A Competency-based Approach to Environmental Education: Learning About “Radioecology”

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Abstract
The research objective was to develop a new approach and methodology for the discipline of “Radioecology.” This ensures that the education is practice-orientated, with the possibility of distance and independent learning, skills improvement, and the development of interdisciplinary relationships. The research methods used a theoretical and methodological analysis of scientific and educational literature, logical and semantic modeling of the learning content, design, theoretical analysis and synthesis. The research achieved a new curriculum for "Radioecology," the creation and implementation of a theoretical course and the development of the practical part of the discipline. This was differentiated by difficulty levels and aimed at solving specific situational problems. The work proposed the creative component of the practical part in the form of individual tasks requiring the learner to resolve a specific production problem situation. It also created a laboratory workshop with the development of modern scientific methods a textbook on radioecology and an electronic version of the methodological support of the discipline, facilitating independent training and making distance learning possible.
Keywords: methodological approach, differentiation of training, practical skills, electronic course-resource, self-training, interdisciplinary connections, competence.

Компетентностный подход при обучении экологов на примере изучения дисциплины «Радиоэкология»

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Аннотация
Целью исследования является разработка нового методологического подхода и создание методического комплекса по дисциплине «Радиоэкология», обеспечивающих дифференциацию и практико-ориентированность обучения, возможность дистанционного обучения, самостоятельной подготовки и повышения квалификации, формирование междисциплинарных связей. Методы исследования: теоретический и методологический анализ научной и учебно-методической литературы; логико-семантическое моделирование содержания образования по дисциплине, проектирование, теоретический анализ и синтез. Решены следующие задачи: разработан новый учебный план по дисциплине «Радиоэкология», в соответствии с которым создан и внедрен теоретический курс дисциплины; разработана практическая часть дисциплины, дифференцированная по уровням сложности и направленная на решение конкретных ситуационных задач; предлагается творческая составляющая практической части в виде индивидуальных заданий, при выполнении которых необходимо разрешить конкретную производственную проблемную ситуацию; разработан лабораторный практикум с освоением современных научных методов; создан учебник «Радиоэкология» и электронная версия методического обеспечения дисциплины, облегчающие самостоятельное обучение бакалавров и делающие возможным дистанционное обучение.
Ключевые слова: методический подход, дифференциация обучения, практические навыки, электронный курс-ресурс, самоподготовка, междисциплинарные связи, компетентность.

Introduction

The problem

Radioactive contamination of the environment in the period after the Chernobyl accident, and transfers of radionuclides across boundaries are of great importance not only for Ukraine, but also for many other countries. Therefore, specialists need to be trained the theory of radioactivity, ionizing radiation, nuclear power, radiation protection, dosimetry, radiation ecology, etc. The discipline of “Radioecology” has lately become of great importance in the university training of environmental engineers. As an academic discipline, radioecology, like the entire 20th century education is undergoing a radical and dynamic renovation. Modernization of higher education, improvement of radioecological education and improved quality of training undergraduate and and master students are the main goal for innovations in this area.

Literature analysis

Advanced methods of teaching involve a comprehensive approach, new learning technologies, distance and on-line training, and independent work (Kuskin, 2019; Oleškevičienė et al., 2019; Bosch et al., 2019). The main objectives are to increase the role of self-study and ensure the competence of future specialists (Yakhyeva, 2015; Olsson et al., 2020). The key competence indicators for the study of "Environment" are proposed by (Seo et al., 2020) Teaching disciplines should be based on requests for qualifications needed by future specialist. Curriculum is implemented by teachers through their understanding of themselves as professional participants in educational policy (Poteliūnienė et al., 2019; Gadušová et al., 2019).

An important feature of modern education and, primarily, science education is the effective continual learning (Asgari et al., 2019). In higher education, in the preparation of future environmental specialists, there are no great difficulties in the implementation of continuing education. Firstly, there are no large time gaps between the learning of disciplines. Secondly, in all courses the latest achievements of modern science, information on research methods and new technologies are presented. The implementation of continual education meets the demands of an innovative economy for engineering and scientific personnel (Pentin et al., 2018).

Problem statement

Simultaneously, there has been a recent tendency to reduce resources in every aspect of education – financial, intellectual and infrastructural (Lisyutkin, 2017). One of the methodological approaches that will preserve and expand the intellectual resource component is the creation of a new model of educational literature that takes into account all the requirements for higher education. Modern textbooks should be required to comply with the curriculum, the gradual build up knowledge, be based on the principles of modularity, differentiation and didactics, develop abilities and skills of analysis, ensure interdisciplinary communications and implement a competence-based approach in education (Seo et al., 2020; Taylor, 2018; Khobotova, 2018). They must develop and consolidate scientific analytical and creative thinking, motivate learning and cognitive activity, and make it possible to acquire practical skills (Ransome & Newton 2018; Knight 2015). The practical aspects of textbooks require situational significance and the novelty of the formulation of educational tasks (Larina 2016). An important feature of modern educational methodological papers is a focus on control or self-control of the educational process quality (Aleksandrov & Vorontsova, 2015).

Methodology

Objective of the research

The objective was the development of new methodological approach and creation of educational and methodological complex for the topic of "Radioecology," which ensures the differentiation of education, the possibility of distance learning, independent training and improvement of skills, the formation of interdisciplinary relationships and competences. To achieve this, it was necessary to

- develop a new curriculum for Radioecology
- create and implement a theoretical course,

- develop the practical aspects of the course, differentiated by difficulty levels and aimed at solving specific situational problems
- propose the creative component of the practical part in the form of individual tasks
- develop a laboratory workshop for mastery of modern scientific methods
- create an electronic course-resource of the discipline on the university's educational platform.

