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5 EDUCATION-SCIENCE-VALUES: A TRIPLE HELIX APPROACH TO NANOTECHNOLOGY EDUCATION FOR SUSTAINABLE DEVELOPMENT

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ABSTRACT

The field of nanotechnology has significant prospects for solving global problems of sustainable development. In Ukraine, the need for highly qualified specialists in nanoscience is exacerbated by socio-economic disruptions and the ongoing war, which requires innovative solutions to both new and existing problems.

This chapter explores the conceptual and theoretical frameworks necessary for the effective training of nanoscience professionals in the Ukrainian context, emphasizing the integration of education, science, and values, which is called the education – science – values triple helix. This model is based on the classic "triple helix" theory of collaboration between university, industry and government, complemented by a strong ethical and sustainable orientation. We provide an in-depth analysis of how nanotechnology education can be aligned with the Sustainable Development Goals (SDGs), as well as discuss specific challenges and opportunities in Ukraine's educational environment.

The practical implementation of this integrative educational model is illustrated by the example of Berdyansk State Pedagogical University. This research is addressed to a broad audience, including policymakers, educators, and industry leaders, advocating a collaborative approach to reshaping nanotechnology education to produce not only skilled technologists, but conscious leaders, committed to sustainable progress. Through this framework, we emphasize creating an inclusive, barrier-free and immersive educational environment that engages students in authentic research and innovation while nurturing core values for sustainable development.

KEYWORDS

Nanotechnology, nanoeducation, specialists, higher education, universities, Sustainable Development Goals, immersive education, values, science, innovation, STEAM, NanoArt.

5.1 INTRODUCTION

Due to today's global challenges, the role of new technologies in stimulating sustainable development is becoming increasingly important. Among these technologies, nanoscience has a unique potential to solve complex problems ranging from energy stability to medical innovation. This is especially relevant in the context of Ukraine, where socio-economic pressures, exacerbated by the ongoing war, require innovative solutions to both immediate and long-term problems. The intersection of nanotechnology with sustainability offers a promising avenue for promoting sustainability and growth in such environments.

The United Nations' Sustainable Development Goals (SDGs) provide a framework for assessing and directing technology's impact on global challenges. Nanotechnology can significantly contribute to many of these goals through applications in clean energy, efficient manufacturing processes, and environmental protection. However, the realization of this potential largely depends on the capabilities of specialists in this field. Thus, the education and training of specialists in the field of nanomaterials science become crucial not only for advancing technological frontiers, but also for ensuring a harmonious combination of these achievements with the principles of sustainability.

In Ukraine, the relevance of such specialists increases due to the ongoing war, which has disrupted the traditional educational and industrial sectors and created an urgent need for fast, adaptive and reliable solutions to both new and existing problems. Despite, or perhaps because of, these challenges, the country presents a unique landscape for rethinking and modernizing educational approaches to nanotechnology. This need brings with it the opportunity to create educational programs that not only meet international standards, but also include a deep understanding of sustainable development, civic responsibility, and the specific needs of Ukraine's recovery and development.

Based on the fundamental concepts of the integration of nanotechnology education with sustainable development, the triple helix of "education – science – values" emerges as a key model. This model reinforces the classic concept of the "triple helix" of university – industry – government relationships, intertwining them with the core values inherent in sustainable development. In the traditional triple helix model, synergies between academia, industry and government drive innovation and technological progress. However, by integrating a value-based approach where ethical considerations, social responsibility and environmental impact are at the fore, the triple helix of education, science and values extends this model to ensure that technological progress has a positive impact on society.

The training of specialists in the field of nanotechnology, especially in the complex context of Ukraine, requires a revision of the educational base, which not only imparts scientific knowledge and technical skills, but also instills a deep commitment to sustainable values. This approach supports an educational system, in which curricula not only meet the latest scientific and technological developments, but also reflect ethical standards and the sustainable development goals. By fostering a value-based educational environment, future nanomaterials professionals have not only the capacity to innovate, but also the vision that their innovations contribute to public welfare and environmental sustainability. This holistic approach to learning aims to produce professionals who are not only proficient in their technical fields, but also committed advocates of sustainable development, capable of driving transformational change in both local and global contexts.

The central discussion in this article is the creation of an immersive, inclusive and barrier-free educational environment that will allow future specialists in the field of nanomaterials science to deeply engage in real scientific research and innovative activities. Such an environment is necessary to overcome traditional barriers to education, such as physical disabilities, socioeconomic status, or geographic location, ensuring future professionals have access to high-quality training and resources. This inclusive approach not only fosters a diverse community, but also enriches the research and innovation landscape by incorporating a wide range of perspectives and ideas.

In an immersive educational environment, students are not passive recipients of knowledge, but active participants in their educational process. They participate in hands-on projects and collaborative research initiatives that solve real-world problems, bridging the gap between theoretical knowledge and practical application. This direct involvement in research and innovation instills a strong sense of responsibility and ethical behavior, aligning their scientific pursuits with sustainable values. By fostering these values in an environment that emphasizes inclusiveness and hands-on participation, academic institutions can effectively prepare nanoprofessionals to lead with integrity and foresight, advancing technology progess with a conscientious approach to global and local issues.

This article aims to explore how Ukraine can harness the transformative power of nanoscience to achieve its sustainable development goals while overcoming the challenges, posed by the current crisis. We will delve into the conceptual and theoretical foundations that support training in the field of nanomaterials science, consider the practical implementation of these ideas using the example of Berdyansk State Pedagogical University, and propose effective strategies to improve the alignment of nanoscience education with the imperatives of sustainable development. Through this multifaceted research, we aim to contribute to a broader understanding of how specialized nanotechnology education can catalyze sustainable development under significant socio-political and economic pressure.

The significance of this study goes beyond the Ukrainian context, serving as a model for other countries seeking to improve their technological education systems under similar constraints. The insights in this article are critical for policymakers, academics, and industry leaders around the world navigating the intersection of technology, education, and sustainability. By adopting the strategies discussed, they can produce a generation of professionals who are not only capable of driving technological innovation, but also have a keen understanding of its wider impact on society and the environment.

Ultimately, this article is addressed to academic researchers, science and technology educators, government officials, and industry stakeholders. It is a call to action for these groups to collaboratively redesign and implement educational frameworks that are both innovative in their technological ambitions and deeply integrated with sustainable values. In doing so, the study contributes to the global dialogue about the role of education in achieving a sustainable future, highlighting the important role that specialized training must play in fields such as nanotechnology.

5.2 CONCEPTUAL BASIS OF INTEGRATION FOR NANOTECHNOLOGY AND SUSTAINABLE DEVELOPMENT

5.2.1 A BRIEF OVERVIEW OF THE SUSTAINABLE DEVELOPMENT GOALS (SDGS) AND THE GLOBAL COMMITMENT TO ACHIEVE THEM BY 2030

In 2015, the United Nations General Assembly issued a universal call to action to end poverty, protect the planet and ensure peace and prosperity for all people by 2030. This ambitious agenda is embodied in 17 Sustainable Development Goals (SDGs), which provide a shared blueprint for peace and prosperity for people and planet now and in the future. The SDGs are interconnected and encompass a wide range of social, economic and environmental goals, aimed at creating a sustainable and resilient world [1].

Each goal is accompanied by specific indicators to guide progress and ensure accountability and makes a unique contribution to the global agenda for dignity, peace and prosperity for people and planets now and in the future.

As we cross the equator of the SDG deadline, the urgency for action increases. Success in achieving the SDGs will not only shape the legacy of the current generation, but also determine the well-being of future generations. Global commitment to the SDGs is more than a political promise; the moral imperative is to build a more sustainable, just and stable world for all. Governments, businesses, civil society and individuals around the world are invited to contribute to the realization of this shared vision [2]. Among the key players in this global endeavor are experts in various fields whose expertise and innovation are critical to making progress on the SDGs [3] (**Table 5.1**).

Together, these goals emphasize the need for integrated and innovative approaches where education plays a fundamental role in equipping people with the knowledge and skills they need to participate and contribute to all sectors of society. Through the lens of these goals, the importance of personal development and the societal impact of each specialized field become apparent, underscoring the interconnected nature of global challenges and the multifaceted contributions, needed to address them.

The strategies of this development are closely related, practically intertwined, with the ideas of human development, spread throughout the world. The concept of "human development" assumes that the goal of social progress should be to expand the range of choices and opportunities available to individuals, increasing their potential for personal growth [4]. Three components are monitored – well-being, health and education of a person, which collectively contribute to the growth of human potential as a driving force of sustainable development, its impact on economic and social processes, preservation of the environment and its balanced development. Therefore, sustainable development should ensure the accumulation, preservation and transfer of the potential of spiritual and personal development of a person.

