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**ВІДОМОСТІ ПРО АВТОРА**

**ДУДКА Тетяна** – доктор педагогічних наук, професор кафедри педагогіки та психології професійної освіти Національного авіаційного університету.

***Наукові інтереси***: загальна педагогіка та історія педагогіки, туризмологія.

**INFORMATION ABOUT THE AUTHOR**

**DUDKA Tetiana** – Doctor of Pedagogical Sciences, Professor of the Department Pedagogy and Psychology of Vocational Education Kyiv Aviation Institute.

***Scientific interests:*** general pedagogy and history of pedagogy, tourism studies.

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**КУЗЬМЕНКО Ольга –**
доктор педагогічних наук, професор,
учений секретар секретаріату Вченої ради
Донецького державного університету внутрішніх справ
ORCID: https://orcid.org/0000-0003-4514-3032
e-mail: Kuzimenko12@gmail.com
**ДЕМБІЦЬКА Софія –**
доктор педагогічних наук, професор,
професор кафедри безпеки
життєдіяльності та педагогіки безпеки
Вінницького національного технічного університету
ORCID: https://orcid.org/0000-0002-2005-6744
e-mail: sofiyadem13@gmail.com
**КОБИЛЯНСЬКИЙ Олександр –**
доктор педагогічних наук, професор,
завідувач кафедри безпеки життєдіяльності
та педагогіки безпеки
Вінницького національного технічного університету
ORCID: https://orcid.org/0000-0002−9724-1470
e-mail: akobilanskiy@gmail.com
**КОБИЛЯНСЬКА Ірина –**
кандидат педагогічних наук, доцент,
доцент кафедри безпеки життєдіяльності
та педагогіки безпеки
Вінницького національного технічного університету
ORCID: https://orcid.org/0000-0002-3430-5879
e-mail: irishakobilanska@gmail.com
**ПІНАЄВА Ольга –**
кандидат педагогічних наук, доцент,
доцент кафедри педагогіки і освітнього менеджменту
Вінницького державногор педагогічного університету
імені Михайла Коцюбинського
ORCID: https://orcid.org/0000-0002-8829-1388
e-mail: pinolga00@gmail.com

# АКСІОМАТИКО-ДЕДУКТИВНА СИСТЕМА ОНТОЛОГІЙ НА ЗАСАДАХ STEM-ОСВІТИ

*Сталий розвиток суспільства та, загалом, добробут людей забезпечується розвитком техніки, інженерії, математики та інформаційних технологій. Ці сфери потребують спеціалістів, попит на яких стабільно зростає, що робить дослідження розвитку освітнього середовища з використанням STEM-технологій актуальним.*

*Відповідно до сучасних тенденцій розвитку інноваційної парадигми освіти та основні напрями вдосконалення освітнього процесу закладів вищої освіти, розроблена аксіоматико-дедуктивна система онтологій навчання фізики та математики, що ґрунтується на принципах аксіоматики та інформатики на засадах STEM-освіти. Система забезпечує ефективне ознайомлення* *здобувачів освіти з організацією метадисциплінарності логіко-семантичного ядра онтологій, що потрібно для подальшого вивчення дисциплін професійного напряму з урахуванням прикладного аспекту (навчання інжинірингу, радіоелектроніки, електротехніки, основ безпілотних літальних апаратів, робототехніки та інших) і спрямована не тільки на якісне, науково та методично обґрунтоване викладання змісту онтологій, що забезпечується навчальною діяльністю викладача, а й, головним чином, на активізацію самостійної навчально-пошукової діяльності студентів.*

*Гіпотеза дослідження: забезпечення ефективності формування STEM-skills в майбутніх фахівців технічних спеціальностей можливе за рахунок наукового обґрунтування та побудови АДСО, яка сприятиме розвитку готовності до розв'язання професійних завдань у майбутньому.*

*Метою статті є теоретичне обґрунтування аксіоматико-дедуктивної системи онтологій навчання фізики та інформатики на засадах STEM-освіти.*

*Об'єктом дослідження є процес моделювання та розроблення аксіоматико-дедуктивної системи онтологій для навчання фізики та інформатики за вимогами трансдисциплінарності.*

*Предметом дослідження є моделювання, симуляції, онтоорієнтовані інформаційні системи для навчання фізики, інформатики в ЗВО.*