The research shows the possibility of improving the ecological education of students through the development of a new approach and methodology for Radioecology. The novelty is that the new methodological approach is based on the principles of practice-orientation and the acquisition of competencies. These ensure the development of students' professional qualities, independence and practical skills through undertaking real situational tasks that take into account differentiation and individualization.

Methods

The research used a theoretical and methodological analysis of scientific and educational-methodical literature together with logical and semantic modeling of the educational content, design, theoretical analysis and synthesis. The curriculum is based on a practice-oriented approach, which ensures the development of students' professional competencies and practical skills through undertaking real situational tasks, taking into account differentiation and individualization.

The approach was tested at the Kharkiv National Automobile and Highway University, which trains Natural Sciences undergraduates in the educational program "Ecology and Environmental Protection." "Radioecology" is studied in the 5th semester. The work program in this subject provides 90 academic hours (16 lectures, 16 laboratory sessions, 8 practical lessons, 50 hours of independent work including 30 hours of exam preparation). A new approach to teaching started in 2014. The experimental bas comprised 290 undergraduates.

Results

Interdisciplinary communications

"Radioecology" is a system of concepts about the laws of ionizing radiation, the migration of radioactive substances in the biosphere, and the biological action of radiation. The purpose of undergraduate study is training the ecology student to perform professional tasks in the field of radioecology. Modern radioecology is at the intersection of biological, physical and chemical sciences (human, animal and plant ecology, biology, radiobiology, radiation genetics) on one hand, and nuclear physics (nuclear geophysics, nuclear geochemistry, radiochemistry and dosimetry) on the other. The theory includes:

- Atomic nucleus structure
- Natural radioactivity
- Artificial radioactivity
- Ionizing radiation
- Dosimetry
- Technologically-modified radiation background
- Radiation protection
- Sources of man-made radioactivity
- Nuclear power engineering
- Prospects for development of nuclear power engineering after the Chernobyl accident
- Circulation of artificial radioisotopes in the external environment

- Dose limits of exposure and acceptable reference levels as a basis for radiation safety
- General laws of radiobiological effect of radiation, and
- Radiation syndromes and radiation poisoning

The principle of logical interdisciplinary and inter-thematic relations is observed in presenting the material. Nuclear physics and nuclear geophysics allow the study of radiation fields, (ie, the distribution of sources of ionizing radiation in the atmosphere, waters, soils and rocks), radiochemistry (investigating the state of radioactive substances in aqueous solutions and aerosols, to determine the chemical forms and oxidation levels of radioactive elements, the forms in which the migration of radioactive substances in the medium takes place). Radiobiology provides information on the concentration of radioactive elements by various organisms and their individual organs, data on the genetic and other consequences of exposure to ionizing radiation. While genetics develops methods for calculating dose-rate radiation and radiation protection methods. When studying the theory, the students should acquire a complex of knowledge and ideas about the effects of ionizing radiation from natural and man-made sources, types of ionizing radiation, units of radioactivity and radiation doses, positive and negative aspects of atomic power engineering, methods of radiation protection, radiation doses affecting the functions of living organisms, patterns of internal and external exposure of the human body, the extent of its damage depending on the dose of radiation and toxicity of the substance.

Each section has a large and comprehensive volume of theoretical material. For example, when studying the composition of an atomic nucleus, not only nuclear particles and the concepts of isotopes, isobars and isotones are considered, but also nuclear forces, the calculation of the radius of the nucleus, the shell model of the nucleus, the magic numbers of nucleons. Representatives of natural radioactivity and their content in the components of the environment and food are considered. The components of external radiation (cosmic, soil and rock, tropospheric, aquatic environment) are studied in detail. It is also useful for students to familiarize themselves with the variation of cosmic radiation in the form of latitudinal and barometric effects. In dosimetry, both the principles and recently developed methods of dosimetry monitoring are presented. In the section about the sources of technologically-modified background radiation the data on the radioactivity of building materials, the radon problem, the radioactivity of industrial wastes, phosphoric ores and fertilizers, and thermal water sources are given. Particular attention is paid to radioactive waste generated during the operation of nuclear power plants, methods of processing and disposal, radioactive contamination of all components of the biosphere and foodstuff with artificial nuclear explosion radionuclides and accidents at nuclear power plants. It is very important for future ecologists to know the dose limits of exposure and permissible reference levels as the basis for radiation safety. Therefore, in the theoretical part, they study the main regulated values, dose limits and permissible levels for various routes of entry of radionuclides into the human organism. The theoretical material on the biological effects of radiation will make possible for the students to unite previously disaggregated ideas about radiation effects into a single system that enables them to predict the effects of radiation exposure.

For the first time, the new curriculum includes those sections that will be necessary for students in the study of subsequent professionally oriented disciplines of the environmental direction. The presentation of theoretical material is aimed at the future; therefore, the latest achievements in the field of radioecology and radiobiology are presented as the additional material. When mastering the theoretical part of the discipline, the students perceive its content, learn the new concepts and phenomena connected with the action of various types of ionizing radiation, and acquire new knowledge. When compiling a new curriculum on discipline, fundamental and applied knowledge were not allowed to be opposed. Theoretical knowledge is aimed at solving real tasks, which is the practical orientation of higher education.

Practical orientation and differentiation

The practical part of the discipline, includes a variety of educational tasks of various levels of difficulty - easy, medium, hard and creative. Previously, a similar approach was used by the authors to create a problem book in chemistry (Khobotova et al., 2016). Such differentiation provides an opportunity for students to choose and improve the process of acquiring practical skills. For example, calculations using the law of radioactive decay use three analytical expressions in the interrelation between the quantitative characteristics of the process - the constant radioactive decay (λ), half-life period (T) and the average lifetime of the isotope (τ). The variety of tasks of various difficulty levels, the algorithm for solving them and the skills acquired are presented in Table 1.

