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USE OF DIGITAL TECHNOLOGIES IN TEACHING THE TOPIC "MECHANISMS OF THE EFFECTS OF IONIZING RADIATION ON THE HUMAN BODY"

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Abstract. This article highlights the scientific and pedagogical foundations of using digital technologies in teaching the topic "Mechanisms of the Effects of Ionizing Radiation on the Human Body." Based on the complex and multistage nature of radiobiological processes, the importance of visualization, modeling, and an interactive educational environment in teaching these processes is analyzed. The study investigates the integration of computer simulations, virtual laboratories, multimedia tools, and problem-based learning methods. The results demonstrated that the use of digital technologies is of great importance in deepening students' knowledge, developing their analytical thinking, and forming interdisciplinary competencies.

Keywords: ionizing radiation, radiobiology, DNA damage, digital education, simulation, virtual laboratory, competency-based approach, interactive methods.

Ionizing radiation and its biological effects represent a complex scientific field located at the intersection of modern physics, biology, and medicine. This topic has fundamental significance in such fields as radiation safety, medical diagnostics, and radiotherapy, and its thorough mastery requires a high level of theoretical and practical preparation. Therefore, the application of modern pedagogical approaches, particularly digital technologies, in teaching the mechanisms of ionizing radiation effects is considered an актуal issue. The works of E.J. Hall and A.J. Giaccia [1], Sh. Khushmatov et al. [2], O.M. Khramchenkova [3], S.P. Yarmonenko [4], and A.N. Remizov [5] in radiobiology are regarded as fundamental sources that comprehensively explain the mechanisms of ionizing radiation effects on cells and tissues. UNSCEAR reports provide the most reliable statistical data on global radiation background and natural and artificial sources of radiation. The IAEA safety standards are among the principal regulatory documents for organizing radiation protection in medical and educational institutions [6,7]. Radiobiological processes, including ionization phenomena, the formation of free radicals, single and double breaks occurring in DNA molecules, and changes at the cellular level, are abstract in nature and occur at the microscopic level. It has been established that radionuclides accumulate in high concentrations in the thyroid gland, liver, intestines, kidneys, skeleton, and muscles of the human body.

Radiation syndromes are generally classified into three main types: bone marrow (hematopoietic system) radiation syndrome, gastrointestinal radiation syndrome, and cerebral (brain) radiation syndrome. For example, under exposure to radiation doses around 10 Gy, bone marrow (hematopoietic system) radiation syndrome develops in the organism. In this condition, suppression of the production of formed blood elements in the peripheral blood system and severe morphofunctional disruption of bone marrow cells are observed within 4–20 days. Gastrointestinal radiation syndrome begins with disruption of epithelial cell function in the gastrointestinal tract of

mammals under the influence of radiation exposure. Subsequently, the apoptosis program is activated in the cells, vascular function is impaired, the balance of salt solution absorption through the membranes of intestinal epithelial cells is severely disrupted, and the degree of infectious damage increases. Cerebral (brain) radiation syndrome differs sharply from the two above-mentioned types of radiation syndromes because brain nerve cells are highly differentiated cells. Cerebral radiation syndrome occurs under the influence of relatively high radiation doses, and although many symptoms of this syndrome have been studied, its molecular mechanisms have not yet been comprehensively identified.