*Авторами виокремлено основні принципи застосування комп'ютерних моделей на заняттях з фізики та інформатики в аксіоматико-дедуктивній системі онтологій на засадах STEM-освіти. Ефективність розробленої аксіоматико-дедуктивної системи онтологій фізики та інформаційних технологій на засадах STEM-освіти підтвердилась експертною оцінкою.*

***Key words:*** *онтології, STEM, фізика та інформатика, система.*

**KUZMENKO Olha –**
Doctor of Pedagogical Sciences, Professor,
Academic Secretary of the Secretariat of the Academic Council
Donetsk State University of Internal Affairs
ORCID: https://orcid.org/0000-0003-4514-3032
email: Kuzimenko12@gmail.com
**DEMBITSKA Sofia –**
Doctor of Pedagogical Sciences, Professor,
Professor of the Department of Life Safety and Safety Pedagogy
Vinnytsia National Technical University
ORCID: https://orcid.org/0000-0002-2005-6744
email: sofiyadem13@gmail.com
**KOBYLYANSKYI Oleksandr –**
Doctor of Pedagogical Sciences, Professor,
Head of the Department of Life Safety and Safety Pedagogy
Vinnytsia National Technical University
ORCID: https://orcid.org/0000-0002−9724-1470
email: akobilanskiy@gmail.com
**KOBYLYANSKA Iryna –**
Candidate of Pedagogical Sciences, Associate Professor,
Associate Professor of the Department of Life
Safety and Safety Pedagogy
Vinnytsia National Technical University
ORCID: https://orcid.org/0000-0002-3430-5879
email: irishakobilanska@gmail.com
**PINAEVA Olga –**
Candidate of Pedagogical Sciences, Associate Professor,
Associate Professor of the Department
of Pedagogy and Educational Management
Vinnitsa State Pedagogical University named
after Mikhail Kotsubynsky
ORCID: https://orcid.org/0000-0002-8829-1388
email: pinolga00@gmail.com

# AXIOMATIC-DEDUCTIVE SYSTEM OF ONTOLOGY BASED ON THE FUNDAMENTALS OF STEM EDUCATION

*Sustainable development of society and general well-being of people is ensured by the development of technology, engineering, mathematics and information technologies. These areas require specialists, the demand for which is steadily growing, this makes the study of the educational environment development using STEM technologies relevant.*

*In accordance with the current trends in the development of the innovative paradigm of education and the main directions of improving the educational process of higher education institutions, an axiomatic-deductive system of ontologies for teaching physics and mathematics has been developed, which is based on the principles of axiomatics and computer science on the basis of STEM education. The system provides effective familiarization of students with the organization of the metadisciplinarity of the logical-semantic core of ontologies, which is necessary for further study of disciplines of the professional direction taking into account the applied aspect (teaching engineering, radio electronics, electrical engineering, the basics of unmanned aerial vehicles, robotics, and others) and is aimed not only at high-quality, scientifically and methodically substantiated teaching of the content of ontologies, which is provided by the teacher's educational activities, but also, mainly, at activating the independent educational and search activities of students.*

*Research hypothesis: ensuring the effectiveness of STEM-skills formation in future specialists of technical specialties is possible due to scientific substantiation and the construction of ADOS, which will contribute to the development of readiness to solve professional tasks in the future.*

*The purpose of the article is the theoretical substantiation of the axiomatic-deductive ontology system of teaching physics and computer science on the basis of STEM education.*

*The object of the study is the process of modeling and development of axiomatic-deductive ontology system for teaching physics and computer science according to the requirements of transdisciplinarity.*

*The subject of the research is modeling, simulations, onto-oriented information systems for teaching physics, informatics in higher education establishments.*

*The authors identified the main principles of using computer models in physics and computer science classes in the axiomatic-deductive system of ontologies based on STEM education. The effectiveness of the developed axiomatic-deductive system of ontologies of physics and information technologies based on STEM education was confirmed by expert evaluation.*

***Key words:*** *ontologies, STEM, physics and informatics, system.*

**Statement and justification of the relevance of the problem.** Education in the epoch of the fourth Industrial Revolution is the driver of social development. Therefore, it acquires the status of a leading institution for the implementation of a consistent state policy, aimed at the activation of innovative processes, in particular digitalization, the introduction of STEM technologies, the development of artificial intelligence, which will interest students in studying physical, technical, engineering disciplines in institutions of higher education.