Table 5.1 Description of the sustainable development goals and the role of specialists in their achievement

Goal	Description	Agents of change
1	**2**	**3**
SDG 1 No Poverty	Eradicating poverty in all its forms remains one of the greatest challenges facing humanity	Economic development professionals, together with financial technology innovations, can help create sustainable jobs and improve access to financial services
SDG 2 Zero Hunger	Achieving food security and improving nutrition and promoting sustainable agriculture	Agricultural scientists and technologists play a critical role in developing sustainable agricultural technologies that increase productivity and reduce environmental impact
SDG 3 Good Health and Well-being	Ensuring healthy lives and promoting well-being at all ages are essential for sustainable development	Medical researchers and healthcare professionals are at the forefront of developing new treatments and healthcare technologies
SDG 4 Quality Education	Ensuring inclusive and equitable quality education and promoting lifelong learning opportunities for all	Educators and technology professionals play a key role in developing digital and distance learning solutions that make education more accessible and inclusive
SDG 5 Gender Equality	Achieving gender equality and empowering all women and girls	Sociologists and policy experts have an important role to play in shaping policies that ensure equal opportunities in education and the workplace
SDG 6 Clean Water and Sanitation	Ensuring availability and sustainable management of water and sanitation for all	Environmental engineers and sustainability experts play an important role in developing technologies that improve water consumption efficiency and cleaning
SDG 7 Affordable and Clean Energy	Ensuring access to affordable, reliable, sustainable and modern energy for all	Engineers and innovators in the energy sector play a key role in the development of renewable energy technologies
SDG 8 Decent Work and Economic Growth	Promoting sustainable, inclusive and stable economic growth, full and productive employment and decent work for all	Economists and business leaders play an important role in creating policies and strategies that promote economic development and job creation in high-tech industries

Continuation of Table 5.1

1	2	3
SDG 9 Industry, Innovation and Infrastructure	Building sustainable infrastructure, promoting inclusive and sustainable industrialization and promoting innovation	Industrial development and infrastructure experts are essential to developing technological capacity and building efficient and sustainable systems
SDG 10 Reduced Inequality	Reducing inequality within and between countries	Analysts and policy advocates are critical to ensuring that economic growth benefits everyone and helps reduce inequality
SDG 11 Sustainable Cities and Communities	Making cities and settlements inclusive, safe, stable and sustainable	Urban planners and civil engineers develop solutions that increase the sustainability and stability of cities
SDG 12 Responsible Consumption and Production	Ensuring models of sustainable consumption and production	Environmentalists and business innovators are key to developing sustainable business practices and consumer products mitigation strategies
SDG 13 Climate Action	Taking urgent measures to combat climate change and its consequences	Climatologists and environmental activists are essential to improving understanding of climate change and developing
SDG 14 Life Below Water	Preservation and rational use of oceans, seas and marine resources for sustainable development	Marine biologists and ecologists work to protect aquatic ecosystems and ensure their sustainable use
SDG 15 Life on Land	Protecting, restoring and promoting sustainable use of terrestrial ecosystems, sustainable forest management, combating desertification, and halting and reversing land degradation and biodiversity loss	Conservationists and ecologists are working to preserve terrestrial habitats and biodiversity
SDG 16 Peace, Justice and Strong Institutions	Promoting peaceful and inclusive societies for sustainable development, ensuring access to justice for all and building effective, accountable and inclusive institutions at all levels	Legal and policy experts ensure that governance systems support justice and human rights
SDG 17 Partnerships for the Goals	Strengthening the means of implementation and revitalization of the global partnership for sustainable development	International relations professionals and strategic planners facilitate collaborations that leverage global resources and expertise to achieve the SDGs

5.2.2 BEYOND TRADITIONAL ROLES: THE ROLE OF EDUCATION AND THE SPECIALIST IN ACHIEVING THE SUSTAINABLE DEVELOPMENT GOALS

In the context of sustainable development, the role of a specialist goes beyond traditions, combining personal values, professional skills and civic responsibility [5]. This holistic approach emphasizes the importance of ethical considerations, social responsibility and commitment to the public good alongside technical expertise. In this way, professionals are seen not just as workers in their respective fields, but as informed and engaged members of the global community who share responsibility for achieving the SDGs.

The SDG concept gives education a central role as a catalyst for transformational changes [6]. Universities can play an important role in the implementation of the SDGs, as they have long been powerful drivers of global, national and local innovation, economic development and social well-being [7]. They can help shape new ways of learning for global citizens and spread knowledge and innovation into society, contribute to the achievement of the SDGs through teaching and learning, research, organizational management, culture and action, and external leadership.

Education has the greatest potential that universities can bring to sustainability, and this is reflected in SDG 4 "Quality of Education". Higher education is mentioned in target 4.3, which aims to "ensure equal access for all women and men to affordable and quality technical, vocational and higher education, including university, by 2030". Higher education is also an important part of other goals related to poverty (SDG 1), health and well-being (SDG 3), gender equality (SDG 5), management, decent work and economic growth (SDG 8), responsible consumption and production (SDG 12), climate change (SDG 13) and peace, justice and strong institutions (SDG 16). The Education 2030 Framework for Action (EFA) [8] calls for the reform of the higher education sector through international agreements that establish and regulate teaching and learning activities to be consistent with sustainable development (SD). In addition, this roadmap aims to harness the power of digital tools, open educational resources and online learning to promote access, equity, quality and relevance. Task 4.7 clearly mentions education for sustainable development (ESD) as a type of education that can provide students with important knowledge, skills and attitudes to achieve sustainable development [9].

Universities can be engines of social transformation. They nurture future leaders, professionals and citizens and can guide them towards sustainable development through their educational programs. Thus, the role of higher education in realizing the SDGs lies in its contribution to the transformational transition to sustainability. Sustainability is envisioned as a systemic state that society is constantly trying to define and achieve, guided by the SDGs, and thus the contribution of education is to create favorable conditions for the emergence of this vision [10]. It requires identifying first the competencies, i.e. the knowledge, skills, behaviors and attitudes that learners need to develop to realize such a state, and then the curricula, teaching methods, teacher training programs and learning environments at each level of their development. Although there are general lists of competencies, associated with education programs for sustainable development, the more appropriate choice should be based on the local vision of sustainable development. Thus, educational communities need to develop their own vision of sustainable development in the future, to define the sustainable development competencies, provided by their programs, and to implement the right pedagogy, curricula and assessment to align the favorable conditions for the emergence of such a vision [11]

These learning opportunities cover a wide range of topics, including environmental responsibility, social accountability and economic viability, aligning them with the Sustainable Development Goals. The demand for qualified experts in sustainable development is increasing, which emphasizes the importance of continuous education and training [12].

The integration of Ukraine into the global educational space requires constant improvement of the national education system, which is determined by a number of orders of the Ministry of Education and Science of Ukraine and state regulatory and legal documents, which declare the requirements for the educational process of higher education, professional and pedagogical activities and the personality of teachers of the new generation – the law "On higher education" (2014), the law "On education" (2017), the order of the Ministry of Education and Culture "On the approval of the concept of the development of pedagogical education" (2018), the order of the Ministry of Education and Culture "On the approval of the professional standard for the group of professions "Teachers of higher education institutions"" (2021) and others. In particular, Article 4 "Strategic Priority Areas of Innovation" of the Law of Ukraine "On Amendments to Certain Laws of Ukraine Regarding Priority Areas of Science and Technology Development" emphasizes the development of new materials production technologies, their processing and connection, creation of the industry of nanomaterials and nanotechnologies.

5.2.3 THE ROLE OF NANOTECHNOLOGY IN ADVANCING THE SUSTAINABLE DEVELOPMENT GOALS

Nanotechnology, which is characterized by the manipulation and application of materials at the nanoscale, has a huge potential to revolutionize various sectors and, thus, significantly contribute to the achievement of the Sustainable Development Goals (**Fig. 5.1**). This cutting-edge technology intersects with sustainable development, offering innovative solutions to some of the most pressing global challenges, including environmental degradation, health crises, energy shortages, and more. The unique ability of nanotechnology to work at the atomic or molecular level opens up unprecedented opportunities to improve product functionality and create new materials and processes that are more efficient, less resource-intensive and environmentally friendly.

Nanotechnology has a staggering global impact, marking its presence in almost every industry due to its versatile applications. As the cornerstone of today's technological progress, they are changing the way industries operate, contributing to significant improvements in efficiency, safety and sustainability. This widespread adoption underscores the technology's key role not only in empowering the industry, but also in addressing pressing global challenges. Through its comprehensive integration into various fields, from medicine and agriculture to energy and manufacturing, nanotechnology is recognized as a key factor in achieving sustainable development worldwide.

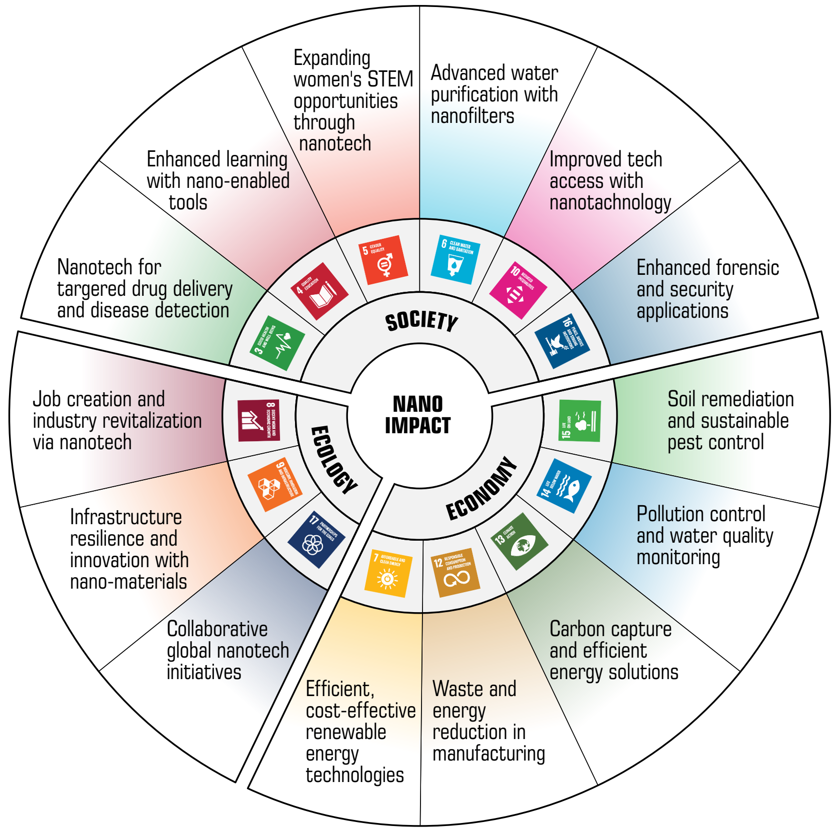

Fig. 5.1 Role of nanotechnology in promoting the sustainable development goals

IMPACT ON SOCIETY

Nanotechnology is greatly improving healthcare by increasing the effectiveness of treatments with targeted drug delivery systems and improving public health monitoring with sophisticated nanodiagnostic tools. These technological advances directly contribute to improvements in global health and well-being. In the field of education, nanotechnology enriches the learning experience by integrating advanced tools and curricula that make education more engaging and effective, thereby preparing students for future technological challenges [13]. In addition, initiatives to promote participation in nanotechnology and STEM fields are crucial to the empowerment of women and girls, helping to close gender gaps in education and employment in high-tech, thus promoting gender equality. The role of nanotechnology extends to strengthening social structures and intensification of global cooperation. Enhanced forensic capabilities and security measures, enabled by nanotechnology, support stronger and fairer institutions and governance systems. In addition, the collaborative nature of nanotechnology research fosters global partnerships, emphasizing the importance of international collaboration between academia, industry and governments. These partnerships are essential for harnessing and sharing knowledge and innovation, which are key to achieving all the Sustainable Development Goals.