Two tasks related to the radon problem were developed: (a) calculating the radon egress from the soil depending on its porosity and radon diffusion coefficient, and (b) calculating the average tissue (pulmonary) dose due to inhalation of isotopes $^{220,\,222}$Rn, depending on the intensity of ventilation in the premises. The calculations of the dose of γ-radiation indoors depending on the construction materials used, the mathematical rationale for replacing construction materials with increased specific activity of natural radionuclides (NR) with alternatives are of interest.

An important practical focus in the section Dose limits of exposure is the use of acceptable reference levels as a basis for radiation safety. In tasks of various levels of complexity, students calculate the maximum permissible annual entry of radionuclides, their permissible concentration, the permissible content of radionuclides in the body, permissible levels of internal irradiation for a mixture of radionuclides, permissible concentrations and dose rates of noble gas radionuclides, and the absorbed tissue dose.

An example of a practical task aimed at solving a specific situational problem is to determine the minimum length of the manipulator handle that provides a safe working environment for a researcher with radionuclides with a total activity of 60 mEq Ra for 28 hours a week without additional radiation protection.

Mastering the practical part of the discipline motivates the learner through increasing intellectual activity and cognitive interest. Differentiation of the practical aspects according to the difficulty level and a gradual transition to higher levels contributes significantly.

The creative component of individual tasks to solve problem situations

Individual tasks were first introduced into the curriculum as an indispensable element. When performing a task that combines various topics of the discipline, interdisciplinary links are traced and different approaches to the solution are possible. The student must have good knowledge, show erudition and perform the calculations correctly. Such individual tasks are advisable since they present the profiled problem situations and contribute to shaping the model of the specialist and his independence, increase his level of qualification and competence. Individual tasks are of great importance in enhancing the study of various professionally-oriented environmental disciplines by students (Khobotova & Sayenko, 2017).

Table 1: Changing practical activity skills depending on the difficulty level of tasks

Difficulty level	Statement of problem	Knowledge of formulas, algorithm of solution	Acquiring the skills
easy	Find the mass of isotope (m) ^{81}Sr (T = 8.5 h), decayed for t=25.5 h of storage, if its initial mass (m_0) was 200 mg.	Calculation of the mass of an undecayed isotope by formula: $m = m_0 \cdot 2^{-\frac{t}{T}}$.	Calculation using one analytical expression of the radioactive decay law.
medium	Half-life period of isotope ^{14}C is 5760 years. In how many years will the activity of ^{14}C sample decrease to 90 % from the initial value? What do the radioactive constant λ and an average isotope life τ equal to?	When solving the task, the student must know all expressions of the radioactivity decay law and the connection between the decay constants. 1. Determination of λ and τ: $\lambda = \frac{0.693}{T}$; $\tau = 1.44 \cdot T$. 2. Using the radioactive decay law in the form of $N = N_0 \cdot e^{-\lambda t}$ or $N = N_0 \cdot 2^{-\frac{t}{T}}$ to determine the time of decay: $t = T \lg(\frac{N_0}{N})/0.301$.	Ability to calculate all quantitative characteristics of radioactive decay by one known constant. Ability to transform the expression of radioactive decay law (2 types) to determine the target value.
hard	To determine specific radioactivity (C) of β^--active isotope ^{140}Ba, if T = 12.8 of the day. To find the mass of the daughter product of decay (specify the isotope), which form from 1.5 g ^{140}Ba in 64 days.	1. Conversion of T in the units of second measurement. 2. Calculation of specific activity by total number of nuclei (a), in 1 kg of isotope ^{140}Ba: $C = \lambda \cdot a = \frac{6.02 \cdot 10^{23} \cdot 10^3 \cdot 0.693}{140 \cdot 12.8 \cdot 24 \cdot 3600} = 2.69 \cdot 10^{18}$ Bq/kg. 3. Calculation of m is similar to the task of the "easy" level. 4. Calculation of $m_{Ba\text{-}140} = m_0 - m$ 5. Knowledge of the types of radioactive decay and the laws of radioactive displacement. The short form of electronic (β^-) decay of isotopes is: $^{140}Ba \rightarrow {}^{0}_{-1}e + {}^{140}La$.	Apart from the skills of the medium level: calculation of specific radioactivity using the atomic mass of isotope and the Avogadro number N_A=6.02·10^{23}. Ability to write the equality of the types of radioactive decay.

An example

As an example, one individual task is "Assessment of the radiation situation at the mining and processing plant and the adjacent territory."

General situation

A mining and processing plant, an enterprise for processing iron ore, has 7 main workshops. When the iron concentrate is being received, the tailings are formed in the shops of the plant by way of a suspension of finely ground rock. Natural radionuclides contained in iron ore are concentrated in the tailings. The main use of the tailings (hereinafter: slags) is as a secondary raw material for the production of building materials.

Formulation of the problem

It is necessary to assess the radiation situation in the workshops of the plant, the degree of exposure at workplaces due to radon and gamma radiation of natural radionuclides; to characterize the radioactive properties of ore processing residue and predict the area of its use in construction; to evaluate the type of combined radiation and noise in the workshops of the plant.

1st stage: Radiation characteristics of construction materials of the enterprise workshops

The workshops of the enterprise are built of slag concrete. Gamma-spectrometric data on the specific activities of its components and their mass parts are presented in Table 2 (option No 1 is given). Calculate the annual equivalent dose for the workshop workers. Estimate how the natural radionuclides ΔD_{NR}, which are the part of the building materials, contribute to the dose.

