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INTEGRATION OF SUSTAINABLE DEVELOPMENT GOALS INTO NANOTECHNOLOGY PROGRAMS FOR COMPETITIVENESS AND POST-WAR RECOVERY OF UKRAINE

Kovachov S. S., Kurylo O. Yu., Sychikova Ya. O.

INTRODUCTION

The ongoing war in Ukraine has caused deep disruptions across the entire spectrum of societal norms and infrastructure, with the scientific and educational sectors bearing a significant burden[1]. The consequences of the war have cascaded into the realms of research and higher education, manifesting in the destruction of scientific infrastructure, forced migration of academic institutions, a rapid transition to online education, and a noticeable outflow of scientific talents[2]. These disturbances collectively compromised the country's ability to nurture and retain highly qualified specialists, exacerbating pre-existing issues and highlighting an acute need in today's critical moment[3].

The war has led to the physical destruction of numerous scientific establishments and universities, erasing decades of accumulated knowledge and resources[4]. This destruction is a loss of physical space and substantially diminishes Ukraine's scientific potential[5]. Furthermore, the relocation of universities has become a harsh reality, as educational institutions were forced to vacate their premises, seeking refuge in safer

[1] Gurenko O., Suchikova Y. The Odyssey of Ukrainian Universities: From quality assurance to a culture of quality education. Management in Education. 2023. URL: https://doi.org/10.1177/08920206231218351

[2] University without Walls: Experience of Berdyansk State Pedagogical University during the war / H. Lopatina et al. Problems and Perspectives in Management. 2023. Vol. 21, no. 2. P. 4–14. URL: https://doi.org/10.21511/ppm.21(2-si).2023.02

[3] Peregudova V. People learn fastest on the barricades: Science at war. Management in Education. 2023. URL: https://doi.org/10.1177/08920206231188018

[4] Suchikova Y., Tsybuliak N. Universities without walls: global trend v. Ukraine's reality. Nature. 2023. Vol. 614, no. 7948. P. 413. URL: https://doi.org/10.1038/d41586-023-00380-y

[5] Polishchuk Y., Lyman I., Chugaievska S. The "Ukrainian Science Diaspora" initiative in the wartime. Problems and Perspectives in Management. 2023. Vol. 21, no. 2. P. 153–161. URL: https://doi.org/10.21511/ppm.21(2-si).2023.18

regions or adapting to a nomadic existence that hampers stable research and learning environments[6].

Due to these dire circumstances, Ukrainian universities and scientific institutions have rapidly transitioned to online learning. Although this shift has ensured the continuity of education to some extent, it has also unveiled the limitations and challenges of digital learning platforms, including accessibility issues, the practicality of conducting sophisticated scientific research remotely and preserving academic integrity and quality[7].

A significant consequence of the ongoing conflict is the mass migration of scientific talent. This exodus encompasses established researchers and promising students seeking safety, stability, and opportunities abroad. The dispersion of human resources and students worldwide leads to a brain drain that further depletes Ukraine's scientific and academic landscape, impairing its ability to recover and rebuild in the post-war period[8].

This confluence of factors has significantly impaired Ukrainian universities' ability to train highly qualified specialists. The disruption in traditional education and research methodologies, combined with the loss of physical infrastructure and human capital, poses a severe challenge[9]. Ukraine feels an acute need for specialists capable of navigating and contributing to complex fields of science and technology, which are essential for the nation's recovery and future growth.

Amid the profound destruction of Ukraine's scientific and educational fabric, the field of nanotechnology emerges as a beacon of high-tech prospects and potential. The role of nanotechnology, as one of the most advanced sectors in modern science, has never been more critical, especially given the country's current circumstances. The demand for nanotechnology is increasing, underscored by its crucial contributions across various domains including defense, healthcare, energy, and environmental protection[10].

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[6] Science in times of crisis: How does the war affect the efficiency of Ukrainian scientists? / Y. Suchikova et al. Problems and Perspectives in Management. 2023. Vol. 21, no. 1. P. 408–424. URL: https://doi.org/10.21511/ppm.21(1).2023.35

[7] Ukrainian universities at the time of war: From occupation to temporary relocation / N. Tsybuliak et al. Torture Journal. 2023. Vol. 33, no. 3. P. 39–64. URL: https://doi.org/10.7146/torture.v33i3.136256

[8] de Rassenfosse G., Murovana T., Uhlbach W.-H. The effects of war on Ukrainian research. Humanities and Social Sciences Communications. 2023. Vol. 10, no. 1. URL: https://doi.org/10.1057/s41599-023-02346-x

