UDC 378:004:502.131.1
DOI https://doi.org/10.31392/UDU-nc.series5.2026.109.16

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INTERNATIONAL EXPERIENCE IN DEVELOPING FUTURE IT SPECIALISTS’ PROFESSIONAL COMPETENCE IN THE CONTEXT OF SUSTAINABLE DEVELOPMENT

The article synthesizes international experience (2020-2025) in developing the professional competence of prospective IT specialists within sustainable development. The study integrates a theoretical review of scholarly sources with content analysis of publicly available descriptions of degree programs, courses, and institutional initiatives, and applies comparative pedagogical analysis to purposively selected cases in North America, Europe, and Asia (e.g., MIT, Stanford, Cambridge, ETH Zurich, TU Delft, NUS, the University of Tokyo). The comparison identifies transferable patterns and region-specific emphases: interdisciplinary integration of computing with humanities and social sciences; project- and challenge-based learning focused on real sustainability problems; early engagement in research and capstone projects; institutional support through laboratories/ centers and partnerships with industry and civic stakeholders; internationalization via joint programs and virtual mobility; and systematic development of soft skills, ethical reasoning, responsible computing, and accountability for digital solutions’ societal impact. The findings show that sustainability is most effectively embedded not as a standalone «add-on» course, but as a cross-cutting component of curriculum content and program organization, aligned with assessment tools (rubrics, portfolios, expert review, and project defenses) that evaluate technical quality alongside environmental, social, and ethical impacts of student products, and make learning outcomes traceable across modules. The results can support modernization of Ukrainian IT programs by adapting reproducible mechanisms (interdisciplinarity, project-based learning, research tracks, partnerships) and by refining a competency assessment framework for sustainable development in IT education.

Key words: *curriculum integration, IT education, sustainability mainstreaming, project-based learning, interdisciplinarity, responsible computing.*

(стаття подана мовою оригіналу)

The development of professional competence in prospective IT specialists is a global educational challenge, requiring synthesis of international experience to identify effective approaches adaptable to national systems and sustainable development goals. International practice demonstrates diverse training models shaped by educational traditions, economic priorities, technological maturity, and sociocultural contexts.

In 2020–2025, IT education has increasingly focused on innovative pedagogical solutions that develop both strong technical skills and awareness of IT’s role in supporting sustainable development. Key trends include interdisciplinary integration of computer science with the humanities and social sciences; project-based learning grounded in real sustainable development problems; close industry collaboration; internationalization via virtual mobility and joint programs; and stronger attention to soft skills, ethical reasoning, and social responsibility.

The purpose of the article is to synthesize and systematize international experience in developing the professional competence of prospective IT specialists in the context of sustainable development, as well as to identify key trends and reproducible educational mechanisms for integrating sustainability into IT education for subsequent adaptation within national educational programs.

Objectives of the article: to analyze key trends in international IT education regarding the integration of technical training with a sustainable development orientation; to compare dominant models/practices of IT specialist training and approaches to incorporating sustainability topics into educational programs; to identify the most effective mechanisms for developing professional competence in the context of sustainable development; and to formulate generalized conclusions on how sustainable development is implemented systematically within educational programs.

Research methods included theoretical analysis and synthesis of scholarly sources and descriptions of educational practices; comparative pedagogical case analysis; content analysis of publicly available information on programs, courses, and initiatives; purposive sampling of universities to identify reproducible mechanisms for integrating sustainable development into IT training; and systematization and classification of the mechanisms identified.

Universities were selected purposively to capture transferable practices. The sample prioritized institutions with strong international standing in computer science and engineering and with formalized initiatives (courses, centers, or programs) that explicitly emphasize sustainability, ethics, societal impact, or responsible computing. Only cases with sufficiently detailed, publicly accessible information on curricula and learning formats were included to enable valid cross-case comparisons. To reduce regional bias, the selection spans multiple regions and educational models and reflects varied competency-development mechanisms, including interdisciplinarity, project-based learning, research tracks, industry and civic partnerships, and impact-oriented evaluation of digital solutions.

The Massachusetts Institute of Technology (MIT) is widely regarded as one of the pioneers in developing innovative approaches to IT education that incorporate the principles of sustainable development. MIT’s computer science curriculum includes required coursework on technology ethics, the social impact of computing, and the sustainability of digital systems, delivered through the Social and Ethical Responsibilities of Computing (SERC)

program. A distinctive feature of MIT's approach is its emphasis on research-oriented learning, whereby students are engaged from the early years of study in authentic research projects with practical relevance to addressing global challenges.

The "Computing & Society Community of Research" within MIT's Computer Science and Artificial Intelligence Laboratory (CSAIL) focuses on understanding and shaping the interplay between computational systems and society by drawing on engineering and computer science, as well as public policy research [1].