ECONOMIC DEVELOPMENT AND INFRASTRUCTURE

In the economic sector, nanotechnology stimulates innovation and productivity, creating jobs and accelerating economic growth, especially in new emerging industries [14]. The development of nanotechnological materials increases the sustainability and efficiency of infrastructure, which is important for sustainable industrialization. These materials and technologies also help build smarter and more sustainable cities, optimize energy use, and reduce urban pollution. By making basic technologies more accessible, nanotechnology plays a critical role in reducing inequality, allowing diverse communities to benefit from technological progress.

ENVIRONMENTAL SUSTAINABILITY AND RESOURCE EFFICIENCY

The impact of nanotechnology on environmental sustainability is crucial, from improved water treatment systems to increasing the efficiency of renewable energy sources, such as solar panels and fuel cells. These technologies help minimize the impact of production processes on the environment, aligning them with the goals of responsible consumption and production [15]. In addition, nanotechnology helps climate action and initiatives by providing effective solutions for carbon sequestration and environmental monitoring, which is crucial to mitigating the effects of climate change. Protection of aquatic and terrestrial ecosystems is also enhanced by nanomaterials that remove pollutants and improve soil health, supporting the sustainability of life below water and on land.

With this broad impact, nanotechnology not only solves specific technical problems, but also fundamentally supports the integration of sustainable development into global industries and societies. Their diverse applications highlight the potential as a key engine for achieving a sustainable and just future, demonstrating how deeply intertwined technological progress is with societal progress.

5.2.4 SPECIALISTS IN THE FIELD OF NANOMATERIALS SCIENCE AS AGENTS OF CHANGE TO ACHIEVE THE SUSTAINABLE DEVELOPMENT GOALS

Nanomaterials scientists play a critical role in sustainable development, offering innovative solutions that could lead to breakthroughs in energy efficiency, medical treatment, water purification, and more. Their contribution is not limited to the direct application of experience, but extends to influencing policy, educating future generations and fostering a culture of sustainable development within their spheres of influence.

Nanotechnology is by its very nature a multidisciplinary field that synthesizes knowledge from a multitude of disciplines spanning the technical, natural, social, and political spheres. This integration is vital because it enables the development of innovative solutions that can be effectively applied to real-world problems across sectors.

Applicants of higher education in the specialty 105 Applied physics and nanomaterials are able to perform professional work according to DC 003:2010, such as: 21 Professionals in the field of physical, mathematical and technical sciences, 2111 Professionals in the field of physics and astronomy, 2111.1 Scientific employees (physics, astronomy), 2310 Teachers of universities and higher educational institutions, 2310.2 Assistant, 2310.2 Teacher of a higher education institution, 2320 Teacher of a vocational and technical educational institution, 31 Technical specialists in the field of applied sciences and technology, 3111 Laboratory assistants and technicians related to chemical and physical research.

5.2.4.1 INTEGRATION BETWEEN DISCIPLINES

At its core, nanotechnology draws heavily from the technical and natural sciences, including physics, chemistry, biology, and engineering. These fundamental sciences allow nanomaterials specialists to manipulate matter at the molecular and atomic levels, creating materials and devices with improved properties and functions. In addition, the industry relies increasingly on computer science and information technology, as nanoscale devices often require complex algorithms to operate and manage data.

In addition, the application of nanotechnology often extends to the field of medical and pharmaceutical sciences, especially in drug delivery and diagnostics, closely linking them to health care and bioengineering. Environmental science is another important field where nanotechnology is used for pollution control, water purification and sustainable energy solutions.

However, the scope of application of nanotechnology is not limited to scientific and technical disciplines. It also covers the social sciences, ethics and policy making. The societal implications of nanotechnology implementation, such as privacy issues with nanosensors or the health effects of nanoparticles, require careful study and understanding by sociologists and ethicists. Political science also plays a role, particularly in shaping the policies that govern the use, dissemination, and ethical considerations of nanotechnology developments.

5.2.4.2 THE NEED FOR UNIQUE COMPETENCIES

Given this wide and diverse canvas, specialists in the field of nanomaterials science must possess a fundamentally unique set of knowledge, skills, abilities and competencies. They need solid training in many scientific disciplines, combined with the ability to apply that knowledge to practice in innovative ways. Critical thinking and problem-solving skills are essential, enabling them to develop solutions that are not only effective, but also sustainable and ethically sound.

Flexibility in learning and adaptability are also key attributes for these professionals. Nanotechnology is a rapidly evolving field where new discoveries and technologies are constantly changing the landscape. Therefore, specialists must maintain a constant passion for science and openness to constant learning and adaptation. Additionally, given the potential global impact of their work, these professionals need strong communication and collaboration skills to work effectively across disciplines and cultures. They must be able to navigate a complex regulatory environment and understand the implications of their work for society, ensuring responsible research and innovation.

5.2.4.3 CHANGING EDUCATIONAL PARADIGMS

The training of such uniquely qualified specialists is a serious challenge and requires a change in educational paradigms. Traditional education systems, often segregated by discipline, must evolve to foster interdisciplinarity by integrating courses that allow students to acquire knowledge in multiple scientific fields and their applications. This integration should be complemented by problem-based learning where students solve real-world problems using an interdisciplinary approach, thus developing practical skills alongside theoretical knowledge.

Institutions of higher education should also emphasize ethical learning and social awareness, preparing students to consider the broader implications of their work for society and the environment. This holistic approach to education is essential for educating the next generation of nanotechnologists who are not only knowledgeable in their technical fields, but are also conscious global citizens ready to contribute to the sustainable development and improvement of society.

Thus, the training of specialists in the field of nanotechnology is not only about the transfer of knowledge, but also about the formation of innovators and those who solve the problems of tomorrow, who are versatile, ethical and ready to overcome the challenges of a changing world.

5.2.4.4 ACHIEVING THE SDGS THROUGH THE CONTRIBUTION OF SPECIALISTS IN THE FIELD OF NANOMATERIALS SCIENCE

Achieving the SDGs through the contribution of professionals requires a paradigm shift in education and training. There is a growing need for programs that not only impart technical knowledge, but also foster the development of communication skills, ethical reasoning, and understanding of global challenges. Integrating SDG-related content into curricula can inspire students to apply their knowledge to achieve societal impacts, equipping the next generation of professionals with the competencies, needed to effectively promote sustainable development.

The standard of higher education in the specialty 105 "Applied physics and nanomaterials" for the first (bachelor's) level of higher education provides for the achievement by students of higher education of the learning result as "Knowing the sustainable development goals and the possibilities of one's professional sphere to achieve them, including in Ukraine" , which is ensured by mastering a number of competencies: GC 6 The ability to conduct research at the appropriate level; GC 11 The ability to realize one's rights and responsibilities as a member of society, to realize the values of civil (free democratic) society and the need for its sustainable development, the rule of law, the rights and freedoms of a person and a citizen in Ukraine; GC 12 The ability to preserve and multiply moral, cultural, scientific values and achievements of society based on understanding the history and patterns of development of the subject area, its place in the general system of knowledge about nature and society and in the development of society, technique and technology, to use different types and forms of motor activity for active recreation and leading a healthy lifestyle; GC 1 The ability to participate in the planning and implementation of scientific and technical projects; GC 8 The ability to work in teams of performers, including in interdisciplinary projects.

Therefore, training a specialist in nanotechnology for sustainable development involves a comprehensive educational approach that integrates interdisciplinary knowledge and practical skills. To meet the growing demand for qualified professionals in the field of nanomaterials science, educational programs must focus on the development of competencies that combine different fields and prepare to solve current societal problems through interdisciplinary collaboration.

5.2.5 CHALLENGES AND OPPORTUNITIES: TRAINING SPECIALISTS IN THE FIELD OF NANOMATERIALS SCIENCE IN UKRAINE IN NEW REALITIES

The war, started by Russia against Ukraine, vividly emphasized the critical importance of the development of technological sectors [16]. This conflict exposed the vital role that high-tech industries play in a nation's resilience and recovery, highlighting the connection between national security, sustainable development, and technological progress. Amidst the daily challenges of constant shelling, infrastructure destruction, and resource scarcity, Ukraine's ability to maintain its competitiveness and defense capabilities, not to mention develop its technological prowess, is being severely tested.

The demand for high-tech solutions, including portable solar cells, thermal imagers and night vision devices, has increased dramatically, highlighting the urgent need to improve the nanomaterials [17], required for modern electronics. Despite a strong scientific potential capable of leading significant developments in the industrial sector, Ukraine faces a significant shortage of specialists able to navigate complex high-tech industries. The training of such specialists requires significant resource investments, including highly qualified teaching staff, a modern technical base, uninterrupted access to engineering communications and connection to complex operations – resources that are currently in short supply [18, 19].

The role of nanotechnology in post-war reconstruction and strengthening of national security is enormous, but current educational and infrastructure problems create significant obstacles [20, 21]. The war not only led to the physical destruction of educational institutions, but also led to the transition to online education, the mass migration of university teachers and students, the dispersion of communities and significant educational losses [22, 23].