[9] Inclusive education in higher education institution: Are Ukrainian faculty members' ready for it? / H. Lopatina et al. Research in Education. 2023. URL: https://doi.org/10.1177/00345237231207721

[10] Kovachov S., Bohdanov I., Suchikova Y. Nano or Na-No? Ukraine's crisis of opportunity in nanotechnology education. Industry and Higher Education. 2023. URL: https://doi.org/10.1177/09504222231209259

Nanotechnology's significance in enhancing Ukraine's defense capabilities is particularly notable. Developing advanced materials, sensors, and communication devices through nanotechnology can significantly boost the nation's resilience and strategic response in the face of ongoing threats[11]. Beyond defense, the applications of nanotechnology in healthcare, such as creating new diagnostic tools and treatment methods, offer hope for addressing medical issues exacerbated by the war. In the energy sector, nanotechnological innovations promise more efficient solutions for renewable energy sources, contributing to energy independence and sustainability–a vital concern for a country striving for self-reliance amid conflict[12] [13].

Thus, destroying Ukraine's scientific infrastructure and related educational challenges emphasize the urgent need to revive nanotechnology programs. Despite the formidable barriers created by the conflict, such as the destruction of laboratories, the migration of skilled scientists, and the dispersion of students, the potential of nanotechnology remains a vital asset. This is an area where strategic investments and support can yield significant dividends for the country's recovery and future security.

Today, Ukraine stands at a crossroads where the strategic integration of Sustainable Development Goals (SDGs) into its nanotechnology programs becomes a pivotal lever for national competitiveness and post-war recovery. This integration aligns with global sustainability agendas and enables Ukraine to tap into the transformative potential of nanotechnology across various sectors, including energy, healthcare, environmental protection, and manufacturing.

Ukraine's dual challenges underscore the relevance of such integration: the immediate need for reconstruction and the global imperative of implementing sustainable practices. Nanotechnologies, capable of stimulating innovation and economic growth, offer a unique set of tools for effectively

[11] Suchikova Y., Kovachov S., Popov A. I. Chemical Deposition and Characterization of CdS/ZnS Heterostructures for Optoelectronic Applications. 2023 IEEE International Conference on Information and Telecommunication Technologies and Radio Electronics (UkrMiCo), Kyiv, Ukraine, 13–18 November 2023. 2023. URL: https://doi.org/10.1109/ukrmico61577.2023.10380410

[12] Singh A., Amiji M. M. Application of nanotechnology in medical diagnosis and imaging. Current Opinion in Biotechnology. 2022. Vol. 74. P. 241–246. URL: https://doi.org/10.1016/j.copbio.2021.12.011

[13] Design and Structural Investigation of CuIn(Ga)Se2 Films for Solar Energy Applications / I. Bohdanov et al. 2023 IEEE 13th International Conference Nanomaterials: Applications & Properties (NAP), Bratislava, Slovakia, 10–15 September 2023. 2023. URL: https://doi.org/10.1109/nap59739.2023.10310680

addressing these issues[14]. By incorporating the principles of the Sustainable Development Goals into nanotechnology education and research, Ukraine can cultivate a new generation of scientists and engineers who are not only versed in cutting-edge technologies but also committed to the principles of sustainable development and societal well-being[15].

The Sustainable Development Goals, adopted by all United Nations Member States in 2015, provide a shared blueprint for peace and prosperity for people and the planet, now and into the future. Integrating these goals into nanotechnology programs entails a multidimensional approach encompassing curriculum development, research orientation, industry collaboration, and policy support. Such an approach requires concerted efforts from academic institutions, government bodies, industry stakeholders, and the international community to reconfigure educational and research frameworks towards sustainability-oriented outcomes.

This article explores strategies and challenges associated with integrating SDGs into Ukrainian educational and research programs in nanotechnology. It discusses the potential of nanotechnologies to contribute to sustainable development and resilience in Ukraine, highlighting specific SDGs where nanotechnologies can have a significant impact. The discussion extends to this integration's institutional and policy aspects, offering insights into how Ukraine can leverage nanotechnologies for sustainable development and a competitive advantage on the global stage.

The significance of this integration extends beyond academic discourse, touching on the broader implications for Ukraine's economic recovery, societal resilience, and environmental stewardship. As the country navigates its immediate recovery needs, integrating SDGs into nanotechnology programs opens a path to rebuilding a stronger, more resilient, and competitive Ukraine.