MIT actively advances an interdisciplinary approach through dual-degree programs that combine computer science with economics, biology, ecology, and sociology. The MIT Media Lab is a distinctive example of integrating technological research with art, design, and the social sciences [2, 3]. Students work on projects at the intersection of technology and the humanities, developing innovative solutions for education, healthcare, environmental sustainability, and social justice. MIT's assessment system emphasizes not only technical knowledge, but also students' capacity for critical thinking, creative problem solving, communication skills, and social responsibility.

Stanford University has developed an innovative model through the Hasso Plattner Institute of Design (d.school), founded in 2004 by Professors David Kelley and Bernard Roth, which integrates design-thinking methodologies into information technology (IT) education [4]. Students study not only the technical aspects of software development, but also user research methods, prototyping, testing, and iterative product development. The d.school serves as a hub for innovators at Stanford, where students and faculty from engineering, medicine, business, law, the humanities, the natural sciences, and education collaborate to address complex global challenges [5]. A distinctive feature of Stanford's approach is its close engagement with Silicon Valley, which provides students with access to internships, mentorship programs, and startup incubators.

The University of Cambridge delivers the Computer Science Tripos (CST) undergraduate program, which combines rigorous mathematical training with intensive engineering and research practice. The contemporary structure of the program – Part IA, Part IB, Part II, and the optional Part III – integrates mathematical disciplines with the core of computer science. Students study algorithm theory, data structures, digital electronics, operating systems, and software engineering [6, 7].

A distinctive feature of Cambridge's approach is the supervision system, which involves individualized work between students and academic staff. This format enables learning to be tailored to students' personal interests and supports the development of research competencies. At the same time, the program includes practice-oriented courses and team projects in which students design and test real-world software solutions [7].

Although the program does not include a separate mandatory course on "digital human rights," the department actively supports interdisciplinary research spanning AI ethics, human-machine interaction, and issues of technological accountability. These themes are addressed through elective courses (e.g., *Interaction with Machine Learning*) and through the research agenda of the Learning and Human Intelligence group, which focuses on the ethics, explainability, and societal impact of technologies [7, 8]. Overall, the Cambridge model combines a strong theoretical foundation with an innovative research culture oriented toward the social responsibility of IT.

The Swiss Federal Institute of Technology (ETH Zurich) has developed a distinctive model through the Future Cities Laboratory, where IT students collaborate with architects, urban planners, and environmental scientists to design technological solutions for sustainable cities [9]. The program encompasses projects in smart transportation, energy-efficient buildings, waste management systems, and environmental monitoring. A hallmark of the Swiss approach is close integration with industry through cooperative education schemes, in which students spend semesters in technology companies, working on real-world projects.

The University of Toronto (Canada) has established the Vector Institute for Artificial Intelligence, founded in 2017, which places strong emphasis on the ethical dimensions of artificial intelligence (AI) and machine learning [10]. Students study not only the technical foundations of AI, but also algorithmic fairness, decision transparency, privacy protection, and the social impact of automation. The curriculum includes required coursework in the philosophy of technology, law and data ethics, and the sociology of digital technologies. A distinctive feature of the Canadian approach is a sustained focus on multiculturalism and inclusivity, reflecting the country's demographic context.

European experience is characterized by a systematic approach to integrating sustainable development principles into IT education through pan-European initiatives and programs. The Erasmus+ Digital Education Action Plan (2021-2027) outlines strategic priorities for the digital transformation of education while incorporating the principles of the green transition and social inclusion [11]. European universities are actively developing joint IT curricula that include modules on digital ethics, green software development, and technologies for sustainable development.

The Technical University of Munich (TUM) has developed the "Sustainable Software Engineering" program, which integrates software life-cycle principles with environmental sustainability requirements. Students study methods for assessing the energy consumption of software, techniques for optimizing code to reduce its carbon footprint, and principles for designing energy-efficient algorithms. The program includes practical projects focused on developing software for energy system management, environmental monitoring, and resource optimization [12].

The KTH Royal Institute of Technology in Stockholm has introduced the concept of "Digital Sustainability," encompassing the technical, social, and economic dimensions of digital technologies. Its educational offerings

include courses in the digital economy, social entrepreneurship, technologies for development, and inclusive design. A distinctive feature of the Swedish approach is its emphasis on social innovation and entrepreneurship with societal impact. Students develop startups aimed at addressing social and environmental challenges through digital technologies [13].

Delft University of Technology (TU Delft) in the Netherlands is advancing initiatives in the field of Sustainable Information and Communication Technologies (Sustainable ICT). The university positions itself as a climate-action–oriented institution and implements measures aimed at achieving energy neutrality. Within the Sustainable ICT Initiative, TU Delft conducts research on energy-efficient data centers, energy-efficient 5G communications, and the development of energy-aware code. A distinctive feature of TU Delft’s approach is its focus on designing battery-free, less polluting, and more sustainable Internet of Things systems [14].