Taking into account the technological nature of the development, operating knowledge of physics and information technologies based on virtual simulation (use of STEM technologies, robotic kits, elements of a virtual experiment, 3D printing, use of PhET Interactive Simulations, etc.), is the foundation for using the definition of end-to-end generative nature, based on STEM technologies.

**Purpose of the article** is the theoretical substantiation of the axiomatic-deductive ontology system of teaching physics and computer science on the basis of STEM education.

The object of the study is the process of modeling and development of an axiomatic-deductive ontology system (hereinafter – ADOS) for teaching physics and computer science, according to the requirements of the transdisciplinary methodological approach.

The subject of the research is modeling, simulations, onto-oriented information systems for teaching physics, informatics in higher education establishments.

The concept of the study is that the creation of ADOS in physics and informatics is the foundation for the further formation in a new generation of specialists of personal and professional qualities, as well as readiness for the appropriate type of professional activity, taking into account modern trends in the development of STEM education.

The leading idea of the study is the assertion that the formation and development of STEM-skills in future technical and engineering specialists in the process of teaching physics at ADOS is based on the principles of fundamentalization, transdisciplinarity, which ensure in the subjects of training readiness to solve educational tasks, which are necessary for their training in the professional field of study.

The theoretical significance of the expected results is:

1) conducting of theoretical and logical-methodological analysis of the problem of the ontology applicatiom in teaching of physics and computer science on the basis of STEM education;

2) creation and substantiation of ADOS teaching of physics and informatics;

3) development of the methods of physics teaching, using PhET Interactive Simulations.

The practical significance of the expected results is the introduction of physics and computer science on the basis of STEM education into the educational process of ADOS; approval and conducting a pedagogical experimen, regarding the effectiveness of the proposed ADOS.

The following methods were used in the conducted research by the authors: systematic and comparative analysis to justify the relevance and setting of a scientific task regarding the implementation of the ADOS system; methods of the theory of sets, relations and formal systems for building onto-oriented knowledge bases for the development and implementation of the ontology of teaching physics and computer science on the basis of STEM education.

**Analysis of recent research and publications.** Today, the most frequently used and popular are several models of knowledge representation, developed within the framework of the empirical approach, which is based on the study of the principles of human memory organization for modeling problem-solving mechanisms.

Production models – knowledge is represented as a set of facts and rules, based on the production (rule) IF <condition> THEN <action>. By "condition" we mean the pattern according to which the search is carried out in the knowledge base, and by "action" we mean the actions performed as a result of a successful search.

Frame models are defined as a flexible data structure for presenting stereotypical situations that can (or should) be described by a set of concepts and entities.

Logical models of knowledge representation are a structured set of relevant sentences (judgments) of natural language, presented in the form of logical formulas for counting predicates of the first order. The logical model is based on a formal system given in the form: $M= <T, P, A, B>$, where T is a set of basic linguistic elements, P is a set of syntactic rules, A is a set of axioms, and B is a set of derivation rules.

Semantic networks are oriented graphs, the vertices of which reflect some concepts, facts, objects, and the arcs represent relationships between them.

Network models are given in the form $H = <I, C_1, C_2, ..., C_n, G>$, where I is a set of information units; $C_1, C_2, ... , C_n$ – set of types of connections between information units; G is a mapping specifying connections from a given set of connection types between the information units included in I. Common to all semantic networks is a declarative graphical representation that can be used to represent knowledge or create automated decision-making systems based on knowledge.

Ontological models represent the structural specification of knowledge of a certain subject area, their formalized presentation, which contains a structured dictionary of terms of the subject area and logical expressions that describe the relationship between them.

In terms of digitalization, the authors of the study share the opinion of A. Gomez-Perez, M. Fernandez-Lopez, O. Corcho regarding the definition of ontological engineering, which outlines "a set of actions related to the process of developing an ontology, the life cycle of an ontology, methods and methodologies for building ontologies, and as well as sets of tools and languages that support them" [3]. In the scientific study by N. Guarino [4], distinctive and common features of the term "ontology" in use in the philosophical community and by specialists in artificial intelligence were analyzed.