1. Nanotechnologies for Sustainable Development Goals

Nanotechnologies, with their transformative potential, stand at the convergence of innovation and sustainability, offering novel solutions to some of the most pressing issues outlined by the Sustainable Development Goals (SDGs). Delving into nanotechnology's contributions to achieving the

[14] Nanotechnology for a Sustainable Future: Addressing Global Challenges with the International Network4Sustainable Nanotechnology / L. Pokrajac et al. ACS Nano. 2021. Vol. 15, no. 12. P. 18608–18623. URL: https://doi.org/10.1021/acsnano.1c10919

[15] Training of the Future Nanoscale Engineers: Methods for Selecting Efficient Solutions in the Nanostructures Synthesis / Y. Suchikova et al. 2021 IEEE 3rd Ukraine Conference on Electrical and Computer Engineering (UKRCON), Lviv, Ukraine, 26–28 August 2021. 2021. URL: https://doi.org/10.1109/ukrcon53503.2021.9575745

SDGs reveals how this high-tech field can be pivotal in steering global and national efforts toward a more sustainable and equitable future[16].

Goal 1: No Poverty

Nanotechnologies offer innovative approaches to alleviating poverty by developing affordable materials and solutions for housing, water purification, and energy production. Nano-filters, for example, can provide low-cost access to clean drinking water in impoverished communities, significantly reducing the burden of diseases and fostering better health and well-being[17]. Moreover, agricultural resources enhanced with nano-technologies can improve crop yields and food security, directly contributing to poverty reduction by boosting the livelihoods of smallholder farmers.

Goal 2: Zero Hunger

Addressing hunger requires innovations in food production, storage, and distribution, where nanotechnology can significantly contribute. Nanotechnologies can enhance the nutritional value of food, extend its shelf life, and introduce new methods for combating pests and diseases, thereby improving food security[18]. Additionally, nanosensors in agriculture can optimize resource use, reducing waste and enhancing the efficiency of food production systems, ensuring more consistent and reliable access to nutritious food.

Goal 3: Good Health and Well-being

The impact of nanotechnology on healthcare is profound, offering innovative solutions for the diagnosis, treatment, and prevention of diseases. Nanoparticles can be used for precise drug delivery, minimizing side effects and improving the effectiveness of treatments for various conditions, including cancer and infectious diseases[19]. Nanotechnology also plays a crucial role in developing rapid diagnostic tests, enabling early detection of health conditions and timely intervention. These advancements not only

[16] High-Quality Digital Bichronous Education for Nanoengineers During the War in Ukraine: Does Technology Knowledge Matter? / A. Popova et al. 2023 IEEE 5th International Conference on Modern Electrical and Energy System (MEES), Kremenchuk, Ukraine, 27–30 September 2023. 2023. URL: https://doi.org/10.1109/mees61502.2023.10402460

[17] Masron T. A., Subramaniam Y., Loganathan N. Does nanotechnology contribute to energy poverty reduction?. Management of Environmental Quality: An International Journal. 2023. URL: https://doi.org/10.1108/meq-08-2022-0221 18

[18] Bhattacharya S., Seth A. Application of Nanotechnology for Eco-Friendly and Sustainable Economic Development. Diversity and Applications of New Age Nanoparticles. 2023. P. 1–24. URL: https://doi.org/10.4018/978-1-6684-7358-0.ch001

[19] Fernandez R. M. SDG3 Good Health and Well-Being: Integration and Connection with Other SDGs. Encyclopedia of the UN Sustainable Development Goals. Cham, 2019. P. 629–636. URL: https://doi.org/10.1007/978-3-319-95681-7_64

improve individual health outcomes but also contribute to the population's overall well-being.

SDG 4: Quality Education

While nanotechnology is not directly related to educational content, it can enhance education quality by developing new learning tools and materials. Nanomaterials can be used to create more durable and interactive educational resources, making learning more engaging and accessible. Furthermore, nanotechnology research and innovation can enrich science and engineering curricula, providing students with hands-on experience in cutting-edge technologies. By integrating nanotechnology into educational programs, institutions can inspire the next generation of scientists and engineers, equipping them with the knowledge and skills needed to address future challenges.

Goal 5: Gender Equality

While nanotechnology directly impacts scientific and industrial fields, its indirect contributions to achieving gender equality are noteworthy. By stimulating economic growth and innovation, nanotechnology creates new opportunities in science, technology, engineering, and mathematics (STEM) fields traditionally underrepresented by women. Empowering women through education and career opportunities in nanotechnology not only promotes gender equality but also ensures diverse perspectives in research and development, enhancing the innovation process.