Table 2. Specific activities of construction materials

Workshop	*Cement*		*Sand*		*Gravel*		*Blast furnace slag*	
	C, Bq/kg	*m, tn*	*C, Bq/kg*	*m, tn*	*C, Bq/kg*	*m, tn*	*C, Bq/kg*	*m, tn*
1	95	8	80	24	180	25	150	12

Calculation algorithm

Annual efficient equivalent dose of radiation (μSv/y) of modern stone buildings is calculated according to the formula:

$$D_{room} = 4.74 \cdot \overline{C_{ef.}}\,,$$

$$\overline{C_{ef.}} = \frac{\sum_i (C_{ef.})_i \cdot m_i}{\sum_i m_i}\,, \text{ Bq/kg},$$

where: $(C_{ef.})_i$ is an efficient specific activity of natural radionuclides in construction materials;

$\overline{C_{ef.}}$ is an average efficient specific activity of natural radionuclides in a structural unit made from different materials.

The use of building materials can be forecasted by belonging to a certain class of radiation hazard (table 3).

The dose obtained by the γ-radiation of natural radionuclides of construction materials is calculated by the formula:

$$\Delta D_{NR} = D_{room} - 305, \ \mu\text{Sv/y},$$

where 305 μSv/y is a dose which would be obtained by people if they stay on the open ground the whole year.

2nd stage: Radiation characteristics of production wastes

Table 3. Criteria for using materials depending on the value of efficient specific activity (OECD, 1979)

Waste category	$C_{ef.}$*, Bq/kg*	*Area of usage*
I	<370	In construction without limitations
II	370–740	In industrial and road construction outside residential areas as concrete and reinforced concrete aggregate.
III	740–2240	In industrial zones, outside residential areas, for dam construction
IV	2240–3700	In the areas of receipt, for dam construction, tailing pits and flushing of workings
V	>3700	Only for disposal and flushing of workings

Using the results of γ-spectrometric study of iron ore processing waste, which are listed in Table 4, calculate their effective specific radioactivity. Determine the class of radiation hazard and indicate the possible scope of this waste usage in the construction area.

Table 4. The results of γ-spectrometric research of iron ore processing waste

$C_{sp.}$*, Bq/kg*		
^{232}Th	^{226}Ra	^{40}K
85.1	69.1	858.6

Calculation algorithm

Hygienic evaluation of materials used in construction is accomplished by the value of efficient specific activity $C_{ef.}$:

$C_{ef.} = C_{Ra} + 1.31C_{Th} + 0.085C_K$,

where C_{Ra}, C_{Th}, C_K are specific activities of radium-226, thorium-232 and potassium-40 relatively (Table 4);

1.31 and 0.085 are the weighted coefficients of thorium-232 and potassium-40 related to radium-226.

The criteria of materials usage in construction are determined by value of $C_{ef.}$ (Table 3).

3rd stage

Radon exposure doses

Calculate the doses of radon-222 exposure of people in workshop No 1 when the ventilation equipment is working and during its emergency stop. During calculations use the results of measuring concentration of ^{222}Rn with the help of alpha-radiometer: $C_{^{222}Rn}$ =26 Bq/m³.

Calculation algorithm

The value of the average tissue human dose caused by radon inhalation can be evaluated by the equations:

– ventilation in the room in the following conditions: exchange of 0.001 air volume per 1 sec. $D_{Rn\text{-}222}=0.038 \cdot C_{Rn\text{-}222}$, Sv/y;

– no ventilation $D_{Rn\text{-}222}=0.135 \cdot C_{Rn\text{-}222}$, Sv/y,

where *C* is concentration of emanations of Bq/m^3.

4th stage

Evaluation of the type of a combined effect of radiation and noise

In shop number 1 technological equipment with a high level of noise is placed. Make a conclusion about the nature of the combined effect of radiation and noise on a person, using the graphical dependence of occupational morbidity on the magnitude of the absorbed dose $D_{abs.}$ (data in Table 5). Determine the type of the combined effect of radiation and noise. Calculate the quantitative characteristics of the combined action – dose reduction factor (DRF) at 4.25 % morbidity with the combined effect of two factors.

Table 5. Professional morbidity in conditions of the combined effect of radiation and noise

Morbidity (%) with the following factors in action	*$D_{abs.}$, Gy*							
	0.05	*0.06*	*0.07*	*0.08*	*0.09*	*0.10*	*0.12*	*0.15*
radiation	3.0	3.2	3.4	3.5	3.9	4.1	4.4	4.6
radiation + noise 105 dB	4.0	4.1	4.2	4.3	4.3	4.3	4.5	4.6

Calculation algorithm

Quantitative criterion of a combined effect of radiation and other dose reduction factors equals the relation of radiation doses having the same biological effect (*S* – morbidity) with the other factor present (D_2) and when only radiation is acting (D_1):

$$\text{DRF} = \frac{D_2}{D_1}.$$

Example of graphic determination of dose reduction factors is given in Fig. 1.

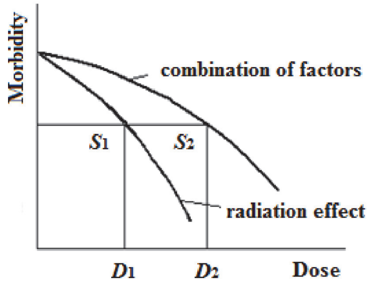


Fig. 1. Example of determination of dose reduction factor

With the synergy of combined action of dose radiation factor <1; on the graph in the coordinates lg*S* – *D* the morbidity curve of the action of radiation is higher. With the antagonism of action dose radiation factor > 1, on the graphical dependence the curve of a combination of factors is situated higher.

According to Table 5, students should build a graphical dependence in the lg*S* – *D* coordinates. From the relative position of the curves, make a conclusion about the mechanism of the combined effect of radiation and noise. For the value of lg$S$ = 0.63 (S = 4.25 %) determine the dose radiation factor.