The natural radiation background consists of radiation reaching Earth from space (cosmic radiation) and radioactive elements present in rocks, construction materials, and food products (terrestrial radiation). Natural sources of radiation can affect humans through internal and external pathways. Among external sources, cosmic radiation and radiation from soil and construction materials occupy a special place. Cosmic rays reaching Earth are streams of nuclear particles and are considered primary cosmic radiation. They include alpha particles and the nuclei of other atoms. High-energy galactic radiation originates from outside the solar system and differs from medium-energy cosmic radiation associated with solar activity. As a result of the interaction of cosmic particles with atmospheric atoms, secondary cosmic radiation producing radionuclides is formed. Solar radiation consists of electromagnetic and corpuscular radiation emitted by the Sun. The Sun emits radiation in the visible, infrared, ultraviolet, and X-ray spectra. Solar flares affect humans. In particular, changes in the magnetic field exert strong effects on individuals suffering from illnesses. A.L. Chizhevsky studied the effects of solar activity on living organisms and identified a relationship between changes in solar activity and the character of reactions in terrestrial organisms. Passengers and pilots of jet aircraft are exposed to cosmic radiation. For example, a transatlantic flight from the USA to Europe is accompanied by an additional exposure of approximately 0.05 mSv of cosmic radiation to the organism. Terrestrial radiation sources account for the majority of radiation exposure humans receive from natural radiation. Approximately five-sixths of the average annual radiation dose received by the population is attributed to these sources. Rocks containing radioactive elements formed during the development and evolution of the planet are considered the main sources of natural radioactive substances in the environment. A number of factors influence the accumulation of radioactive substances in plants. In finely dispersed soil, their absorption occurs with less intensity than in coarsely dispersed soil. When nutrients are added to soil, the entry of radionuclides into plants decreases; moreover, the accumulation coefficient in moist soil is lower than in dry soil. Among radioisotopes, potassium isotopes occupy the principal place in terms of the activity they produce. They are assimilated together with nonradioactive potassium isotopes necessary for the vital activity of the organism. When entering through the gastrointestinal tract, radioactive potassium makes a significant contribution to human irradiation. In the body of an adult weighing 70 kg, the amount of potassium constitutes 130 g (0.19%). Skeletal musculature, nervous tissues, the heart, liver, and gallbladder are particularly rich in potassium. Natural radionuclides are usually abundant in granite rocks. Limestone and sandy rocks possess lower radioactivity. The rate at which radon enters the atmosphere depends on soil condition, humidity, and temperature, and decreases when the ground is covered with snow. A 50 cm layer of snow persisting until spring shields up to 80% of terrestrial radiation formed by natural gamma emitters during summer. Artificial sources of radiation include nuclear tests, medical diagnostic and treatment equipment, radioactive waste, and nuclear power plants. Since the discovery of X-rays, the greatest achievement in the development of X-ray diagnostic methods has been computed tomography, which makes it possible to reduce radiation exposure several times compared with conventional

methods. Other sources of radiation include coal combustion at thermal power plants, phosphate fertilizers, consumer goods (radioluminescent devices, electronic приборы, color televisions, and others), materials used in space technology, smoking, and others. Although smoking depends on the individual, it remains one of the leading contributors among radioactive effects. Today, there are various perspectives regarding the biological role of low doses of radiation. According to the first, the radiation-hygienic perspective, even the smallest dose corresponds to a certain harmful effect; that is, the biological effect of radiation can be expressed by a linear "dose–effect" relationship. This viewpoint is becoming increasingly conservative, and there is still no definitive scientific evidence regarding its correctness or incorrectness with respect to low doses. The second perspective is opposite to the first: the natural radiation background is considered essential for the normal development of all living organisms. Radiation hormesis—the principle that low doses of radiation are necessary for the normal development of living organisms—continues to be debated. Experimental results are known in which reductions in natural background radiation doses led to weakening and inhibition of growth in living organisms.According to the third perspective, there exists a threshold for the effects of ionizing radiation on living organisms, below which radiation does not produce harmful effects.

Explaining such processes solely on the basis of traditional lectures often does not produce sufficient results. Digital technologies significantly enhance students' understanding by presenting these processes in visual and interactive forms. The teaching process was organized on the basis of the following digital tools. First, computer simulations were used to model damage occurring in DNA molecules under the influence of ionizing radiation. This process enabled students to observe step by step the formation of double-strand breaks, repair mechanisms, and mutations. Second, through virtual laboratories, the relationship between radiation dose and biological effect was studied interactively. Students conducted experiments with different doses and achieved a practical understanding of the essence of the linear-quadratic model. Third, multimedia presentations and animations visually illustrated the oxygen effect, free radical dynamics, and radiation processes. This facilitated the mastery of complex concepts in a simple and understandable form. Fourth, elements of problem-based learning were introduced, and questions were posed to students. The research results showed that the level of knowledge acquisition was significantly higher in the group taught on the basis of digital technologies. Students gained a deeper understanding of the essence of radiobiological processes and acquired skills for applying theoretical knowledge to practical situations. In particular, simulations and virtual laboratories played an important role in developing their analytical thinking. In addition, digital technologies serve as effective tools for ensuring interdisciplinary integration. Knowledge of physics, biology, and medicine is integrated within a unified educational environment, leading to the formation of complex concepts. This fully corresponds to the requirements of the competency-based approach.

In conclusion, the use of digital technologies in teaching the topic "Mechanisms of the Effects of Ionizing Radiation on the Human Body" demonstrates high didactic effectiveness. They provide opportunities to explain complex radiobiological processes in visual and interactive forms, deepen students' knowledge, and develop their independent thinking. In the future, the introduction of artificial intelligence, augmented reality, and virtual reality technologies into the educational process will become one of the important prospects for the development of this field.

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