This contradiction between the acute need for high-tech specialists and the expediency of their training in modern conditions requires a paradigm shift in education. The war necessitates the study of new educational models capable of withstanding the pressure of the military, energy, environmental, and information crises [24]. Innovative approaches are necessary to ensure continuous training of specialists, using both synchronous and asynchronous learning technologies to adapt to the limitations of distance education [25].

As Ukraine goes through these turbulent times, the need to develop a sustainable and competitive high-tech industry in the post-war period is becoming increasingly apparent. The way forward requires a concerted effort to meet current challenges through innovation and adaptability in education and technology. Thanks to this, Ukraine can not only recover from the devastation of the war, but also secure a sustainable and prosperous future, underscoring the indelible link between technological progress and national resilience.

5.3 THEORETICAL BASIS: FRAMEWORK AND COMPETENCIES FOR TEACHING NANOTECHNOLOGY

5.3.1 MODERN EDUCATIONAL PARADIGMS FOR TRAINING SPECIALISTS IN THE FIELD OF NANOMATERIALS SCIENCE

The need to understand education as a social phenomenon, designed to solve certain tasks of society, in particular regarding the achievement of the SDGs, requires a thorough study of the existing educational paradigms in it. The modern *competence paradigm* of education is practically oriented (being competent means able to make adequate decisions in life and professional activity) in accordance with the values of a society of sustainable development [26].

Education needs to be modernized in the context of the requirements and opportunities of the 21st century. Since ideas and technologies change faster than generations of people, first of all it is necessary to ensure *high functionality of a person* in various, often unpredictable conditions. Secondly, it is necessary to find *rational schemes of the relationship between the development of knowledge, technologies and the ability of a person to creatively assimilate them*. Thirdly, in the conditions of globalization, it is very important to ensure an optimal *balance between the local and the global*, so that a person, as a patriot of his/her country, is aware of the realities of the globalized world, bears responsibility for it, that is, he/she is both a citizen of the country and a citizen of the world, and at the same time to form a social and at the individual level of understanding a person as the highest value that has the right to be him/herself. Fourth, in the realities of the information society, it is necessary to develop *people's communicative abilities*, to cultivate high spiritual ideals in each person based on constructivism as a way of life, to affirm the culture of tolerance and acceptance of representatives of other cultures.

Innovative education is also global education, which should contribute to the acquisition of cross-cultural literacy based on knowledge of one's own national culture and the formation of relationships with people from the standpoint of universal values. Global education in its humanistic aspect gives an individual more opportunities for successful and competent activity at the global level, helping everyone become a "person of the world" [27]. At the same time, innovative education should be aimed at fostering a new promising type of tolerant worldview, the main attribute of which is the perceived right to one's own point of view without limiting the interests of other people and a high level of personal responsibility.

Innovations in the field of higher education, aimed at the formation of the personality of a professional, his/her ability to scientific, technical and innovative activities based on social order, renewal of the content of the educational process, professional and creative activities, are gaining the greatest relevance. In the field of nanomaterials science, training specialists who are not only skilled, but also adaptive and innovative is critically important. This requires the transformation of educational paradigms in higher education, the transition to more dynamic and flexible models that effectively meet the needs of professional activity and societal demands. The transition to innovative education in the field of nanomaterials science focuses on the development of a holistic personality of a professional, increasing his/her ability to participate in scientific, technical and innovative activities [28].

A key aspect of this educational transformation is the formation of versatile cooperation and personal contacts. By creating a collaborative environment, educational institutions encourage students to network with peers, educators, and industry professionals. This collaboration is not limited to the academic realm, but extends to joint projects with research institutions and industries, enriching students' practical experiences and influencing real-world challenges.

Another fundamental shift is the individualization of educational trajectories. Allowing students to tailor their educational path to their personal interests and career goals enables them to specialize in nanotechnology areas most relevant to their future roles. This setting not only increases the engagement and motivation of students, but also ensures the direct application of acquired skills to the demands of the labor market and scientific innovations.

Increasing the efficiency of individual creative work is also of crucial importance. Educational paradigms that promote independent inquiry and project-based learning encourage students to develop critical thinking and problem-solving skills.

Optimizing course content to keep pace with the latest industry advances ensures that students are well prepared to enter the professional environment. Regular updating of the curriculum and the introduction of advanced topics in nanomaterials science are important to maintain the relevance and effectiveness of the educational program.

Another important component is increasing the volume of independent work. It encourages students to develop self-directed learning skills that are vital for continued professional development and success in their future careers. This approach promotes an active attitude to learning and discovery, which is important in the science-intensive field of nanotechnology.

In addition, education should adapt to the intellectual qualities and learning styles of individual students. Such personalization of the learning process maximizes educational outcomes and helps students reach their full potential by matching learning methods to individual learning preferences and intellectual abilities.

Finally, ensuring program flexibility is critical to adapting to the rapid changes that characterize the nanotechnology sector. Flexible educational programs allow for the rapid integration of new scientific discoveries and technological advances into the curriculum, thus keeping education relevant and comprehensive.

By integrating these elements into nanomaterials science educational paradigms, higher education institutions can educate a new generation of nanomaterials specialists who are not only technically proficient, but also versatile, innovative, and well-prepared to contribute to sustainable development through their work. This holistic approach to education is vital to preparing students to meet the challenges of tomorrow and succeed in the globalized world of nanotechnology.

A modern global strategic trend is the formation of *a dynamic concept of education* in the interests of sustainable development, the implementation of which occurs through the integration of its topics into all academic disciplines, as well as the organization of special thematic programs [29].

A special role in this case belongs to higher education, where scientific work is combined with educational work, there is a powerful personnel scientific and pedagogical potential, an appropriate educational base. It is here that the training of specialists of the new generation, along with the assimilation of purely professional knowledge, should focus on finding ways and means of balanced development both in terms of outlook and in relation to a specific field of activity.

In higher education, there is an opportunity to introduce *the topic of sustainable development* into almost all aspects of the educational process. The first task is to introduce the issue of sustainable development into the educational programs of training students of higher education. Since the state regulates the normative part of education (through approved educational standards), it is suggested to start with making changes to the relevant disciplines taught (additional sections, arrangement of accents, etc.), as well as introducing a new academic discipline into the variable component of educational programs. In addition, it is considered appropriate to actively involve students of higher education in scientific and innovative activities, the result of which should be certain positive shifts in consciousness, the formation of new approaches, the acquisition of skills and concrete steps in the advancement of sustainable development of society.

Therefore, the ideas of sustainable development of society should take their place in the training of future specialists in the field of nanoscience and technology. To achieve efficiency, it is necessary:

– integration of education for sustainable development into educational disciplines, programs and courses;

– organization of separate courses and programs on sustainable development;

– dissemination of positive experience in education, which will contribute to changes in behavior in favor of sustainability;

– strengthening of the cooperation and partnership with other process participants;

– promotion of the understanding of the essence of global, national and environmental problems with an emphasis on their socio-economic consequences;

– introduction of new approaches to education.

5.3.2 DEFINITION OF PROFESSIONAL EXCELLENCE: BASIC SKILLS AND COMPETENCIES FOR SPECIALISTS IN THE FIELD OF NANOMATERIALS SCIENCE

The taxonomy of sustainable development competencies is based on the following categories [31]:

– understanding of sustainability;

– critical and creative thinking skills, as well as systemic thinking, empathy and interdisciplinary cooperation;

– attitude, which means commitment to sustainable development, respect for past, present and future generations.

Based on the above analysis of educational paradigms, regulatory frameworks and the taxonomy of sustainable development, we can specify the skills that specialists in the field of nanomaterials science need to effectively promote sustainable development:

– knowledge in the field of nanoscience and nanotechnology: understanding the principles and applications of nanoscience and nanotechnology is fundamental for specialists in the field of nanoscience;

– characterization and analysis of materials: the ability to characterize and analyze materials at the nanoscale is essential for nanoscience professionals to effectively study and manipulate nanomaterials;

– design and selection of materials: the ability to design and select materials at the nanoscale is crucial for the development of innovative solutions and the creation of new materials with specific properties;

– processing and fabrication of materials: competence in processing and fabrication of nanomaterials is necessary for nanoscience specialists to produce nanoscale devices and structures;

– interdisciplinary understanding: nanotechnologists must have a strong interdisciplinary understanding, as nanotechnology is an interdisciplinary field that requires knowledge from various disciplines, such as physics, chemistry, biology, and engineering;

– ethical awareness: understanding the ethical implications of nanotechnology is critical to ensuring responsible development and addressing societal issues related to health, safety and environmental impact;

– innovative problem solving: nanotechnologists must possess strong problem-solving skills to develop innovative solutions to sustainable development challenges in areas, such as health, water treatment, agriculture and energy;

– risk management: knowledge of risk assessment and risk management is essential to address the potential health and environmental risks, associated with the use of nanotechnology;

– collaboration and communication: effective collaboration with experts from different fields and clear communication skills are vital to the successful integration of nanotechnology into sustainable development efforts.

That is, for nanomaterials professionals seeking to make an effective contribution to sustainable development, a specific set of competencies is critical to navigating the complexities of their field while contributing to long-term global sustainability. These competencies provide them with the necessary tools to innovate and apply nanotechnology solutions that are environmentally safe, socially responsible, and economically viable.

Systems thinking competence is essential for nanomaterials scientists because it enables them to understand and manipulate materials at the nanoscale within larger environmental, economic, and social systems. This holistic view is critical to ensure that nanotechnology innovations contribute positively to sustainable development without unintended consequences.

Future thinking, or predictive competence, prepares future nanomaterials professionals to predict the consequences of their innovations. Given the rapid development of nanotechnology, the ability to anticipate and mitigate the potential risks, associated with new materials and technologies, is vital for responsible development and implementation.

The competence of strategic thinking allows specialists in the field of nanomaterials to develop long-term strategies that meet the sustainable development goals. It involves planning and executing projects in a way that optimizes the use of resources, minimizes environmental impact and maximizes benefits for society.