SDG 6: Clean Water and Sanitation

Nanotechnology plays a crucial role in addressing global water scarcity and sanitation issues. Nano-filtration systems and nanomaterials designed for water purification can remove pollutants, pathogens, and heavy metals from water sources, making it safe for consumption and use. These technologies offer scalable, energy-efficient solutions for clean water access, directly contributing to the health and well-being of millions of people and supporting sustainable water management practices[20].

Goal 7: Affordable and Clean Energy

The quest for sustainable energy solutions has propelled nano-technologies to the forefront of innovations in solar cells, batteries, and energy storage systems. Nanomaterials enhance the efficiency and performance of renewable energy technologies, reducing costs and making clean energy more accessible. From improving the efficiency of photovoltaic cells to developing high-capacity batteries, nanotechnologies play a crucial

[20] Sufiani O., Sahini M. G., Elisadiki J. Towards attaining SDG 6: The opportunities available for capacitive deionization technology to provide clean water to the African population. Environmental Research. 2023. Vol. 216. P. 114671. URL: https://doi.org/10.1016/j.envres.2022.114671

role in transitioning to sustainable energy systems and reducing global dependence on fossil fuels[21].

SDG 8: Decent Work and Economic Growth

Nanotechnologies contribute to economic growth and the creation of decent work by developing new industries and revitalizing existing ones. Through advancements in materials science, electronics, and biotechnology, nanotechnologies stimulate innovation, productivity, and competetiveness. It creates employment opportunities in high-tech sectors, supports skill development, and offers pathways to secure, fulfilling work[22]. Moreover, by ensuring sustainable industrial processes and products, nanotechnologies aid in building resilient economic structures capable of withstanding global challenges.

SDG 9: Industry, Innovation, and Infrastructure

Nanotechnologies are integral to building resilient infrastructure, promoting inclusive and sustainable industrialization, and fostering innovation. Its applications range from developing more robust and lighter construction materials to enhancing manufacturing processes and efficiency[23]. Nanotechnologies also support the creation of intelligent infrastructure solutions, including sensors and monitoring devices for environmental and structural health monitoring, driving forward innovations that underpin sustainable development and economic growth.

Goal 10: Reduced Inequalities

Nanotechnologies can play a crucial role in reducing inequalities by providing scalable and adaptable solutions to underserved populations' needs. For instance, affordable nanotechnology-based diagnostics and treatments can bridge the gap in healthcare access, offering low-cost, effective alternatives to traditional methods. Additionally, the application of nanotechnologies in agriculture, such as nano-enhanced fertilizers and pesticides, can improve food security and livelihoods for smallholder farmers in developing regions, helping to level the playing field and reduce economic disparities.

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[21] Study of the structural and morphological characteristics of the CdxTeyOz nanocomposite obtained on the surface of the CdS/ZnO heterostructure by the SILAR method / Y. Suchikova et al. Applied Physics A. 2023. Vol. 129, no. 7. URL: https://doi.org/10.1007/s00339-023-06776-x

[22] Training Prospective Nanotechnologists to Select Optimum Solutions for the Nanostructures Synthesis Using the Analytic Hierarchy Process / Y. Suchikova et al. TEM Journal. 2021. P. 1796–1802. URL: https://doi.org/10.18421/tem104-42

[23] Abdelzaher M. A. Sustainable development goals for industry, innovation, and infrastructure: demolition waste incorporated with nanoplastic waste enhanced the physicomechanical properties of white cement paste composites. Applied Nanoscience. 2023. URL: https://doi.org/10.1007/s13204-023-02766-w

SDG 11: Sustainable Cities and Communities

The urban environment benefits significantly from nanotechnologies through the development of smart materials and systems that enhance city sustainability and resilience. Nanomaterials can contribute to more durable and energy-efficient buildings, while nanosensors can monitor air and water quality, creating a smarter and more responsive urban infrastructure. Furthermore, nanotechnologies can improve waste management practices, facilitating the breakdown of pollutants and enhancing recycling processes, contributing to cleaner and more sustainable urban ecosystems.

SDG 12: Responsible Consumption and Production

Nanotechnologies offer pathways to sustainable consumption and production models by developing materials and processes that minimize waste and energy use. Nanocatalysts, for example, can increase the efficiency of chemical processes, reducing the consumption of raw materials and energy. Nanotechnologies also support the creation of longer-lasting products, from electronics to textiles, reducing the need for frequent replacements and facilitating a shift towards sustainability in consumer goods.