The authors H. I. Zhang, M. Y. Choi proposed an ontology of classical mechanics, which is formulated by dynamic theory, that is an important aspect when considering the motion process for determining definitions from physics, professionally oriented disciplines of technical and engineering profiles [7]. The proposed author`s ontology is based on two processes, regarding the delineation of the concept of "state" and the unification of space, position, momentum into a single entity using Fourier transforms. So, according to this ontology, the assumptions of quantum mechanics (quantum state, Hilbert space and self-adjoint operators) are very easily derived.

Accordingly, comparing the concept of ontology with physical, mathematical and technical sciences, we found interdisciplinary features, which is a significant aspect for revealing the peculiarities of the application of ontology in the educational process of higher education. These features include: hierarchy, conceptualization, structuring, joint use; application of ontology as knowledge structures of STEM education, which will help predict the direction of the development of reality.

**Presentation of the main material of the study.** Taking into account the modern trends in the development of the innovative paradigm of education and main directions, aimed at the improvement of the educational process of higher education, ADOS (Fig. 1.) of teaching physics was created, which is oriented on the principles of axiomatics [1] and informatics on the basis of STEM education, which is aimed at efficient familiarization of the students with organization of the metadisciplinarity of the logico-semantic core of the ontology, required for the further study of professional disciplines, taking into account the applied aspect (teaching engineering, radio electronics, electrical engineering, the basics of unmanned aerial vehicles, robotics) and should be aimed not only at high-quality, scientifically and methodically based content teaching of ontology [5], which is provided by the educational activity of the teacher, but also mainly for the activation of the independent educational and research activities of students.

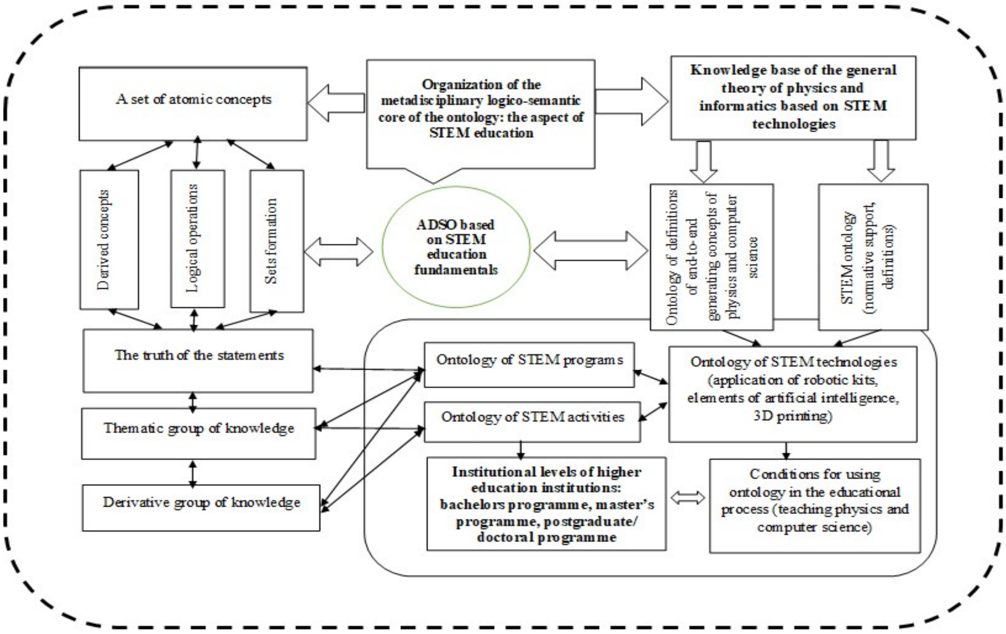


Fig. 1. Model of the axiomatic-deductive system of ontology based on STEM education

Such ADOS should develop and stimulate interest in knowledge and understanding of physics and informatics on the basis of STEM education [2], their application in explaining the phenomena and processes of the microcosm and the surrounding world as a whole, and provide students with an effective system of knowledge, skills and abilities and form natural scientific outlook, form a competitive specialist of the next generation in the conditions of Industry 4.0.

The components of ADOS are interdependent, systemically united and determined by general goals of the educational process of higher education establishment. Change in the quality of these components causes a change in the quality of the innovative educational and scientific space.