The competence of interpersonal communication or cooperation is especially important in the interdisciplinary field of nanotechnology. Nanomaterials scientists must collaborate effectively with other scientists, engineers, policymakers, and industry leaders to ensure that nanotechnology developments are scalable, sustainable, and responsive to the diverse needs of society.

Integrated problem-solving competence is critical for nanomaterials professionals to apply their technical knowledge and innovation skills to real-world problems. This competency involves synthesizing information from various sources and disciplines to develop solutions that effectively address specific sustainable development challenges.

Finally, **value thinking, or normative competence**, is indispensable for professionals in the field of nanomaterials science. This competency involves thinking about the ethical implications of their work, integrating sustainability values into research and development, and considering the wider impact of nanotechnology on society and the environment. This ensures that nanomaterials professionals not only pursue innovations that are technically feasible and economically viable, but are also socially just and environmentally sound.

Thus, *the competencies* of specialists in the field of nanomaterials science constitute a complex set of *knowledge, skills and values* that are crucial for effective promotion of sustainable development. This suite combines deep technical knowledge with a broad understanding of the social, ethical and environmental implications of nanotechnology.

The multifaceted nature of these competencies reflects the complex interaction between nanotechnology and sustainable development. Professionals who possess this diverse skill set are uniquely positioned to deliver innovations that not only push technological boundaries, but also enhance societal well-being and environmental stewardship. This integrated approach ensures that advances in nanomaterials science positively impact both current and future generations, balancing technological progress with the need to preserve and develop the global ecosystem.

Essentially, the competencies, required of nanomaterials specialists, encompass not only mastery of scientific and technical disciplines, but also the development of strategic, ethical, and collaborative skills. These professionals must navigate an environment where interdisciplinary knowledge is combined with the commitment to sustainable development, making them key figures in achieving the global goals of sustainable development. Their role is not only to function within their technical domains, but also to act as bridges connecting science to the wider needs of society, thus embodying the true spirit of innovation in the service of humanity.

5.3.3 HARMONIZATION OF THE VALUES OF NANOTECHNOLOGY EDUCATION WITH THE SUSTAINABLE DEVELOPMENT GOALS

Values play a special role in the training of nanotechnologists. According to Leiserowitz et al. [32]:

"Values are abstract ideals, such as freedom, equality and sustainability. They often evoke emotional responses and are usually expressed in terms of "good" or "bad", "better" or "worse", "desirability" or "avoidance". Values define or guide us toward goals, shape our attitudes, and provide standards, by which to measure the behavior of individuals and society. Attitude refers to the assessment of a particular object, quality or behavior as good or bad, positive or negative. Attitudes often derive from and reflect abstract values. Finally, behavior refers to specific decisions and actions, taken by individuals and groups, often based on core values and attitudes".

There are many studies that support how personal well-being, curiosity, empathy, kindness and non-materialistic values are associated with more sustainable behavior [33, 34].

For example, Mearns and Norton defined the role of values for sustainable development [35]:

"Sustainability really boils down to nurturing and combining values, beliefs and behaviors with environmental stewardship and collective responsibility. Through our everyday choices, we can choose to either improve or weaken the planet, our society, and our commercial wealth. Based on this, a global attitude to the values of the Millennium Declaration involves freedom and democracy, justice, solidarity, acceptance, respect for nature and shared responsibility".

Pappas research defines "individual sustainability" as follows [36]:

"Sustainable individuals are characterized by creating harmony, interconnectedness, and a relatively high level of self-awareness in their values, thoughts, behaviors, and actions, as well as by cultivating continuous individual growth in their physical, emotional, social, philosophical, and intellectual abilities. Individual sustainability involves having a well-developed and demonstrated value system that recognizes the importance and interconnectedness of all global biological and social systems and our appropriate place within them".

Cultivating core values in future nanomaterials science professionals is imperative to fostering sustainable development in the field of nanomaterials science. This necessity arises from the profound influence of values on attitudes and behavior, which in turn shape professional practice and interaction with society and the environment.

Values, such as freedom, equality, sustainability and respect for nature, are not just abstract ideals; they evoke strong emotional responses and direct people toward certain behaviors and goals. For specialists in the field of nanomaterials science, these values become the standards, by which they evaluate their professional behavior and the impact of their innovations. As highlighted in various studies, values related to personal well-being, empathy and care for the environment are associated with sustainable behavior, which is crucial in the context of the potential impact of nanotechnology on the environment and society.

The role of values in sustainable development is mainly to nurture and combine these ethical principles with environmental responsibility and collective responsibility. Armed with a value system that emphasizes interconnectedness and harmony, nanomaterials professionals can make decisions that not only advance technological progress, but also enhance societal well-being and the health of the planet.

Therefore, to effectively promote sustainable development, specialists in the field of nanomaterials science must embody what can be called "individual sustainability" [37]. This concept involves a deep alignment of values, thoughts, behaviors and actions that promote continuous personal growth along with commitment to global biological and social systems. A well-developed and actively demonstrated value system allows these professionals to understand and fulfill their roles in these systems thoughtfully and responsibly.

When defining a value system for nanomaterials specialists, it is extremely important to integrate these principles at every level of education and professional training. This integration ensures that future professionals not only possess the scientific and technical skills necessary for their field, but are also guided by a strong ethical compass. The development of such a value-based framework is essential to ensure that nanotechnology advances contribute positively to sustainable development, reflecting a balance between innovation and ethical responsibility, between individual achievement and collective well-being (**Fig. 5.2**).

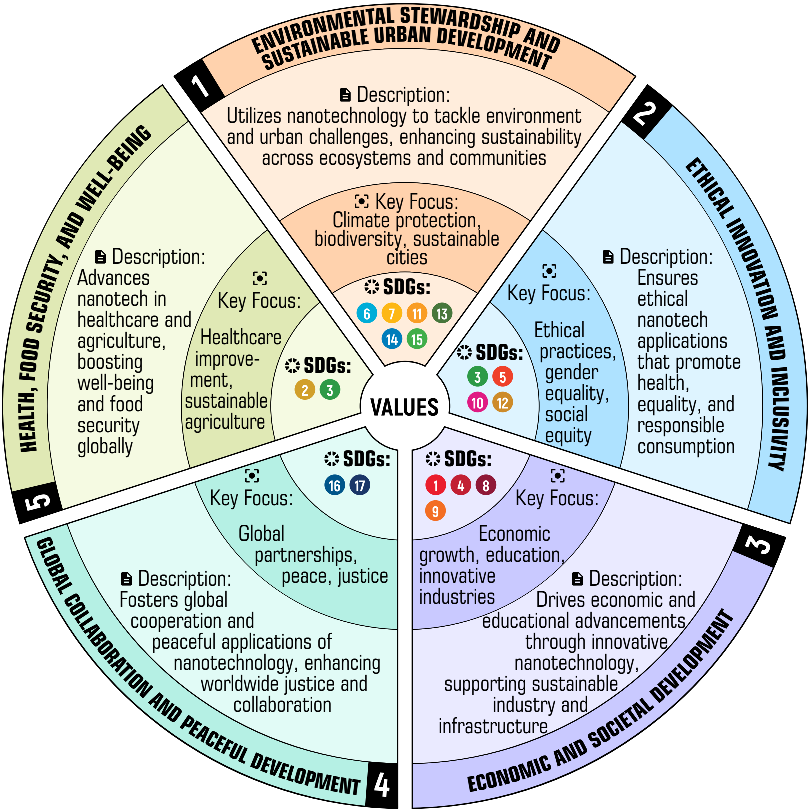

Fig. 5.2 Framework of values of a specialist in the field of nanomaterials science for achieving the sustainable development goals

By learning these values, aligned with the global sustainable development goals, future specialists in the field of nanomaterials science not only enrich their professional development, but also make a significant contribution to solving global problems. This not only fulfills the expectations of stakeholders in the immediate context, but also aligns the field of nanotechnology with broader humanitarian and planetary goals.

5.3.4 INTEGRATION OF SCIENTIFIC FOUNDATIONS IN NANOTECHNOLOGY EDUCATION

Education in the field of nanotechnology is inextricably linked to the promotion of the sustainable development goals, with a special emphasis on the inclusion of a reliable scientific component in the curricula of future specialists in the field of nanomaterials science. This approach is vital because nanotechnology is one of the most science-intensive fields, and the ability to develop sustainable innovative solutions depends on a deep understanding of complex scientific principles and methodologies.

For future specialists in the field of nanomaterials science, it is very important that their curriculum is saturated with rigorous scientific training from the very beginning of their studies. This immersion should not be limited to traditional learning models, but should extend to dynamic hands-on experience in state-of-the-art laboratories [38]. Active participation in advanced scientific projects allows students to apply theoretical knowledge in practice, improving the learning process and preparing them for real challenges.

In addition, educational programs should facilitate regular interaction with industry leaders and experts through guest lectures, seminars and conferences. Such engagements provide students with invaluable insight into the latest developments and trends in nanotechnology and environmental practices. These opportunities not only broaden their understanding, but also inspire innovative thinking and problem-solving approaches.

Another important element of this educational strategy is to ensure that students have access to the best laboratories. Not every university can afford advanced research tools and technologies. Therefore, exploring student internship opportunities and partnering with institutions that have these opportunities becomes vital. Such collaborations can provide hands-on experience and exposure to cutting-edge experimental work, positioning students at the forefront of technological progress. Providing access to state-of-the-art laboratories, whether physically or virtually, ensures that students are properly prepared to contribute to future innovations in the industry. This experience not only improves their practical skills, but also deepens their understanding of complex scientific concepts, which is crucial for their future careers in nanotechnology.

In addition, by encouraging collaboration with interdisciplinary teams within academic institutions and professional networks, students can gain a more comprehensive understanding of how nanotechnology intersects with different sectors, such as healthcare, agriculture and energy. This broad perspective is essential for developing technologies that are not only scientifically sound, but also socially acceptable and aligned with the global sustainable development goals.