SDG 13: Climate Action

In the fight against climate change, nanotechnologies emerge as a critical ally, offering innovative carbon capture and storage solutions, renewable energy, and energy efficiency[24]. Nanomaterials can significantly enhance the performance of solar panels and batteries, reducing greenhouse gas emissions by facilitating the transition to renewable energy sources. Additionally, nanotechnology-based solutions for capturing and converting carbon dioxide into valuable products present a novel approach to mitigating the impact of fossil fuel use, aligning with global efforts to combat climate change.

SDG 14: Life Below Water

Nanotechnologies contribute to the conservation and sustainable use of the oceans, seas, and marine resources. Innovations such as nanotechnology-based sensors can monitor water quality and detect pollutants at deficient concentrations, facilitating early identification of environmental hazards. Furthermore, nanomaterials can be used in wastewater treatment, removing harmful substances before they reach marine ecosystems. These technologies are crucial for protecting marine biodiversity and ensuring the health of our oceans.

[24] Thammadi S. P. D., Pisini S. K. Nanotechnology and building construction: Towards effective stakeholder engagement. IOP Conference Series: Earth and Environmental Science. 2022. Vol. 1084, no. 1. P. 012074. URL: https://doi.org/10.1088/1755-1315/1084/1/012074

SDG 15: Life on Land

The application of nanotechnologies extends to combating desertification, restoring degraded land and soil, and promoting sustainable land use. Nano-enhanced materials can improve soil quality and water retention, supporting agriculture in arid regions[25]. Additionally, nanotechnologies can aid in the conservation of ecosystems and biodiversity by enabling more precise and targeted delivery of pesticides and fertilizers, reducing the environmental impact of these substances, and supporting the sustainable management of natural resources[26].

SDG 16: Peace, Justice, and Strong Institutions

While the contribution of nanotechnologies to achieving SDG 16 is more indirect, the development and application of nanotechnologies can facilitate the creation of peaceful and inclusive societies. For instance, nanotechnologies can play a significant role in forensic science, enhancing the accuracy and efficiency of law enforcement investigations and contributing to the rule of law. Moreover, the ethical development and deployment of nanotechnologies require robust institutional frameworks that ensure transparency, accountability, and inclusiveness, aligning with the broader objectives of SDG 16.

SDG 17: Partnerships for the Goals

The achievement of all SDGs, facilitated by nanotechnologies, underscores the importance of partnerships across scientific, public, private, and civil society sectors. Collaborative research and innovation projects in nanotechnology can combine diverse expertise and resources, stimulating innovations and scaling solutions to address global challenges[27]. International cooperation in nanotechnology research, standards, and regulation can also ensure the widespread dissemination of nanotechnology benefits and contribute to sustainable development efforts worldwide.

Exploring the contributions of nanotechnologies to the Sustainable Development Goals highlights their potential as a transformative force for good. From protecting marine life and terrestrial ecosystems to supporting

[25] Analysis of the ways to provide ecological safety for the products of nanotechnologies throughout their life cycle / S. Vambol et al. Eastern-European Journal of Enterprise Technologies. 2017. Vol. 1, no. 10 (85). P. 27–36. URL: https://doi.org/10.15587/1729-4061.2017.85847

[26] Assessment of improvement of ecological safety of power plants by arranging the system of pollutant neutralization / S. Vambol et al. Eastern-European Journal of Enterprise Technologies. 2017. Vol. 3, no. 10 (87). P. 63–73. URL: https://doi.org/10.15587/1729-4061.2017.102314

[27] Evaluating the nexus of funding and scientific output in Kazakhstan / A. Abdikadirova et al. Knowledge and Performance Management. 2024. Vol. 8, no. 1. P. 17–31. URL: https://doi.org/10.21511/kpm.08(1).2024.02

peace and justice and fostering global partnerships, nanotechnologies promise to advance sustainable development on multiple fronts. However, realizing this potential requires investing in nanotechnology research, encouraging interdisciplinary collaboration, and ensuring nanotechnologies' ethical and equitable deployment. By addressing these challenges, the global community can leverage nanotechnologies as a tool for innovation and a catalyst for a sustainable and prosperous future for all.

2. Problems of Integrating Sustainable Development Goals into Nanotechnology Programs

Integrating Sustainable Development Goals (SDGs) into nanotechnology programs presents challenges that reflect the complexity of aligning advanced scientific research with broader global sustainability objectives. This integration is crucial for directing the vast potential of nanotechnologies toward addressing urgent global issues such as poverty, climate change, and inequality. However, the path to successful integration is fraught with obstacles, ranging from curriculum development and research prioritization to funding constraints and stakeholder engagement.