As an example, two more individual tasks related to radioecological situations of different levels of complexity and danger. They are aimed at formation of students' scientific thinking.

1. Radiation-hygienic evaluation of the consequences of an accident at a nuclear power plant with the depressurization of the active zone and the release of uranium fission products into the environment. The task includes the following steps: evaluation of the level of radiation contamination of the biosphere components; forecast of strontium contamination of agricultural products; calculation of quantitative criteria of ^{90}Sr migration by trophic levels; evaluation of intensity of discriminatory acts; the effectiveness of protective measures during decontamination operations in the core and adjacent territory; evaluation of the nature of the recovery in time of radiation poisoning of the human organism in the contaminated area.

2. Evaluation of the radiation situation at the plant by regeneration of nuclear fuel with the stages: calculation of the permissible concentration of radionuclides of noble gases (RNG); calculation of the dose rate of β- and γ-radiation upon the human exposure by the RNG with their joint presence in the air of the room; calculation of tissue irradiation doses; protective measures taken during depressurization of the process equipment.

Individual tasks of various difficulty levels are the new integrated approaches, focused on the knowledge and practical professional training. They develop analysis skills and the ability to use professional knowledge in a particular situation, which creates the basis for the formation of a competitive personality.

A laboratory workshop for mastering new methods and technologies

After acquiring the appropriate instrument base: a gamma radiation scintillation spectrometer (СЕГ-001 «АКП-С») with a system for analyzing, processing and visualizing spectrometric information and dosimeter-radiometer МКС-05 «Терра» it was possible to introduce a laboratory workshop. In this workshop, students master modern scientific methods for determining the specific activities of radioisotopes, radiation-chemical assessment of various media and materials (water, soil, food, fertilizers, building materials, etc.), study the external γ-radiation of building materials and components of technologically-modified radiation background (ash, slag, sludge, phosphate). Using the methods of dosimetric control, the doses of a person's external exposure are determined at various radiation geometries. Radiobiological methods include determining the amount of strontium-90 in milk, methods for assessing the content of radioactive substances in the organism, and methods for accelerating the elimination of radionuclides from the organism.

Successful development of laboratory practice techniques forms professional competence and research thinking, increases the competitiveness of future environmental engineers.

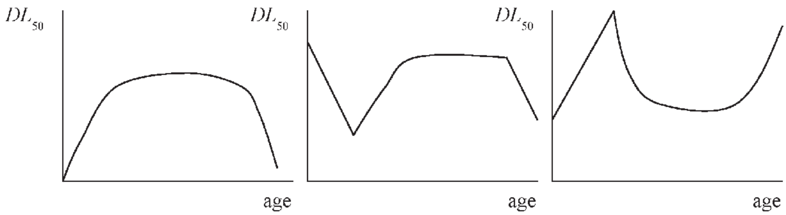
Controls of students' knowledge and skills

Controls of students' knowledge and skills are presented in the form of closed and open tasks for self-control. The closed test tasks offer alternative choices, as shown below. They are aimed at "rough" testing of knowledge and classifications on a specific section, testing the skills of correct application of knowledge in the process of mastering the discipline. For example:

1. THICKNESS OF CONCRETE PROTECTION ($\rho_{concrete}$=2.3 g/cm³), WEAKENING γ-RADIATION BY 20 TIMES AT μ_m = 0.0268 cm²/g, EQUALS A. $d = \frac{0.0268 \cdot \ln 20}{2.3}$ B. $d = \frac{2.3 \cdot \ln 20}{0.0268}$ C. $d = \frac{0.0268 \cdot 2.3}{\ln 20}$ D. $d = \frac{\ln 20}{0.0268 \cdot 2.3}$

Some test tasks are given in graphic form:

2. AGE DIFFERENCES IN RADIOSENSITIVITY ARE ILLUSTRATED BY THE DEPENDENCE



A. B. C.

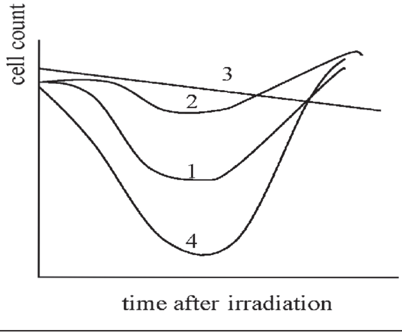
The closed test tasks are built on the principle of conformity:

3. LONG-TERM EFFECTS OF IRRADIATION

Form of irradiation effect	*Manifestation of irradiation effects*
1. neoplastic	A. reduction in life expectancy
2. non-neoplastic	B. aplastic state of tissues
	C. blastomogenesis
	D. dishormonal disorder
	E. hardening of tissues
	F. leucosis

4. CURVES OF BLOOD CELL RENEWAL AFTER IRRADIATION

A. erythrocytes
B. thrombocytes
C. lymphocytes



The open type tests require full knowledge of formulas, units of measurement, and the ability to make calculations:

5. IN ORDER TO ENSURE THE LIMITING DOSE OF IRRADIATION WHEN WORKING WITH THE SOURCE OF γ-RADIATION OF ^{60}Co WITH ACTIVITY 30.3 Cu AT THE DISTANCE OF 3 m FOR 36 hr/day, THE USE OF PROTECTIVE STRUCTURES FROM THE FOLLOWING MATERIALS IS OBLIGATORY: CONCRETE ($\rho_{concrete}$=2.3 g/cm³), ______ cm THICK OR BRICK (ρ_{brick}=1.4 g/cm³), _______ cm thick.

Self-training of students by the test tasks of the discipline makes possible to monitor the knowledge, to check the students' skills and creative component at different stages of education.

