learning activities, while the amygdala mediates the emotional component of memorisation, strengthening or weakening the strength of memory traces depending on the emotional significance of the learning material [1]. At the cellular level, learning is based on mechanisms of synaptic plasticity, primarily on the phenomena of long-term potentiation and long-term depression, which reflect persistent changes in the efficiency of synaptic transmission. Neurotransmitter systems play an important role in learning: acetylcholine increases neural excitability and concentration; dopamine is associated with motivation, reinforcement and the formation of learning behaviour; noradrenaline regulates the level of activation and adaptation to novelty, and serotonin affects emotional background and cognitive flexibility.

The balance between these systems is critically important for effective information assimilation in the educational process [1; 6]. Age-related characteristics of learning and memorisation are determined by the uneven maturation of brain structures and changes in neuroplasticity during ontogenesis [1]. In early school age, the high level of structural and functional plasticity of the cerebral cortex creates favourable conditions for the formation of basic cognitive skills, but the insufficient maturity of the prefrontal cortex limits the development of voluntary regulation of attention and self-control. In adolescence, there is an active restructuring of neural networks, in particular the processes of synaptic pruning and myelination, which increases the efficiency of neural transmission but at the same time causes increased emotional reactivity and variability in learning motivation. In senior school age and adolescence, the maturation of executive functions is completed, which contributes to the development of abstract thinking, metacognitive strategies, and conscious self-regulated learning [5]. Age-related neurophysiological characteristics of learning and memory reflect dynamic changes in the structure and functional organisation of the brain during ontogenesis and determine the effectiveness of learning and retrieval of educational information [3]. In early school age, the high plasticity of the cerebral cortex ensures the rapid formation of new associative neural connections, and the hippocampus actively encodes new information, integrating it with the sensory and associative areas of the cortex. At this age, acetylcholine, which increases the ability to concentrate and encode information, glutamate, which ensures the stable formation of long-term neural connections, and dopamine, which forms the basic motivation for learning and positive reinforcement, play a key role. Active protein synthesis and expression of genes associated with synapse growth contribute to the stabilisation of neural connections. From a pedagogical point of view, the most effective methods for this group are imaginative and emotionally charged tasks, interactive game methods, and repetition, which activate the neural and motivational mechanisms of the brain [4]. During adolescence, there is an active restructuring of neural networks, processes of synaptic reduction and myelination of nerve fibres, which increases the efficiency of cognitive functions and the ability to voluntarily regulate attention.

The prefrontal cortex, which is responsible for planning, self-regulation and executive functions, is still maturing, which explains increased emotional lability and risky behaviour. During this period, dopamine, which regulates motiva-

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tion and response to reward, noradrenaline, which ensures optimal activation and the ability to concentrate on new material, and serotonin, which affects cognitive flexibility and emotional state, are particularly important. Biochemical processes include active restructuring of synaptic networks and local enhancement of long-term potentiation in the prefrontal cortex and hippocampus, which contributes to the formation of strategic learning skills [6]. In pedagogical practice, adolescents learn more effectively through project activities, discussions, problem-oriented learning, and interactive methods that stimulate the brain's motivational and neurotransmitter systems [2; 3]. In senior school and adolescence, the maturation of the prefrontal cortex and associative areas of the cerebral cortex is completed, which contributes to the development of abstract thinking, metacognitive strategies and self-regulated learning. The hippocampus and cerebral cortex integrate information from different sensory modalities, forming stable, long-term knowledge. During this period, dopamine and noradrenaline are important for maintaining motivation and attention, as are acetylcholine and glutamate, which ensure effective working memory and consolidation of learning information. Serotonin is responsible for emotional stability and cognitive flexibility, which are necessary for independent learning. Gene expression is activated, ensuring the stabilisation of synaptic ensembles and the formation of strategic cognitive skills [5]. In the pedagogical process for this age group, independent projects, integrated tasks, problem-oriented learning, and critical discussions are effective, allowing for the maximum development of the brain's neurophysiological resources and the formation of long-term competencies [2]. Thus, age-related neurophysiological characteristics of learning and memory demonstrate a consistent transformation of the structural, functional, and neurotransmitter mechanisms of the brain, which determines the need for a scientifically sound and age-sensitive approach to the organisation of the educational process.

Understanding the role of the hippocampus, prefrontal cortex, synaptic plasticity, and neurotransmitter systems such as dopamine, norepinephrine, serotonin, acetylcholine, and glutamate allows educators to optimise teaching methods, pace, workload, and knowledge retention strategies, ensuring the effectiveness and longevity of acquired competencies. Optimising memorisation processes in the educational process requires the use of active and interactive teaching methods that stimulate neural networks and promote the formation of long-lasting memory traces. Active methods, such as problem-based learning, research projects and discussions, as well as interactive technologies, contribute to the attention, motivation and emotional significance of the material [2]. Pedagogical planning of such processes should take into account the age characteristics of students, in particular the level of maturation of the prefrontal cortex, hippocampus and sensory areas, as well as the activity of neurotransmitter systems that regulate attention, motivation and emotional state.