One of the primary challenges is developing curricula that effectively incorporate SDGs into nanotechnology education. Educators must balance technical nanotechnology training with a comprehensive understanding of sustainability and its global implications. Achieving this balance is challenging, given the depth of knowledge required in both areas. Furthermore, there is often a lack of readily available teaching materials and resources that combine these subjects, complicating educators' efforts to provide students with an integrated learning experience that spans the complexities of nanotechnology and sustainable development[28].

Another significant issue is aligning research priorities within nanotechnology programs with SDGs. While nanotechnologies hold promise for contributing to many SDGs, directing research efforts towards these goals requires a deliberate strategy that may not always align with prevailing scientific interests or funding priorities. Researchers often face pressure to pursue projects with immediate commercial potential or that align with the specific priorities of funding bodies, which may not necessarily coincide with long-term, broad-based sustainable development goals.

Funding constraints represent another hurdle to integrating SDGs into nanotechnology programs. Developing new technologies contributing to sustainability goals often requires substantial initial investment, lengthy development timelines, and interdisciplinary collaboration. However,

[28] Ghattas N. I., Carver J. S. Integrating nanotechnology into school education: a review of the literature. Research in Science & Technological Education. 2012. Vol. 30, no. 3. P. 271–284. URL: https://doi.org/10.1080/02635143.2012.732058

funding for such integrative projects can be limited, competitive, and fragmented, posing a challenge for programs aiming to pioneer nanotechnology initiatives focused on SDGs.

Effectively engaging stakeholders is also critical to the integration process but comes with its own set of challenges. Stakeholder groups, including industry partners, government agencies, NGOs, and communities impacted by nanotechnology applications, have diverse interests and priorities. Establishing meaningful collaborations and dialogues among these groups to advance SDGs through nanotechnology requires careful negotiation and relationship-building. Additionally, there is a need for public engagement and education to ensure broader societal support and understanding of the potential of nanotechnologies to contribute to sustainable development.

Lastly, measuring the impact of nanotechnology initiatives on achieving SDGs poses challenges. Quantifying contributions to broad, interconnected goals requires comprehensive metrics and long-term studies to assess outcomes and impacts[29]. Developing these metrics and methodologies is essential for tracking progress and guiding future efforts but requires concerted effort and coordination among researchers, policymakers, and funding bodies.

The integration of Sustainable Development Goals (SDGs) into nanotechnology programs in the Ukrainian context is further complicated by the ongoing conflict and its cascading effects on the country's educational and scientific landscape. War, intellectual capital loss, and infrastructure destruction exacerbate the challenges of aligning advanced scientific research with global sustainability goals[30]. These conditions create unique obstacles that require innovative solutions and resilient approaches to sustain the momentum of integrating SDGs into nanotechnology education and research in Ukraine.

The war has led to the significant displacement of universities and research institutions, many of which have relocated due to occupation or destruction[31]. This displacement disrupts the continuity of nanotechnology programs and complicates the integration of SDGs, diverting resources and

[29] The role of FAIR nanosafety data and nanoinformatics in achieving the UN Sustainable Development Goals: the NanoCommons experience / B. Alfaro Serrano et al. RSC Sustainability. 2024. URL: https://doi.org/10.1039/d3su00148b

[30] Resilience in Wartime Research: Case of Anticrisis Management at a Ukrainian University / I. Bohdanov et al. 2023 IEEE 18th International Conference on Computer Science and Information Technologies (CSIT), Lviv, Ukraine, 19–21 October 2023. 2023. URL: https://doi.org/10.1109/csit61576.2023.10324134

[31] Youth views on the role of local government and universities in the development of deoccupied territories / I. Bohdanov et al. Knowledge and Performance Management. 2023. Vol. 7, no. 1. P. 29–46. URL: https://doi.org/10.21511/kpm.07(1).2023.03

attention to immediate survival and adaptation. Furthermore, the physical destruction of scientific infrastructure severely limits the possibilities for high-level research activities essential for exploring the contribution of nanotechnologies to SDGs.

The migration of students and teachers, both internally and as refugees, represents a substantial loss of Ukraine's intellectual capital. This departure depletes the talent pool necessary for advancing nanotechnologies and sustainable development goals and fragments academic communities, undermining collaborative efforts and exchanging ideas. The resulting dispersion challenges the cohesion and effectiveness of nanotechnology programs to achieve SDGs.

Adapting to online learning environments and unconventional conditions, such as bean warehouses or under the pressure of air raid sirens and missile attacks, introduces additional complexities. While digital platforms offer a means to continue education amidst disruptions, they can hinder practical training and laboratory work, which are crucial for nanotechnologies. Moreover, the stresses of war and related mental health issues weigh heavily on students and educators, affecting their ability to engage effectively in the learning process[32].