Thanks to these comprehensive educational strategies, future specialists in the field of nanomaterials science become not just education seekers, but also active participants in the formation of new scientific approaches and the promotion of sustainable development. This proactive involvement in scientific discovery and application is critical to fostering well-rounded professionals who are ready to address tomorrow's challenges with innovative solutions that benefit society and the environment.

5.3.5 IMMERSIVE EDUCATIONAL ENVIRONMENT: THE BASIS OF A COMPLEX ECOSYSTEM FOR TRAINING SPECIALISTS IN NANOMATERIALS SCIENCE

IMMERSIVE EDUCATIONAL ENVIRONMENT

When developing a reliable system of training specialists in the field of nanomaterials science, it is important to base the educational environment on three main components: education, science and values. The unity and seamless integration of these components into educational plans is critical to creating an immersive educational environment. This integration ensures that each aspect is not taught in isolation, but as interconnected elements that enhance the student's learning experience and understanding.

The Venn diagram, shown in **Fig. 5.3**, illustrates how each sector uniquely contributes to the development of a profession that is well-equipped to innovate in the field of nanomaterials science while making a positive contribution to sustainable development.

At the intersection of education and science, "Innovative Problem-Solving" becomes a key direction that marks the integration of traditional learning with advanced scientific practice. Here, the educational model encourages not only the acquisition of knowledge, but also its innovative application. This combination of concepts fosters the ability to approach complex problems with new solutions and is an integral part of the field of nanotechnology, where the problems we face require not only analytical thinking, but also creative breakthroughs.

Where science meets values, the focus is on "Ethical Responsibility", emphasizing the important role of ethical considerations in scientific work. Nanomaterials scientists must navigate the ethical dimensions of their research, balancing technological advances with considerations of public health, safety, and environmental impact. This point underscores the need for a value-based approach to research that prioritizes accountability at every stage of discovery and application.

The intersection between education and values provides "Commitment to the Global Goals of Sustainable Development", which reflects the integration of sustainable development principles into educational content. Training specialists in the field of nanomaterial science is not just the transfer of knowledge; it is about fostering a sense of care for the planet and striving to solve the grandiose tasks, outlined in the UN Development Goals. This commitment ensures that the nanotechnologists of tomorrow are not only skilled, but also committed to applying their skills to global sustainable development efforts.

At the center of all three circles is the "Specialist", a professional who embodies the integration of education, scientific acumen and a strong value system. Such specialists are not only capable of conducting cutting-edge research and developing innovative technologies, but also deeply aware of the wider impact of their work. They are ready to make a significant contribution to their field, conscientiously approaching the broader goals of societal development and environmental preservation.

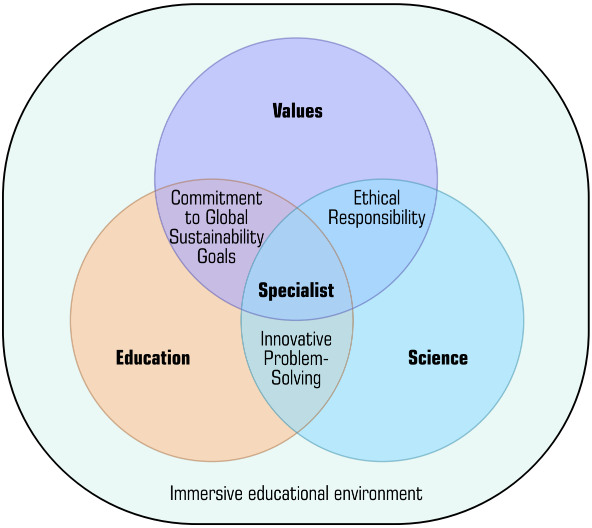

Fig. 5.3 Immersive educational environment for training a specialist in the field of nanomaterials science

ECOSYSTEM OF NANO-EDUCATION

The proposed model of the educational environment is more than just a space for learning; it is an ecosystem that aligns with the university-industry-government triple helix model, establishing a symbiotic relationship where each entity plays a key role in the cultivation and application of knowledge (**Fig. 5.4**).

The ecosystem of nanoeducation is the driving force behind the harmonious integration of the principles of sustainable development in the field of nanotechnology education. This ecosystem is a complex but well-balanced structure where education, science and values intersect under the influence of government, industry and universities to produce well-rounded professionals in the field of nanomaterials science.

At the heart of this ecosystem is an education where students have a deep understanding of the principles and practices of nanoscience. Public policy and funding, together with the legislative and regulatory framework, ensure that educational programs not only meet high standards, but are also aligned with the national and global sustainable development goals. This grassroots support enables educational institutions to provide state-of-the-art knowledge while fostering the commitment to sustainable practices.

The combination of education and science is an element of innovation, encapsulated in the practice of innovative problem solving. This practice is developed through a flexible and dynamic curriculum that encourages students to think creatively and apply their knowledge to real-world tasks. Industry plays a vital role here, providing a pathway for technology transfer and commercialization, ensuring that scientific discoveries move from the laboratory to the marketplace, where they can drive progress and contribute to economic growth.

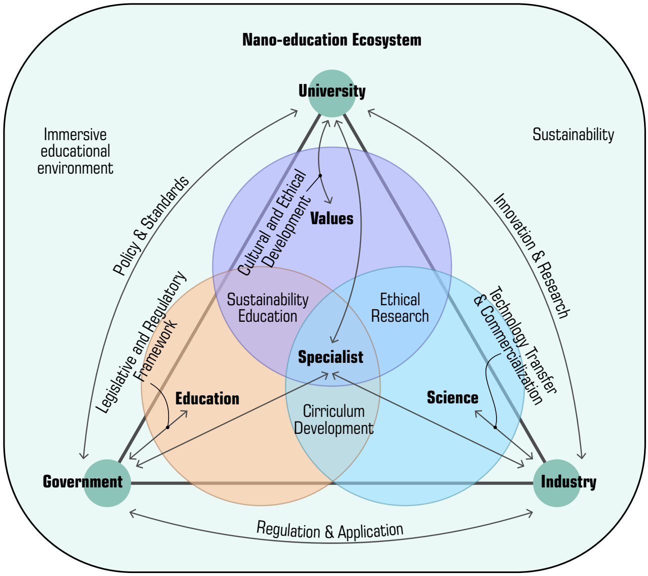

Fig. 5.4 Ecosystem of nano-education

The university environment is a catalyst for introducing values into the ecosystem, promoting cultural and ethical development. Here, students learn to integrate ethical considerations into their scientific endeavors, ensuring that their future work as nanomaterials specialists will positively impact society and the environment. Industry involvement further enriches this learning by allowing students to experience first-hand the practical application of these values in business practice and technological development.

Essentially, the nano-education ecosystem is a model, designed to train specialists who are not only technically knowledgeable, but ethically aware and sustainability oriented. The synergy between the components of the triple helix – government, university, and industry – creates an immersive and enabling environment where future nanotechnology professionals can thrive. These professionals emerge as leaders ready to face the challenges of the 21st century, driven by innovation, ethical responsibility and committed to promoting sustainable development in their field.

In this ecosystem, the specialist becomes the fulcrum of change. His/her education is a combination of knowledge and practice, reinforced by the commitment to values that advocate sustainable development. Such professionals are the nexus of this triple helix model, ready to apply their expertise in ways that enhance societal well-being, stimulate economic growth, and contribute to ecological balance.

5.4 THEMATIC STUDY: IMPLEMENTATION OF THE CONCEPT OF "EDUCATION-SCIENCE-VALUES" AT BERDYANSK STATE PEDAGOGICAL UNIVERSITY IN THE TRAINING PROGRAMS OF SPECIALISTS IN THE FIELD OF NANOMATERIALS SCIENCE

5.4.1 INNOVATIVE PRACTICES: TECHNOLOGIES, METHODS AND TOOLS FOR ORGANIZING THE EDUCATIONAL PROCESS

Before the war, students majoring in "Applied Physics and Nanomaterials" had access to the nanotechnology laboratories and equipment of the Research Institute of Nanotechnology of Berdyansk State Pedagogical University. During the war, in connection with the occupation of the city of Berdyansk and the relocation of the university, the entire material and technical base was lost, the university changed to the "University without Walls" format [39]. The training of specialists was under threat, which required an immediate change in the educational paradigm. To make it impossible to stop the educational process and reduce the quality of education, all courses were digitized, a number of presentations and educational videos were developed, and a selection of video lectures by industry leaders was made.

To implement the research component of the training of future specialists in the field of nanomaterials science, the teachers of the Department of Physics and Teaching Methods of Physics of BSPU focused on the digitalization of education and the use of artificial intelligence technologies for the training of students studying under the "Applied Physics and Nanomaterials" program.

To analyze the properties of nanomaterials, as well as to check their functional properties, technologies for remote control of the sample testing process (using SEM, TEM, XRD, EDX, RAMAN, etc.) were developed. Since the university's own material and technical base was lost, an agreement was concluded with Sumy State University, with which close partnership relations were established before the war.

A set of experimental samples was transferred to the Laboratory of Materials Science of Helioenergy, Sensor and Nanoelectronic Systems. The study of the properties of the above-mentioned equipment took place with the involvement of applicants in online format at ZOOM meetings.

The next stage was the involvement of foreign partners and strategic cooperation with respected international institutions to support the improvement of the qualifications of their specialists in the field of nanomaterials science. This international partnership contributed to the fact that the quality of scientific research and education did not decrease, despite the loss of material and technical resources of the university.

The involvement of foreign partners in the educational process has opened up new horizons for teachers and students of BSPU. The teachers had the opportunity to conduct fundamental research on nanostructures in the laboratories of the Institute of Physics of the Polish Academy of Sciences in Warsaw, Poland.