Interdisciplinary relationships

The continuity of environmental education is implemented in this methodological approach. There is a direct correlation between continuing environmental education and professional competence. The knowledge previously obtained by students in the study of chemistry, physics, biology, is the basis for the development of theoretical and practical material on radioecology. However, in the future, when developing professionally-oriented environmental disciplines, students will actively use their knowledge of radioecology. For example, in the sections of Human Ecology, and Eco-hygienic problems of human nutrition when considering the migration of radionuclides along food chains with their accumulation in food products. At the same time, they are studying quantitative indicators of radioactive xenobiotics at trophic levels and measures to reduce them; in the section Application of fertilizers and their impact on human health, students use the knowledge gained in the study of the radioecology section Technologically-modified radiation background» namely, the content of radionuclides in phosphorus ores and fertilizers. It would be impossible to study the influence of factors of the urban environment on human health, namely, the increase in the number of oncological diseases and mortality without knowledge of the mechanism of ionizing radiation as the physical carcinogenic factor.

Continuity of training is also important when studying Fundamentals of Environmental Toxicology. The combined effect of toxic substances and radiation is most often manifested in the synergy of action. Students should be able to justify this, based on knowledge of the biological effects of ionizing radiation. The section Toxicology of radioactive substances, which separates the concepts of chemical and radiation toxicity, is also being studied.

A new methodological approach to the study of Radioecology, taking into account interdisciplinary relationships, the principle of continuing learning and the formation of scientific research thinking, was implemented in the textbook *Radioecology* (Khobotova, Hraivoronska & Ukhanova, 2018; Khobotova et al. 2020), developed by the authors.

Development of a Radioecology electronic course resource

The electronic course resource is located on the university educational platform. It includes all the components for theoretical, practical and independent training for students to acquire skills. The resource is divided into a general part and separate thematic sections. The general part presents the program of the discipline, requirements for passing the exam, textbooks, collections of problems, packages of test tasks and methodological instructions for laboratory work and practical lessons. The thematic sections include theoretical lecture material, examples of solving problems and test tasks by difficulty levels, presentation material for lectures and practical exercises, with videos for laboratory activities, packages of options for control works, individual tasks and tests.

The electronic resource has proven its relevance for distance learning during a pandemic. It was widely used for all types of educational activities, as well as for self-training of students.

Development of a competence-based approach to training

The competence-based approach assumes the presence of a system for developing the students' professional competence, that is, their ability and readiness for professional activity. Each discipline should contribute to the formation of competencies and meet the requirements for the levels of professional readiness for the types and tasks of the activity: to have an idea, know, have skills, have professional competencies. The introduction of the new curriculum for Radioecology and the new methodological approach meets the following requirements.

Have an idea

Have an idea of: the sources of radioactivity, the main forms of exposure to ionizing radiation on living structures of varying degrees of organization (**Id1**); toxicity criteria for industrial hazardous substances (**Id2**); modern concepts and principles of environmental regulation of exposure to ionizing radiation (**Id3**).

Know

Know the types of ionizing radiation, units of radioactivity and radiation doses (**Kn1**); features of positive and negative aspects of nuclear energy, radioactive waste management methods (**Kn2**); methods of protection against radiation and methods of measuring the level of radioactive contamination (**Kn3**); features of the course of radiation syndromes and human radiation sickness, the main effects of radiation and its long-term consequences (**Kn4**); methods of accelerating the elimination of radionuclides from the body, the main forms of exposure to radiotoxic substances on the human body, patterns of toxic effects under the action of radiation and other harmful factors, the peculiarities of the intake, transport, distribution and release of radionuclides from the body (**Kn5**); the main provisions of hygienic regulation and standardization of radiation exposure (**Kn6**).

Skills

Have the skills to: independently assess the degree of radioactive contamination of the environment and the magnitude of the radiation dose of organisms, determine the degree of biological hazard of radioactive contamination and their main sources, recommend a set of methods for protection against radioactive contamination, use medical and ecological maps (**Sk1**); to evaluate the relative biological effectiveness of radiation, the factor of dose reduction when exposed to radiation protective equipment (**Sk2**); determine the quantitative characteristics of the process of removing various radionuclides (**Sk3**); interpret the “Radiation dose-effect” curves, predict the long-term effects of radiation in a specific radiation situation (**Sk4**); use the criteria of hygienic regulation of ionizing radiation (**Sk5**); use the main parameters of toxicity and hazard of harmful substances, as well as the regularities of the relationship between the composition, structure and properties of chemicals with indicators of toxic and radiotoxic action, estimate the MPC of harmful substances in the air of the working area (**Sk6**); use graphic methods for predicting and assessing the combined action of radiation and other harmful factors (**Sk7**); apply discipline theory and experimental skills in other specialty disciplines (**Sk8**).

Practical skills

Have practical skills of dosimetric control using various types of dosimeters, gamma spectrometric analysis of various materials (**PrSk1**).

Professional competencies

Professional competencies are formed on the basis of a set of knowledge, skills and practical skills. As applied to the radioecology industry, it can be argued that the presented methodological approach forms the following professional competencies.