Despite these daunting challenges, the Ukrainian context also presents opportunities for rethinking the integration of SDGs into nanotechnology programs. The resilience demonstrated by the academic community in the face of adversity underscores a commitment to education and research that can be harnessed to align nanotechnology efforts with sustainable development goals more closely[33]. Innovations in online and blended learning, developed out of necessity, could offer models for expanding access to nanotechnology education, emphasizing SDG-related content.

Moreover, the acute awareness of issues such as health, clean energy, and sustainable cities, intensified by the conflict, can stimulate more focused research and innovations in nanotechnologies to achieve these SDGs. Reconstruction and recovery provide a foundation for applying nanotechnology solutions based on SDG principles, from infrastructure restoration to ensuring public health and environmental sustainability.

Addressing the integration of SDGs into nanotechnology programs in the war-torn Ukrainian context requires a multifaceted strategy. This strategy must recognize the current challenges while seeking to leverage the unique

[32] Burnout dynamic among Ukrainian academic staff during the war / N. Tsybuliak et al. Scientific Reports. 2023. Vol. 13, no. 1. URL: https://doi.org/10.1038/s41598-023-45229-6

[33] Suchikova Y., Kovachov S. Rethinking the Goals and Values of Nanoart During the War: an Artists' Statement. NanoEthics. 2023. Vol. 17, no. 2. URL: https://doi.org/10.1007/s11569-023-00447-0

conditions and resilience of the Ukrainian academic and scientific community[34]. It entails rebuilding physical infrastructure, regathering dispersed intellectual capital, and rejuvenating nanotechnology programs with a renewed focus on sustainable development goals vital for the nation's recovery and future prosperity. Collaborating with international partners, utilizing innovations in digital and remote learning, and prioritizing research and education that align with immediate needs and long-term development goals are critical steps toward overcoming the challenges posed by the current crisis.

3. Strategies for Integrating Sustainable Development Goals into Nanotechnology Programs at Ukrainian Universities

Integrating Sustainable Development Goals (SDGs) into nanotechnology programs at Ukrainian universities requires innovative and resilient strategies. These strategies are crucial for leveraging nanotechnologies as a catalyst for sustainable development and recovery in Ukraine, especially in light of the significant challenges posed by the current situation.

Creating an interdisciplinary curriculum that combines nanotechnologies with sustainable development sciences and ethics necessitates close collaboration among faculties. Developing curriculum frameworks that align course objectives with SDG targets ensures that sustainability is woven into the fabric of nanotechnology education. Additionally, offering professional development opportunities for educators enhances their ability to effectively integrate SDGs into their teaching, enriching the educational experience for students.

The transition to online and distance learning opens paths to enhancing the accessibility of education. Using digital platforms to conduct SDG workshops and seminars can tap into international expertise. Virtual labs and simulations provide students with practical experience in applying nanotechnologies to solve sustainable development problems, compensating for the lack of physical access to laboratories. Furthermore, creating and disseminating open educational resources focused on nanotechnologies and SDGs makes high-quality learning materials widely available.

Encouraging research addressing SDG tasks involves securing funding for relevant projects and promoting international cooperation to pool resources and knowledge. Engaging students in these research initiatives from an early stage cultivates a culture of innovation and sustainable

[34] Development of an Inclusive Educational Environment in Higher Education Institutions: A Project Approach Using IDEF0 / O. Hurenko et al. 2023 IEEE 18th International Conference on Computer Science and Information Technologies (CSIT), Lviv, Ukraine, 19–21 October 2023. 2023. URL: https://doi.org/10.1109/csit61576.2023.10324022

development, preparing them to contribute effectively to nanotechnologies and sustainable development.

Partnerships with industry stakeholders can facilitate the application of sustainable nanotechnology solutions. Interaction with international networks improves knowledge exchange, while community engagement ensures that scientific and educational efforts align with local needs. This collaboration expands the resources and perspectives available for advancing SDGs through nanotechnologies.

Adapting to ongoing challenges requires flexible program structures to accommodate new SDG-related content. Support systems focused on the mental health and well-being of the academic community are vital for sustaining engagement under stress. Continuous assessment and feedback mechanisms ensure that SDG integration strategies remain relevant and practical, allowing programs to evolve in response to new developments.