Similarly, the Institute of Solid State Physics of the University of Latvia in Riga, Latvia, and the Faculty of Physical and Technical Sciences of the University of L. N. Gumilyov Eurasian National University in Astana, Kazakhstan, opened its doors to BSPU researchers. These institutions offered access to their sophisticated equipment and research environment, facilitating research that would otherwise have been impossible.

In an extraordinary display of academic solidarity and sharing of resources, BSPU researchers were also able to conduct a number of studies at two of Europe's most advanced synchrotron facilities: DESY in Hamburg, Germany, and MAX IV in Lund, Sweden. These facilities are among the pinnacle of scientific research centers, housing highly specialized equipment that allows materials to be studied at the atomic level.

Understanding the importance of engaging students in this highly qualified research activity, BSPU has taken active steps to engage students remotely. A series of videos have been filmed that reflect the essence of the research work, carried out in these international laboratories. These videos, along with comprehensive methodical materials, have been designed to give students a virtual yet in-depth view of cutting-edge research in action.

The videos served a dual purpose: they were educational tools that allowed students to observe and learn complex experimental procedures, and they also functioned as motivational resources, showing nanomaterials professionals potential career paths.

Thanks to these efforts, BSPU not only maintained the continuity of its educational programs, but also increased the volume and quality of training. Students were able to virtually participate in world-class research, ensuring that their learning outcomes remain at par with global standards. This stage of international participation was a testimony to the stability and adaptability of the educational programs of BSPU, demonstrating the potential of joint efforts in overcoming geographical, and material and technical barriers in education.

This adaptive strategy not only preserved the educational trajectory of the students of BSPU, but also raised their learning to a new level, which is characterized by sustainability and the ability to use digital tools for scientific research. The revised curricula now include elements of nanotechnology sustainability and ethics, ensuring that graduates are not only proficient in nanomaterials, but also deeply aware of the ethical implications and sustainability considerations of their work. Such an immersive educational environment is inclusive and barrier-free, supporting the idea that education should be adaptive and sustainable – qualities now reflected in the students themselves. As BSPU students engage in virtual laboratories, analyze data from remote synchrotron facilities, and interact with international scientific leaders through online platforms, they are imbued with a sense of global citizenship and collaboration. They are being prepared for the world where interdisciplinary and cross-border collaboration is the norm, and where the challenges they will face as professionals require both scientific expertise and a deep understanding of sustainability and ethics.

The built ecosystem of nano-education at BSPU serves as a paradigmatic example of innovation in crisis conditions, demonstrating that with the help of flexibility and ingenuity, higher education institutions can overcome significant challenges to train specialists in high-tech industries.

5.4.2 SCIENCE IN ACTION: INTEGRATION INTO EDUCATION TO PROMOTE THE SUSTAINABLE DEVELOPMENT GOALS AND NURTURE VALUES AT BERDYANSK STATE PEDAGOGICAL UNIVERSITY

Scientific initiatives at Berdyansk State Pedagogical University are multifaceted efforts, aimed at improving the quality of research and education in accordance with the SDGs. According to the Scopus scientometric database, the SDG are in the focus of scientific research, which confirms the university's commitment to global sustainable development initiatives (**Fig. 5.5**).

Fig. 5.5 Sustainable development goals of in the lens of scientific research by scientists of the BSPU according to the Scopus scientometric database

These initiatives are implemented through a number of projects that are financially supported by both national and international organizations, including projects from the state budget, the National Research Fund of Ukraine, and individual grants (**Table 5.2**).

Table 5.2 Scientific projects, carried out/being carried out by scientists of BSPU and their harmonization with the Sustainable Development Goals and the framework of values of nano-education

Project	Direction	Harmonization with the Sustainable Development Goals	What values are nurtured?
1	**2**	**3**	**4**
Development of technology for evaluating quality and safety indicators of nanotechnology products during the life cycle	Nanotechnologies, new Materials, ecology	SDGs: 3, 9, 12, 13	1. Environmental protection and sustainable development of cities. 2. Ethical innovation and inclusiveness. 3. Economic and social development. 5. Health, food security and welfare
The search for optimal conditions for the synthesis of nanostructures on the surface of semiconductors A3B5, A2B6 and silicon for photonics and solar energy	Nanotechnology, new materials, energy, electronics	SDGs: 7, 9, 13	1. Environmental protection and sustainable development of cities. 3. Economic and social development. 5. Health, food security and welfare
Nanostructured semiconductors for energy-efficient environmentally safe technologies that increase the level of energy saving and environmental safety of the urban system	Nanotechnology, new materials, energy, electronics, urbanization, ecology	SDGs: 7, 9, 11, 13, 15	1. Environmental protection and sustainable development of cities. 3. Economic and social development. 4. Global cooperation and peaceful development. 5. Health, food security and welfare
Design and research of oxide heterostructures for portable solar cells	Nanotechnology, new materials, energy	SDGs: 7, 9, 11	1. Environmental protection and sustainable development of cities. 3. Economic and social development. 5. Health, food security and welfare
Theoretical and methodological principles of systematic fundamentalization of training future specialists in the field of nanomaterials science for productive professional activity	Nanotechnology, education	SDGs: 4, 8, 5, 10	2. Ethical innovation and inclusiveness. 3. Economic and social development. 4. Global cooperation and peaceful development

Continuation of Table 5.2

1	2	3	4
The system of remote and blended specialized training of future nanoengineers for the development of new dual-purpose nanomaterials, 2023–2025	Nanotechnology, education	SDGs: 4, 5, 9, 10	2. Ethical innovation and inclusiveness. 3. Economic and social development. 4. Global cooperation and peaceful development
Design of an inclusive educational environment of a higher education institution	Education	SDGs: 4, 5, 10	2. Ethical innovation and inclusiveness. 5. Health, food security and welfare
Ukrainian universities in new realities: the impact of the war and mechanisms for preserving the scientific and personnel potential of training specialists in high-tech industries	Education, science, high-tech industries	SDGs: 4, 9, 16	2. Ethical innovation and inclusiveness. 3. Economic and social development. 4. Global cooperation and peaceful development. 5. Health, food security and welfare
An integrated approach to the professional training of STEM-oriented teachers: the synergy of science-intensive and digital technologies	Education, STEM, science-intensive technologies	SDGs: 4, 5, 8, 9	2. Ethical innovation and inclusiveness. 3. Economic and social development. 4. Global cooperation and peaceful development

Together, these projects seek to advance environmental assessment technologies, improve nanomaterials science pedagogies, optimize the synthesis of nanostructures for energy applications, and integrate inclusive educational practices. They represent a concerted effort, aimed at increasing academic experience and research potential in the field of nanotechnology, ensuring the relevance and impact of the scientific product of BSPU.

Each project is strategically designed to address specific global challenges through the lens of nanotechnology, from environmental sustainability and ethical innovation to economic development and global cooperation.

It is noteworthy that each of these projects integrates educational components that actively involve students in their implementation. This hands-on involvement is critical in providing students with practical experience and a deeper understanding of theoretical knowledge. This ensures that students are not just passive recipients of information, but active participants in research that has real-world applications and implications.

In addition, it is important that six of the nine listed projects are led by young scientists. This underscores BSPU's desire to foster a culture of innovation and leadership among young faculty and graduate students, giving them the opportunity to lead projects that contribute to sustainable development and technological progress. These projects serve as a vital training ground for young scientists, equipping them with the skills and experience they need to succeed in high-tech industries.

Overall, the integration of students into these projects and the emphasis on projects, led by young scientists, reflect BSPU's commitment to creating an educational environment that is dynamic, inclusive and forward-looking. This approach not only enhances the learning and development of individual students, but also contributes to the broader goal of promoting sustainable development through cutting-edge research and innovation.

In addition to these projects, BSPU teachers actively contribute to COST Action, part of a global program, designed to promote international cooperation in the scientific field. Participation in COST Actions allows BSPU faculty to be at the forefront of cutting-edge scientific discussions and developments, ensuring that their contributions are recognized internationally and have impact at the national level.

The teaching staff of BSPU participates in the steering committees of several COST events, in particular:

– MultIChem (Multiscale Irradiation and Process-Controlled Chemistry and Related Technologies): this action focuses on the effects of radiation on chemicals, which is key to the understanding and development of nanomaterials;

– NETPORE (Network for Porous Semiconductors and Oxides Research, Innovation and Product Development): aims to enhance the development of porous semiconductors that are vital for various nanotechnology applications, including catalysis and sensors;

– WEMov (Women on the Move): advocates for gender equality in science, supports career mobility of women in STEM fields and aligns with development goals on gender equality;

– HIDDEN (History of Identity Documentation in European Nations): although this action is not directly related to nanotechnology, it contributes to a broader understanding of social development and historical context;

– ReMO (researcher mental health): addresses the well-being of researchers, an important aspect of supporting a productive and innovative research community.

Each of these actions enriches the immersive educational environment at Berdyansk State Pedagogical University, bringing international perspectives, interdisciplinary knowledge and innovative methodologies. Participation in such programs not only catalyzes scientific and technological progress, but also strengthens the university's commitment to sustainable development and ethical responsibility.

Thanks to their active participation in these global initiatives, BSPU teachers and researchers are able to form an academic ecosystem that responds to the changing landscape of scientific research. They play a critical role in creating a learning environment that not only prioritizes academic excellence and innovation, but also embodies the values and principles necessary to achieve sustainable development.

5.4.3 VALUES EVERYWHERE THROUGH THE PRISM OF NANOART: PROMOTING STEAM FOR SUSTAINABLE DEVELOPMENT

Berdyansk State Pedagogical University became a pioneer in the integration of nanotechnology and art through the creation of the first Nanoart gallery in Ukraine (**Fig. 5.6**).

Fig. 5.6 First Nanoart gallery in Ukraine and the Artbook of the same name

This innovative intersection of disciplines showcases images of nanostructures that, through color processing, transcend their scientific origins to become visual masterpieces. Nanoart represents a new direction of art born from the symbiosis of nanoengineering and graphic design. In addition to aesthetic appeal, color enhancement of photomicrographs serves the dual purpose of highlighting scientifically important features in images, thus combining technology with creativity.