Optimising memorisation processes in biology lessons involves creating teaching conditions that take into account the neurophysiological mechanisms of memory, age-related characteristics of the brain, and the cognitive needs of students. Firstly, it is important to use active teaching methods that stimulate student participation in the learning process. These include laboratory and practical work, research tasks, modelling of biological processes, and experiments that allow students to independently discover patterns and draw conclusions. Such methods activate neural networks that ensure long-term consolidation of knowledge and engage the hippocampus and prefrontal cortex, which contributes to the formation of lasting memory traces. Secondly, it is necessary to gradually repeat and consolidate educational information, which corresponds to the mechanisms of long-term potentiation and stabilisation of synaptic connections in the brain. Repetition can be organised through interactive exercises, thematic tests, vocabulary cards, small group discussions of biological phenomena, or collective discussions. It is also important to ensure logical and interdisciplinary connections, for example, combining the study of biology with chemistry, physics or ecology to stimulate associative thinking and knowledge integration, which increases their long-term retention in students' memory.

Thirdly, the use of visualisations and visual models is effective in helping to reinforce complex biological concepts. In addition, it is important to use multimodal approaches, combining auditory, visual and motor activity to engage different sensory channels and ensure lasting associative connections in the brain. Fourthly, the motivational and emotional components of learning should be taken into account, as emotionally significant situations enhance memory consolidation through amygdala activity. In biology lessons, this can be achieved by setting problem-solving tasks that require creative thinking, demonstrating real-life examples from life and nature, and using field trips, scientific projects and research tasks. Finally, it is important to organise individualised and differentiated tasks, taking into account the age and cognitive characteristics of students [4]. Optimising memorisation processes in biology lessons involves creating pedagogical conditions that best correspond to the neurophysiological and age characteristics of students. Thus, the pedagogical conditions for optimising memorisation processes in biology lessons include the use of active and interactive methods, repetition and consolidation of knowledge, creation of interdisciplinary connections, development of associative thinking, emotionally meaningful tasks, and differentiation and individualisation of learning in accordance with the age-related neurophysiological characteristics of students.

It should be noted that adapting teaching methods and forms to the age-related neurophysiological capabilities of students is a key factor in an effective educational process. In primary school, it is necessary to focus on imagi-

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native, emotionally charged presentation of material, frequent repetition, and active engagement through interactive game tasks. In adolescence, project-based and problem-oriented tasks, discussions, and integrated exercises that stimulate executive functions, motivation, and cognitive flexibility are effective. In senior school and adolescence, preference should be given to independent work, critical analysis of information, and metacognitive strategies that develop self-regulated learning skills. In addition, creating a psychologically safe and motivational educational environment is a prerequisite for developing learning competencies and maintaining the emotional and physiological health of students.

Optimal organisation of the learning load involves taking into account the biorhythms, fatigue levels and cognitive abilities of students of different age groups. Teachers should design learning tasks in such a way that they correspond to the natural mechanisms of knowledge acquisition and consolidation, ensure motivation and active engagement.

Particular attention is paid to developing self-regulation, time management, concentration and effective memory skills, enabling students to consciously manage their own learning. Optimising the learning process in biology lessons requires the use of differentiated and scientifically sound methods that take into account the age-related neurophysiological characteristics of students and stimulate the activity of neurotransmitter systems. In primary school, lessons using interactive models, board games, group research and the construction of three-dimensional models are effective. For example, when studying the structure of a cell, students can assemble models of organelles, discuss their functions and demonstrate the results to the class. Such tasks stimulate acetylcholine, which increases the ability to concentrate, glutamate, which ensures long-term consolidation of knowledge in synaptic networks, and dopamine, which is activated through emotional encouragement and positive reinforcement. The use of repetition, visual information, and interactive exercises allows you to consolidate learning material in long-term memory and engage the hippocampus and associative areas of the cortex. In adolescence, project-based and problem-oriented lessons, discussions, and experimental tasks are appropriate. For example, when studying photosynthesis and plant respiration, students can conduct experiments measuring plant activity under different lighting conditions, analyse data, and draw conclusions in groups. Such activities stimulate dopamine, which is responsible for motivation and satisfaction with the achieved result, noradrenaline, which increases attention and concentration during experimental activities, and serotonin, which stabilises the emotional state and promotes cognitive flexibility. The integration of knowledge from chemistry and physics forms associative neural networks and helps to consolidate information in long-term memory. Performing such tasks in a group activates the executive functions of the prefrontal cortex and supports the development of self-regulation strategies for learning activities.