The structure of ADSO proposed by the authors on the basis of STEM education (Fig. 1) depends on the psychological and pedagogical factors of its use in the educational process of physics and informatics teaching in conditions of transdisciplinarity [6], namely:

1) formation of motivation for teaching physics and informatics on the basis of STEM education, provided that the subject of the study fully understands the purpose of the experiment (using a set of atomic concepts of ontology, the categorical apparatus of ontology in physics and informatics, theory of sets and graphs, the virtual experiment PhET Interactive Simulations, elements of robotics, unmanned aerial vehicles, etc.);

2) stimulation of cognitive and research activities of the students in the process of studying physics and informatics by means of STEM education (introduction of STEM technologies, digitization, etc.);

3) ensuring compliance with the didactic principles of clarity regarding methods and forms of experimental presentation of educational material in physics classes based on STEM technologies in conditions of transdisciplinarity;

4) individualization of the process of teaching physics and informatics using a virtual physical experiment applying STEM education technologies, as well as the principles of transdisciplinary and synergistic approaches;

5) ensuring openness in the selection of STEM tools for conducting a physical experiment;

6) creation and maintenance of constant feedback between subjects of training, that reduces to a minimum the possibility of making mistakes during the performance of physical practice works using STEM technologies;

6) formation of STEM competencies, using the educational tools, aimed at the development of logical thinking.

The authors developed a methodology for teaching physics and informatics taking into account ADOS on the basis of STEM education, as an example of using the PhET Interactive Simulations program.

PhET Interactive Simulations include research-based practice in effectively teaching material to enhance learning of cross-generative physics concepts. In the author's method of teaching physics and informatics based on the principles of STEM education, the models are intended for the use as lecture demonstrations and physical practice works.

We will consider the determination of gas properties when students of study isoprocesses using PhET simulations.

Gas is pumped into an empty container using a pump. We choose which gas to supply: light (LightSpeciels) and heavy (HeavySpecies). A thermometer and a barometer are installed in the container. In the ConstantParameter function menu, we can choose which isoprocess we use: isobaric (Pressure=const), isochoric (Volume=const) or isothermal (Temperature=const). We will study the properties of gas in a vacuum (Gravity=0).

To demonstrate gas properties, we will use the PhET simulation GasProperties (Fig. 2).

In the second experiment, we will use an isochoric process (V = const). Similarly, we inject 100 particles of heavy gas and 50 particles of light gas. When the container is cooled, the following is observed: a decrease in the speed of particles; decrease in kinetic energy of particles; that as the temperature decreases, the pressure decreases. Conclusion: in an isochoric process, V = const, the value of proportionality of pressure to temperature is a constant value.

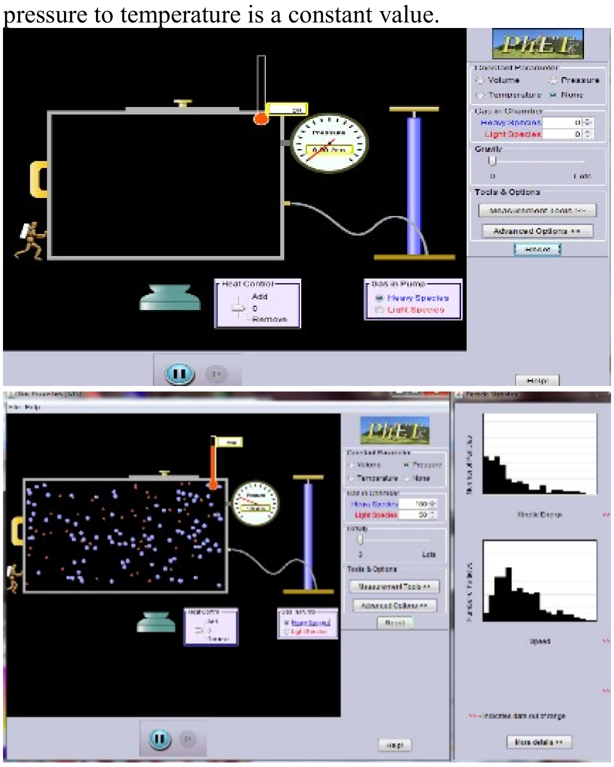


Fig. 2. View of GasProperties simulation

During the third experiment, we will study the isothermal process (T = const). Again, we inject 100 particles of heavy and 50 particles of light gas (Fig. 3).