Ukrainian universities can navigate the complexities of integrating Sustainable Development Goals into nanotechnology programs through these strategic approaches. This integration positions nanotechnologies as a critical driver of sustainable development. It aligns with Ukraine's broader goals for recovery and future prosperity, demonstrating the transformative potential of integrating advanced scientific research with global sustainability goals.

CONCLUSIONS

In conclusion, integrating Sustainable Development Goals (SDGs) into nanotechnology programs at Ukrainian universities is a vital and strategic affair amidst the multifaceted challenges of the ongoing war and its consequences. This article underscores the necessity of leveraging the transformative potential of nanotechnologies to address critical issues of sustainability, recovery, and resilience in Ukraine. Through innovative curriculum adaptation, the utilization of digital and remote learning, fostering research and innovation related to SDGs, establishing robust partnerships, and promoting resilience and adaptability, Ukrainian universities can navigate the complexities of integrating SDGs into their nanotechnology programs.

The challenges, though significant, illuminate the path to a sustainable and prosperous future. They call for concerted efforts from educators, researchers, policymakers, industry stakeholders, and the international community to rethink and rejuvenate Ukraine's scientific and educational landscape. By embedding the principles and goals of SDGs into nanotechnology education and research, Ukraine can cultivate a generation of scientists, engineers, and professionals capable of utilizing nanotechnologies for sustainable development.

Moreover, this integration effort transcends national borders, contributing to global sustainability and innovation. It highlights the role of science and technology in solving pressing global challenges and underscores the importance of education in fostering a sustainable future. As Ukraine moves forward in its recovery and strives for competitiveness on the global stage, the integration of SDGs into nanotechnology programs emerges not just as a response to immediate challenges but as a commitment to long-term sustainability and prosperity.

The journey towards integrating SDGs into nanotechnology programs in Ukraine is fraught with challenges but also replete with opportunities. It requires resilience, innovation, and collaboration to overcome the current obstacles. However, the potential rewards–advancing sustainable development, enhancing Ukraine's scientific and technological capabilities, and contributing to global efforts to achieve the SDGs–make this endeavor necessary and imperative. Successful integration of SDGs into nanotechnology programs will serve as a testament to Ukraine's resilience and vision, marking a significant step towards a sustainable and prosperous future for Ukraine and the world.

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SUMMARY

This article explores the integration of Sustainable Development Goals (SDGs) into nanotechnology programs at Ukrainian universities, highlighting the strategic importance of these efforts against the backdrop

of ongoing conflict and post-war recovery challenges. It outlines the multifaceted obstacles the Ukrainian educational and scientific sectors face, including infrastructure destruction, the flight of intellectual capital, and the shift to online and remote learning. Despite these difficulties, the article argues that the transformative potential of nanotechnologies can significantly contribute to sustainability and resilience in Ukraine. The article provides a roadmap for effectively integrating SDGs into nanotechnology education and research through a detailed examination of strategies for curriculum adaptation, enhancement of digital educational platforms, alignment of research with SDGs, formation of partnerships, and promotion of institutional resilience. It emphasizes the critical role of interdisciplinary approaches, international cooperation, and innovative pedagogy in overcoming the barriers created by the current crisis. The conclusion underscores the broader implications of this integration for global sustainability efforts and the development of nanotechnologies as a tool for addressing global challenges. By situating the discussion within the Ukrainian context, the article makes a valuable contribution to understanding the role of science and technology education in post-conflict recovery and sustainable development. It calls for concerted efforts from stakeholders at all levels to support the integration of SDGs into nanotechnology programs, viewing this as a crucial step towards building a more sustainable, resilient, and prosperous future for Ukraine and beyond.

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Information about the authors:
Kovachov Serhii Serhiyovych,
Researcher of Berdyansk State Pedagogical University
4, Schmidta Str., Berdiansk, Zaporizhzhia oblast Temporarily moved to:
66, Zhukovs`ki Str., Zaporizhzhia, Ukraine

Kurylo Olha Yuriivna,
Candidate of Pedagogical Sciences,
Senior Lecturer at the Department of Vocational Education, Labor Training and Technologies
Berdyansk State Pedagogical University
4, Schmidta Str., Berdiansk, Zaporizhzhia oblast Temporarily moved to:
66, Zhukovs`ki Str., Zaporizhzhia, Ukraine

Sychikova Yana Oleksandrivna,
Doctor of Technical Sciences, Professor, Vice-Rector for Scientific Work Berdyansk State Pedagogical University
4, Schmidta Str., Berdiansk, Zaporizhzhia oblast Temporarily moved to:
66, Zhukovs`ki Str., Zaporizhzhia, Ukraine