The relationship between science and art in nanoart serves as a powerful catalyst for social progress, fostering mutual enrichment that transcends traditional disciplines. The art book "Nanoart", developed by the university, is saturated with artistically and aesthetically attractive content. However, it also addresses critical considerations related to the use of nanotechnology, such as moderation in the use of products containing nanoparticles, disposal practices, certification, standardization in the field of nanotechnology, regulatory frameworks, classification of nanostructures, and current research methodologies.

The educational mission of the Nanoart project goes beyond the development of scientific thought and cultural perception; it is also aimed at popularizing modern science and art among young people, thus contributing to its sustainable development. Visually striking images of nanoart objects are used not only for educational purposes, but also to spark interest and dialogue among young people about the convergence of science, technology, engineering, art and mathematics (STEAM).

In addition, the project emphasizes the need to expand the creative space of nanoart, promoting the exchange of experience and the decentralization of cultural activities. This involves cooperation between artists, designers and nanoengineers both in Ukraine and abroad. Engaging these diverse communities helps create a rich environment for collaborative innovation.

As part of the Future Designer 2023 & Science for SDGs Innovation Contest, the NanoArt project and its subsidiary EcoNano were awarded a silver medal for a series of posters called "Nanoart. New symbolism of science" (**Fig. 5.7**).

These works explore a wide range of topics, from social justice to environmental responsibility, and reflect the importance of science and art in achieving the sustainable development goals.

The Nanoart project reflects commitments to a number of UN Sustainable Development Goals, emphasizing the importance of innovation and interdisciplinary research: from solving the problem of resource scarcity to promoting sustainable agriculture, from supporting global health initiatives to encouraging inclusiveness in STEAM (**Table 5.3**).

Fig. 5.7 Poster series "Nanoart. New symbolism of science", presented at the International Future Designer 2023 & Science for SDGs Innovation Contest

Table 5.3 Representation of Sustainable Development Goals in the Nanoart project

Sustainable Development Goals	Harmonization of Nanoart goals with sustainable development
1	**2**
SDG 1 (No Poverty) and SDG 2 (Zero Hunger)	NanoArt indirectly addresses resource scarcity by exploring materials science at the nanoscale, highlighting its potential for sustainable agriculture and energy-efficient solutions
SDG 3 (Good Health and Well-being)	By visualizing nanostructures that could be applied to drug delivery or water purification, NanoArt advocates for broader healthcare initiatives
SDG 4 (Quality Education)	Paintings in the genre of NanoArt serve as educational tools, demystify the complex principles of nanotechnology and inspire future scientific endeavors
SDG 5 (Gender Equality)	Through inclusive presentations in nanoart, we aim to encourage diversity and inclusiveness in the STEM fields
SDG 6 (Clean Water and Sanitation)	The nanostructures shown are promising for scalable water treatment methods directly related to water availability and purity issues
SDG 7 (Affordable and Clean Energy)	The "EcoNano" project foresees the viability of nanomaterials in creating more efficient energy systems

Continuation of Table 5.3

1	2
SDG 8 (Decent Work and Economic Growth)	The NanoArt project seeks to stimulate discussions on the ethical implications of nanotechnology in industry, while adhering to the principles of fair work
SDG 9 (Industry, Innovation, and Infrastructure)	These works are at the forefront of interdisciplinary innovation, stimulating both artistic and scientific research
SDG 10 (Reduced Inequality)	By making the invisible visible, NanoArt aims to promote a more informed public discourse on the empowerment of technology
SDG 11 (Sustainable Cities and Communities)	NanoArt can inspire sustainable urban projects by demonstrating how nanomaterials can contribute to sustainable architecture
SDG 12 (Responsible Consumption and Production)	Themes of resource conservation permeate the EcoNano project, offering solutions for more responsible use of resources
SDG 13 (Climate Action), SDG 14 (Life Below Water) and SDG 15 (Life on Land)	Environmental themes dominate in specific works, illustrating the catastrophic consequences of climate inaction and promoting environmental stewardship
SDG 16 (Peace, Justice, and Strong Institutions)	NanoArt provides visual commentary on socio-political issues, making a clarion call for peace and justice
SDG 17 (Partnerships for the Goals)	We are committed to building global partnerships to address the broad challenges our NanoArt touches

In essence, the NanoArt and "EcoNano" projects are not simply aesthetic endeavors, but aimed at fostering an informed and engaged citizenry.

Each work in the "Nanoart" series is a testament to the invisible beauty of science and its potential to change the world for the better. This project encourages dialogue about the key global challenges and opportunities that science and innovation open up to us.

During the ongoing war, the "Nanoart" project at Berdyansk State Pedagogical University acquired a new patriotic dimension, connecting with Ukraine's struggle for independence. This transformation was intended to draw the attention of the world community to the events taking place in the country [40].

Patriotic reformation of nanoart serves many purposes:

1. Support of Ukrainian art during the war.
2. Drawing the world's attention to the situation in Ukraine.
3. Advocacy for international support to help Ukraine.
4. Preservation of Ukrainian art assets.
5. Encouraging those in the background to contribute through their professional potential.
6. Unification of the Ukrainian intelligentsia – including artists, scientists, and educators – for cooperation in the reconstruction and development of the nation.
7. Promotion of Ukrainian scientific art and protection of its heritage.
8. Documenting the consequences of the war and the stability of Ukrainian society.
9. Strengthening the Ukrainian spirit and faith in the restoration and victory of the nation.

This reimagined Nanoart project goes beyond academic debates and becomes a powerful expression of national identity and sovereignty. In times of crisis, art and science transcend their traditional roles, becoming crucial elements in maintaining the moral and cultural spirit of a nation. The integration of patriotic themes into nano art not only reflects contemporary realities, but is also an example of how science and art can work together to contribute to peace and national stability.

Thanks to these efforts, Nanoart at Berdyansk State Pedagogical University is an example of how artistic creativity, combined with scientific innovation, can significantly affect education, culture and sustainable development, contributing to the creation of a comprehensive educational ecosystem that resonates with the core values of nanoeducation.

5.5 CONCLUSIONS AND CALL FOR FURTHER ACTIONS

Therefore, for the effective training of specialists in the field of nanotechnology, it is important to develop a complex ecosystem that combines an immersive educational environment with the purposeful development of future specialists. At the core of this ecosystem is the integration of education, science, and values – a trinity that forms the basis for both academic and professional growth in nanotechnology.

This inclusive educational environment is designed not only to impart knowledge, but also to foster deep respect for ethical standards and sustainable development. It supports the culture, in which innovation is driven by the pursuit of societal well-being and care for the environment. In this framework, every aspect of teaching and research is intertwined with values that emphasize the importance of responsible science.

At the other end of this ecosystem is the future professional who emerges from this rich educational environment. These people are not only equipped with technical knowledge, but also deeply attuned to people-centered principles. This includes a keen awareness of the impact of their work both locally and globally, ensuring that their contributions are useful and sustainable.

Thus, the preparation of future specialists in the field of nanomaterials science to implement the requirements of sustainable development of society includes:

– making changes to the relevant disciplines taught;

– introducing a new academic discipline into the variable component of educational programs;

– active involvement of students of higher education in activities, the result of which are positive shifts in consciousness, formation of new approaches, acquisition of skills, and concrete steps in progress towards sustainable development of society.

Such actions are provided for by legislative and regulatory documents, which indicate the need to develop the ability to update curricula of educational disciplines in accordance with the requirements of the internal quality assurance system, as a component of the professional competence of teachers of higher education institutions.

The inclusion of elements of sustainability in existing curricula, changes in teaching (from knowledge transfer to problem discussion) help future specialists in the field of nanoscience and technology to answer the following questions:

– How responsible we are for understanding the problems of sustainable development in society?

– How are positive experiences from implementing sustainable development disseminated and used?

– To what extent do we teach our pupils, students and trainees sustainable approaches to the development?

– To what extent is scientific research focused on solving the problems of sustainable development?

– How important is our personal contribution to the cause of supporting sustainable development?

To effectively support this ecosystem, institutions must ensure that their curricula, research opportunities, and partnerships reflect these priorities. They must create an environment that encourages active learning and collaboration across disciplines, combining theoretical knowledge with practical applications. This approach not only prepares students for success in their immediate tasks, but also equips them with the skills to navigate and shape the future landscape of technology and society.

In summary, we note that the integration of nanoscience and technology in achieving the Sustainable Development Goals (SDGs) opens up a significant opportunity for Ukraine to advance on many fronts: from the development of high-tech industries and promotion of economic growth to solving pressing challenges. The role of specialists in the field of nanoscience cannot be overestimated; they are the architects of this new era where technology meets sustainability to pave the way for a brighter and greener future.

The way forward requires the concerted efforts of all sections of society. Higher education institutions must develop by embedding SDG-focused competencies into their curricula to equip future professionals with the knowledge and skills, needed to drive sustainable development through nanotechnology. At the same time, the policy framework must support the development of high-tech industries with a clear emphasis on sustainability, ensuring not only the recovery, but also the prosperity of Ukraine in the post-war period and beyond.

Partnerships between academia, industry and government are becoming a critical mechanism for realizing these goals. Through collaboration, these sectors can use their unique strengths to foster innovation, accelerate the application of nanotechnology in sustainable development and contribute to the achievement of the SDGs.

Since Ukraine stands at this crossroads, the need to act is obvious. Using the potential of nanoscience and technology, as well as contributing to the creation of an environment that promotes innovation and cooperation, Ukraine can secure a place as a leader in the field of sustainable development. This journey towards sustainable development is not only about meeting the challenges of today, but also about laying the foundations for a resilient, prosperous and sustainable future for generations to come. The time has come to harness the transformative power of nanotechnology for the benefit of the planet and its people.

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