Thus, the authors singled out the main principles of using computer models in physics and informatics classes at ADSO on the basis of STEM education:

1) the model of the considered physical phenomenon must be used when it is not possible to conduct an experiment or when the phenomenon passes very quickly and cannot be followed in detail;

2) the computer model should help to understand the details of the phenomenon under study, or play the role of illustration of the condition of the problem proposed for solution;

3) as a result of working with a model of a physical phenomenon, installation, process, or equipment, students must identify both qualitative and quantitative the relationships between values characterizing this phenomenon in terms of transdisciplinarity;

4) when working with the model, it is necessary to offer students different levels of tasks using STEM technologies.

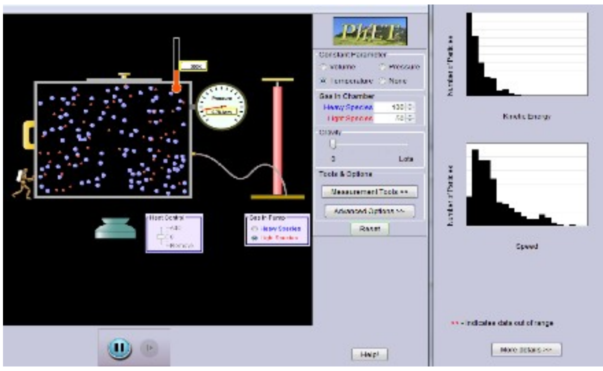

Fig. 3. The container is filled with gas particles during an isothermal process

The effectiveness of the ADOS physics and information technologies developed on the basis of STEM education was confirmed by the expert assessment of the ADOS during the calculation of:

1) the indicator of generalized opinion by finding the arithmetic mean value, dispersion, mean square deviation, coefficient of variation;

2) the degree of agreement of the opinions of experts regarding the significance of the requirements for ADOS was confirmed by the calculation of the concordance coefficient, namely: ontologies of STEM programs (W = 0.045); knowledge bases of the general theory of physics and informatics based on STEM technologies (W = 0.056); sets of atomic concepts (W = 0.0157); ontology of STEM technologies (W = 0.31);

3) the degree of agreement of the experts' opinions was calculated through the coefficient of concordance to the significance of each of the requirements: the average value of the coefficient of the degree of acquaintance, the coefficient of argumentation and the competence of experts.

**Conclusions and prospects for further exploration of the direction.** The authors conducted theoretical and logical-methodological analysis of the problem of using ontology for the teaching of physics and computer science on the basis of STEM education; ADOS was substantiated and created on the basis of STEM as a fundamental factor for education of the students and training of specialists of the next generation; the teaching methodology of physics and informatics using PhET Interactive Simulations was developed and tested. ADOS and the teaching methodology of physics were tested at Donetsk State University of Internal Affairs, Vinnytsia National Technical University and National Center "Small Academy of Sciences of Ukraine", where their effectiveness was noted and a positive assessment was given by the experts.

The performed research does not cover all the aspects of the problem. We see prospects for further research in the substantiation and development of the ESO environment of onto-oriented systems based on STREAM technologies.

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**ВІДОМОСТІ ПРО АВТОРІВ**


**КУЗЬМЕНКО Ольга** – доктор педагогічних наук, професор, учений секретар секретаріату Вченої ради Донецького державного університету внутрішніх справ.

***Наукові інтереси***: професійна підготовка фахівців технічних спеціальностей.

**ДЕМБІЦЬКА Софія** – доктор педагогічних наук, професор, професор кафедри безпеки життєдіяльності та педагогіки безпеки Вінницького національного технічного університету.

***Наукові інтереси***: професійна підготовка фахівців технічних спеціальностей.

**КОБИЛЯНСЬКИЙ Олександр** – доктор педагогічних наук, професор, завідувач кафедри безпеки життєдіяльності та педагогіки безпеки Вінницького національного технічного університету.

***Наукові інтереси***: професійна підготовка фахівців технічних спеціальностей.

**КОБИЛЯНСЬКА Ірина** – кандидат педагогічних наук, доцент, доцентка кафедри безпеки життєдіяльності та педагогіки безпеки Вінницького національного технічного університету.

***Наукові інтереси***: професійна підготовка фахівців технічних спеціальностей.

**ПІНАЄВА Ольга** – кандидат педагогічних наук, доцент, доцент кафедри педагогіки і освітнього менеджменту Вінницького державного педагогічного університету імені Михайла Коцюбинського.