- *General professional competencies*: the ability to navigate in the prospects for the development of technique and technology to protect humans and the natural environment from technogenic and natural hazards (**Kn1, 3; Sk6–8**); the ability to assess risk and determine measures to ensure the safety of the developed equipment (**Kn4; Sk1, PrSk1**); the ability to navigate the main methods and systems for ensuring technosphere safety, to reasonably choose known devices, systems and methods for protecting humans and the natural environment from hazards (**Kn2; Sk1, 5; PrSk1**); the ability to navigate the main regulatory legal acts in the field of security (**Kn6, Sk5, 6, 8**).
- *Expert, supervisory and inspection and audit competencies*: the ability to use methods for determining the normative levels of permissible negative impacts on humans and the natural environment (**Kn4, 5; Sk5; PrSk1**); the ability to measure the levels of hazards in the environment, process the results obtained, make forecasts of the possible development of the situation (**Kn1–3; Sk6; PrSk1**); the ability to analyze the mechanisms of the impact of hazards on humans, to determine the nature of the interaction of the human body with the hazards of the environment, taking into account the specificity of the mechanism of the toxic action of harmful substances, energy impact and the combined action of harmful factors (**Kn4, 5; Sk2–4; PrSk1**); the ability to identify dangerous, extremely dangerous areas, areas of acceptable risk (**Kn6; Sk1, 5, 8; PrSk1**); the ability to monitor the condition of the protective equipment used, to make decisions on the replacement (regeneration) of protective equipment (**Kn2, 3; PrSk1**).
- *Research competencies*: the ability to navigate the main problems of technospheric safety (**Id1; Kn1, 3, 6; Sk1, 5, 6, 8; PrSk1**); the ability to take part in research and development according to the profile of training: systematize information on the topic of research, take part in experiments, process the data obtained (**Id1, 2, 3; Kn1–4; Sk1, 2, 5, 8; PrSk1**); the ability to solve problems of professional activity as part of a research team (**Id3; Sk1, 5, 8; PrSk1**).

Information on the contribution made by Radioecology to the development of competencies is provided by the data of a survey carried out since 2014 (Table 6).

Table 6: Results of a survey of bachelors and graduates in the period 2014-2020 (The percentage of respondents who gave a positive answer is indicated)

No	*Survey question (Total number of respondents)*	*Year of studying the discipline "Radioecology"*						
		2014	*2015*	*2016*	*2017*	*2018*	*2019*	*2020*
1	The differentiation of teaching helped in the study of the discipline "Radioecology" (290)	91	85	79	66	85	87	98
2	Practical orientation was traced in the study of "Radioecology". (290)	78	66	79	86	89	90	75
3	I used the knowledge and skills obtained in the study of radioecology in other environmental disciplines. (290)	55	48	43	67	61	53	73
4	The calculation and graphic component of the discipline of interest and is necessary not only for studying "Radioecology". (290)	43	51	48	50	44	59	61
5	I used the electronic course-resource of the discipline for theoretical and practical training in the course of online classes / for self-training. (40)	–	–	–	–	–	–	82/98

No	*Survey question (Total number of respondents)*	*Year of studying the discipline "Radioecology"*						
		2014	*2015*	*2016*	*2017*	*2018*	*2019*	*2020*
6	I used the knowledge, skills and abilities of the discipline "Radioecology" in my professional activities as an environmental engineer. (150)	68	57	51	44	58	–	–
7	Did you have to use your practical skills in radioecology in your professional activities? (150)	49	44	65	61	58	–	–
8	The methodological approach to teaching radioecology developed: analytical thinking (the ability to calculate the consequences of decisions made, initiative, search and effective use of information) / systems thinking (the ability to foresee how a change in an element will affect the entire system as a whole). (290)	68/ 77	59/ 64	78/ 86	58/ 67	66/ 73	74/ 88	73/ 85
9	Radioecological individual tasks with the resolution of problem situations helped in the formation of creative components / innovative competencies. (290)	54/ 52	49/ 45	56/ 51	61/ 48	49/ 67	53/ 61	65/ 54
10	The methodological complex of radioecology developed the ability for self-education. (290)	89	90	91	91	94	95	96

The number of respondents varied for a number of reasons. For example, 40 bachelors out of a total of 290 answered question No. 5, since the electronic course resource of the discipline began to be used in September 2020. Questions No. 6 and 7 were answered by 150 graduates from 2014-2018 who work as environmental engineers.

The survey showed a high assessment of the methodological approach of teaching and the methodological complex of Radioecology by students and graduates, since more than 50% of the respondents (averaged over the years of the survey) answered positively to all the questions. More than 70% of the respondents indicated that the differentiated approach in teaching helped them in mastering Radioecology: the practical orientation of the discipline and the acquisition of the ability to think systems were noted. The electronic resource was used by students of the 2020 year of study both for self-education and for distance learning. The ability to develop the ability for self-education, the ability to quickly master new knowledge, for self-development, and readiness for professional growth was especially highly appreciated.

Discussion

When compiling the new Radioecology curriculum, the authors did not allow fundamental and applied knowledge to conflict. The practical orientation of training was that theoretical knowledge was directed to solving real problems, and the practical part motivated intellectual activity. The purpose of the differentiation was to align students' practical skills at the professional level. These aspirations are consistent with the creation of modern educational programs that contribute to the gradual build-up of knowledge based on the principles of modularity, differentiation and didactics, and introduce a competency-based approach in education (Seo et al, 2020; Taylor, 2018; Khobotova, 2018). They develop and consolidate scientific analytical and creative thinking, and open up the possibility of acquiring practical skills (Ransome & Newton 2018; Knight, 2015). An important component of the educational process is electronic versions of methodological support and educational and methodological publications. Key parameters should be the situational significance and novelty of the formulation of educational tasks (Larina, 2016), and an orientation towards control or self-control of the quality of the educational process (Aleksandrov & Vorontsova, 2015). The authors tried to take all these features into account, along with the introduction of a new methodological approach, when writing the Radioecology textbook (Khobotova et al., 2018; Khobotova et al., 2020) and creating an electronic course resource for the discipline. The authors pin great hopes on the self-study of students and their acquisition of specialist competencies with the help of these developments.