In senior school and youth age, biology lessons should be based on independent research projects, integration with ecology and sociology, problem-oriented tasks and critical analysis of information. For example, students can study the condition of local water bodies, collect data on pollution, analyse causes and consequences, and prepare presentations and proposals for improving the environmental situation. Performing such tasks stimulates dopamine and noradrenaline, which support motivation and attention, acetylcholine and glutamate, which ensure the integration of large amounts of knowledge and effective working memory, and serotonin, which stabilises emotional state and promotes critical thinking. Teamwork, discussions, and the integration of knowledge from different disciplines activate the neural networks responsible for metacognition, planning, and long-term consolidation of learning information. In addition, it is important for all age groups to use emotionally meaningful tasks that foster positive motivation to learn and enhance memory consolidation. Teachers can use stories about real scientific discoveries, demonstrations of experiments, videos, interactive games, and educational projects that activate neural networks and maintain student interest. It is also necessary to develop self-regulation skills in learning activities, including time management, concentration, systematic repetition of material, and the use of associative thinking, which allows students to effectively manage their own learning.

Thus, practical recommendations for biology teachers consist of combining interactive, visual and research activities, repeating and consolidating knowledge, using interdisciplinary connections, emotionally meaningful tasks and a differentiated approach that takes into account the age and neurophysiological characteristics of students. This approach ensures maximum memorisation efficiency, stimulates the brain's neurotransmitter and biochemical mechanisms, increases students' motivation and attention, forms stable long-term knowledge and promotes the development of self-regulated learning skills.

Conclusions. The study of the neurophysiological basis of learning and memorisation in students of different age groups shows that the effectiveness of knowledge acquisition directly depends on the structural, functional, and biochemical characteristics of the brain at each stage of ontogenesis. At all stages of learning, neurophysiological processes, including the activity of the neurotransmitters dopamine, noradrenaline, serotonin, acetylcholine and glutamate, as well as the biochemical mechanisms of long-term synaptic potentiation and protein expression, determine students' ability to concentrate, motivation, encoding and consolidation of information in long-term memory. Therefore, the effectiveness of biology teaching largely depends on the use

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of methods that are appropriate for the age and cognitive abilities of students. Age-sensitive selection of visual-experimental, problem-solving, project-based research, and interdisciplinary teaching methods contributes to the optimisation of the processes of encoding, storing, and reproducing biological information, the formation of systematic biological thinking, and sustainable learning outcomes. It should be noted that the integration of neurophysiological knowledge into the methodology of teaching biology allows for the scientifically sound modelling of the content and structure of the educational process, the rational organisation of the educational load, and the creation of a psychologically safe, motivationally rich and cognitively optimal educational environment that promotes the development of self-regulation, learning autonomy and positive learning motivation in students. Thus, the integration of knowledge from neurophysiology, psychology and pedagogy allows for the scientifically sound organisation of the educational process, increasing the effectiveness of learning and memorisation in students of different age groups. The use of age-sensitive, active, interactive and differentiated teaching methods, combined with systematic repetition, interdisciplinary connections and emotionally meaningful tasks, ensures the formation of stable long-term knowledge, the development of cognitive and metacognitive skills, and the preparation of students for independent and effective learning throughout their lives.

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ABSTRACT

The article examines the neurophysiological foundations of learning and memorisation in students of different age groups and justifies their consideration in the educational process. The relevance of the work is determined by modern educational requirements for an interdisciplinary approach that combines pedagogy, psychology, and neuroscience to improve learning effectiveness. The aim of the study is to systematise current data on age-related characteristics of the brain, memory and attention, as well as to develop practical recommendations for adapting teaching methods to these characteristics in different age groups.

It is emphasised that younger schoolchildren learn more effectively through interactive games and visual methods that actively engage their attention and encourage repetition of the material. It is justified that project activities, problem-oriented learning and group discussions, which stimulate the development of executive functions and cognitive flexibility, are optimal in adolescence. High school students demonstrate high efficiency in independent research projects, integrated tasks, and critical analysis of material, which contributes to the formation of metacognitive strategies and self-regulated learning.

It has been established that the effectiveness of biology teaching is determined by the extent to which the teaching methods used correspond to the age, cognitive and psychophysiological characteristics of students. It has been found that the introduction of neurophysiological knowledge into the methodological system of biology teaching makes it possible to construct the content and logic of the educational process in a scientifically sound manner, differentiate the educational load in accordance with the functional capabili-

ties of students, and form a psychologically comfortable, cognitively balanced educational environment aimed at developing self-regulation skills and internal learning motivation. It is emphasised that the implementation of an interdisciplinary approach that integrates the achievements of neurophysiology, cognitive psychology and modern didactics is a methodologically sound and promising vector for the modernisation of educational practice. This approach ensures the improvement of the quality of biological education, the development of metacognitive skills and the formation of students' readiness for life-long learning in the context of the transformation of the sociocultural space.

Key words: *neurophysiology of learning, age characteristics of students, cognitive development, methods of teaching biology, educational process.*

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