***Наукові інтереси***: професійна підготовка фахівців педагогічних спеціальностей.

**INFORMATION ABOUT THE AUTHORS**

**KUZMENKO Olha** – Doctor of Pedagogical Sciences, Professor, Academic Secretary of the Secretariat of the Academic Council Donetsk State University of Internal Affairs.

***Scientific interests***: professional training of future technical specialists.

**DEMBITSKA Sofia** – Doctor of Pedagogical Sciences, Professor, Professor of the Department of Life Safety and Safety Pedagogy Vinnytsia National Technical University.

***Scientific interests***: professional training of specialists in technical specialties.

**KOBYLYANSKYI Oleksandr** – Doctor of Pedagogical Sciences, Professor, Head of the Department of Life Safety and Pedagogy safety Vinnytsia National Technical University

***Scientific interests***: professional training of specialists in technical specialties.

**KOBYLYANSKA Iryna** – Candidate of Pedagogical Sciences, Associate Professor, Associate Professor of the Department of Life Safety and Safety Pedagogy Vinnytsia National Technical University.

***Scientific interests***: professional training of specialists in technical specialties.

**PINAEVA Olga** – Candidate of Pedagogical Sciences, Associate Professor, Associate Professor of the Department of Pedagogy and Educational Management Vinnitsa State Pedagogical University named after Mikhail Kotsubynsky.

***Scientific interests***: professional training of specialists in pedagogical specialties.

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**ЛАЗАРЕНКО Наталія –**
доктор педагогічних наук, професор, ректор
Вінницького державного педагогічного університету
імені Михайла Коцюбинського
ORCID: https://orcid.org/0000-0002-3556-8849
e-mail: nataliia.lazarenko@vspu.edu.ua
**ВІЗНЮК Інесса –**
доктор психологічних наук, професор, професор
Вінницького державного педагогічного університету
імені Михайла Коцюбинського
ORCID: https://orcid.org/0000-0001-6538-7742
e-mail: innavisnyuk@gmail.com

# ТЕОРЕТИЧНІ ОСНОВИ ПІДГОТОВКИ МАЙБУТНІХ УЧИТЕЛІВ ПОЧАТКОВИХ КЛАСІВ ДО ІННОВАЦІЙНОЇ ДІЯЛЬНОСТІ

*У статті розглянуто теоретичні основи підготовки майбутніх учителів початкових класів до інноваційної діяльності. Досліджено принципи, підходи та методи формування готовності педагогів до впровадження новітніх освітніх технологій, адаптації до змін у сфері освіти та ефективної взаємодії у сучасному освітньому середовищі. Особливу увагу приділено компетентнісному та особистісно орієнтованому підходам, інтерактивним технологіям навчання та організації педагогічної практики. Окреслено значення інноваційної діяльності для розвитку професійної майстерності та підвищення якості початкової освіти.*

*В дослідженні розкрито теоретичні основи підготовки майбутніх учителів початкових класів до інноваційної діяльності, що відповідає динамічним змінам сучасного освітнього середовища. Акцентовано увагу на важливості гармонійного поєднання теорії та практики, що забезпечує здатність педагогів адаптуватися до впровадження новітніх технологій і формувати ефективну взаємодію з учнями. Висвітлено основні характеристики професійної компетентності, визначені дослідниками професійної початкової освіти, а також компетентнісний підхід до освіти. Результати аналізу педагогічного досвіду сприяли створенню моделі формування готовності майбутніх учителів до міжкультурної комунікації.*

*Представлено поетапний підхід до формування готовності майбутніх учителів початкових класів до міжкультурної комунікації в умовах інноваційної діяльності. Розглянуто теоретичну, практичну підготовку та інтеграцію отриманих знань у педагогічну практику. Наголошено на важливості впровадження сучасних освітніх технологій, інтерактивних методів і технологічних карт. Охарактеризовано основні ознаки інноваційної діяльності, такі як розвиток інтересу до навчання, формування особистості учнів та підвищення якості освіти. Висвітлено вплив технічних, навчальних і позанавчальних інновацій на процес навчання.*

***Ключові слова:*** *інноваційна діяльність, теоретичні основи, підготовка вчителів, початкова школа, освітні технології, педагогічна практика, компетентність, адаптація до змін.*