Conclusion

This work contributes to the modernization of higher education and the improvement of the quality of graduate training. It shows the possibility of improving radioecological education of the students by development of a new methodological approach and an educational and methodological complex in training. The novelty of the results obtained is ensured by the renewal of interdisciplinary relations, practical orientation, differentiation in the process of practical part, individualization of training, laboratory practice, control means, development of an electronic version of the methodological support of the discipline, the creation the Radioecology textbook, possibility of self-training and improving the students' skills.

The organization of cognitive activity is carried out through the formation of students' research thinking. A new methodological approach helps students to organize their independent work while mastering knowledge and skills in radioecology and related environmental disciplines through the formation of interdisciplinary connections. The acquisition of practical skills will allow future specialists to solve specific tasks and problems on radiation problems in the workplace, and will increase their level of qualification and competence. There is a direct correlation between practice-orientation of education and professional competence.

References

Aleksandrov, E., & Vorontsova, M. (2015). Educational text and textual activity in the educational process. *Sovremennyye naukoyemkiye tekhnologii*, **6**, 56–61.

Asgari, A, Fard, H.S., & Tirgoo, F. (2019). The Role of Quality in Higher Education and Lifelong Learning in Entrepreneurship Competencies of Undergraduate Students. *Pedagogika/Pedagogy*, **135**(3), 240–256. DOI: 10.15823/p.2019.135.13.

Bosch, Ch., Baker, A., & Baker, J. (2019). Using Open Educational Resources and TechnologyEnhanced Learning for Teacher Professional Development in Ugandan Schools. *Education and Self Development*, **14**(4), 52–62. DOI: 10.26907/esd14.4.05.

Gadušová, Z., Hašková, A. & Predanocyová, L. (2019). Teachers' professional competence and their evaluation. *Education and Self Development*, **14**(3), 17–24. DOI: 10.26907/esd14.3.02.

Khobotova, E. (2018). Methodological developments for differentiated education. *Bulletin of Kharkiv National Highway and Automobile University*, **80**, 5–11. DOI: 10.30977.BUL.2219-5548.2018.80.0.5.

Khobotova, E., Hraivoronska, I., & Ukhanova, M. (2018). *Radioekologiya.* Kharkiv: KhNADU.

Khobotova, E, Ihnatenko, M., Hraivoronska, I., & Kaliuzhna, Iu. (2020). The textbook of a new generation "Radioecology". *Radiatsionnaya biologiya. Radioekologiya*, **60**(1), 108. DOI: 10.31857/S086980312001010513.

Khobotova, E., Ihnatenko, M., & Kalmykova, Iu. (2016). Individual approach to teaching chemistry. *Education and Self Development*, **1**, 106–109.

Khobotova, E., Sayenko, N. (2017). Organization of active educational activity in the study of environmental disciplines. *Bulletin of Kharkiv National Highway and Automobile University*, **77**, 18–24.

Knight, B.A. (2015.) Teachers' use of textbooks in the digital age. *Cogent Education*, **2**(1), 10 p. DOI: 10.1080/2331186X.2015.1015812.

Kuskin, W. (2018). Mapping a new education ecosystem. *Educational Studies Moscow*, **4**, 9–20.

Larina, G. (2016). Analysis of practical problems in mathematics: a theoretical model and application experience in lessons. *Educational Studies Moscow*, **3**, 151–168. DOI: 10.17323/1814-9545-2016-3-151-168.

Lisyutkin, M. (2017). On the possible causes of the deterioration of the resource base of universities. *Educational Studies Moscow*, **2**, 74–94. DOI: 10.17323/1814-9545-2017-2-74-94.

OECD (1979). *Exposure to radiation from the natural radioactivity in building materials*. Report by an NEA Group of Experts. Paris: OECD, 40 p.

Oleškevičienė, G.V., Puksas, A., Gulbinskienė, D., & Mockienė, L. (2019). Student Experience on the Development of Transversal Skills in University Studies. *Pedagogika/Pedagogy*, **133**(1), 63–77. DOI: 10.15823/p.2019.133.4.

Olsson, D., Gericke, N., Sass, W., & Boeve-de, P.J. (2020). Self-perceived action competence for sustainability: the theoretical grounding and empirical validation of a novel research instrument. *Environmental Education Research*, **26**(5), 742-760. DOI: 10.1080/13504622.2020.1736991.

Pentin, A., Kovaleva, G., Davydova,Y., & Smirnova, Y. (2018). State of science education in a Russian school. *Educational Studies Moscow*, **1**, 79–109. DOI: 10.17323/1814-9545-2018-1-79-109.

Poteliūnienė, S., Ustilaitė, S., Sabaliauskas, S., Česnavičienė, Ju., & Juškevičienė, A. (2019). Teachers' Experiences in Implementing Curriculum: a Teacher as a Participant of Educational Policy, a Member of the School Community and a Professional. *Pedagogika/Pedagogy*, **133**(1), 161–182. DOI: 10.15823/p.2019.133.5.

Ransome, J., & Newton, P. (2018). Are we educating educators about academic integrity? A study of UK higher education textbooks. *Assessment* & *Evaluation in Higher Education*, **43**(1), 126–137.

Seo, E., Ryu, Ja., & Hwang, S. (2020). Building key competencies into an environmental education curriculum using a modified Delphi approach in South Korea. *Environmental Education Research*, **26**(6), 890-914. DOI: 10.1080/13504622.2020.1733493.

Taylor, S. (2018). To understand and be understood: facilitating interdisciplinary leaning through the promotion of communicative competence. *J. of Geography in Higher Education*, **42**(1), 126–142. DOI: 10.1080/03098265.2017.1379059.

Yakhyeva, M. (2015). Methods for implementing the competency-based approach in teaching. *Pedagogika vysshey shkoly*, **3**, 53–55.