Aalborg University (Denmark) has implemented a “Problem-Based Learning” (PBL) model in IT education oriented toward addressing real-world sustainable development challenges. Students work in interdisciplinary teams on semester-long projects that integrate technological innovation with social and environmental needs. These projects include the development of smart-city systems, platforms for the circular economy, technologies supporting the energy transition, and digital solutions for agriculture [15].

Asian practice is characterized by a strong emphasis on technological innovation and close collaboration with industry. The National University of Singapore (NUS) has developed the “Computing for Social Good” program, which integrates the social sciences with computing technologies. Students examine applications of artificial intelligence in healthcare, education, urban development, and environmental sustainability. A distinctive feature of the Singaporean approach is the treatment of the smart city as a living laboratory for testing technological innovations. Students engage in real-world projects in smart transportation, energy management, e-government, and citizen-oriented digital services [16].

The University of Tokyo is one of the leading centers shaping an educational model grounded in the “Society 5.0” concept, proposed by the Japanese government as a strategic response to the challenges of the digital era. The concept envisions the creation of a “super-smart society” in which cyber-physical systems, artificial intelligence, big data, the Internet of Things (IoT), and robotics are integrated to address complex societal problems – from demographic aging to the sustainable development of cities [17, 18]. In the university’s educational policy, this has been reflected in the implementation of interdisciplinary programs that combine technical disciplines with courses in ethics, sociology, and the humanities. This approach enables future engineers and researchers not only to master advanced technologies, but also to critically reflect on their impact on society and on cultural values that traditionally play an important role in Japan’s civilizational model of development. A particularly important role is played by the university’s collaboration with leading technology companies, including the H-UTokyo Lab project implemented jointly with Hitachi Corporation to advance research on Society 5.0 and sustainable innovation-driven growth [17].

At the same time, China’s Tsinghua University exemplifies its own educational strategy for integrating technological innovation into the response to global societal challenges. The university’s “Artificial Intelligence for Social Good” initiative is oriented toward developing solutions that apply artificial intelligence to advance the UN Sustainable Development Goals. The program spans multiple directions, including machine learning for medical diagnostics, computer vision for environmental monitoring, natural language processing for educational platforms, and the development of policies for the safe and ethical deployment of AI [19, 20]. A key feature of the Chinese model is the combination of a strong scientific base with large-scale government investment and partnerships with technology corporations, which facilitates the rapid translation of research outputs into socially meaningful innovations. As a result, Tsinghua is emerging as one of the influential centers in the global discourse on AI as a tool for humanitarian progress, aligning China’s technological capacity with international standards of ethical governance [20].

An analysis of international experience makes it possible to identify several innovative approaches that demonstrate high effectiveness in developing the professional competence of IT specialists. The “Liberal Arts + Computer Science” model, which is widespread in U.S. universities, combines rigorous technical training with a broad liberal arts education. In addition to programming and algorithms, students study philosophy, history, literature, and the arts. This integration supports the development of critical thinking, creativity, communication skills, and cultural literacy [21].

The “Co-operative Education” model, widely used in Canada and Germany, is based on alternating academic semesters at the university with work placements in companies. Students typically spend 16-20 months in paid practical training, contributing to real-world projects. This structure strengthens the link between theory and practice, supports the development of professional skills, and facilitates early networking with potential employers [22].

The “Capstone Projects” approach is widely employed across universities worldwide, including those in Scandinavia, and involves completing a substantial final-year project that integrates the knowledge and skills acquired throughout the program. For example, Aalborg University in Denmark активно applies a Problem-Based Learning (PBL) model, in which students undertake semester-long projects in collaboration with industrial partners and civil society organizations [15]. Working in teams, students demonstrate not only technical competence, but also project management capability, communication skills, and the ability to present results effectively.

The concept of "Social Innovation Labs" is being advanced across universities worldwide, including in Asian higher education institutions. For example, the National University of Singapore has developed the "Computing for Social Good" program, in which students work in interdisciplinary teams on projects related to healthcare, education, and environmental sustainability [16]. Such approaches foster social responsibility and a deeper understanding of the role of technology in societal development.

Comparative analysis of international experience reveals both common trends and distinct strategic emphases in developing IT specialists' professional competence. Across regions, shared priorities include project-based learning, strong industry collaboration, interdisciplinarity, and the cultivation of soft skills and social responsibility. Differences are mainly strategic: U.S. universities more often emphasize entrepreneurship and innovation; European institutions place greater weight on social responsibility and sustainable development; and many Asian universities prioritize technological leadership and deep integration with industry.

Effective practices include mentorship systems in which experienced professionals guide students' specialization choices, career development, and professional adaptation. The "learning by teaching" approach, where senior students support junior peers, also proves valuable by strengthening leadership and instructional skills. Integrating research into education further enhances competence by engaging students in generating new knowledge and technologies.

Overall, successful IT education models balance rigorous theoretical foundations with practical skill formation, connect technical disciplines with the humanities and social sciences, and maintain active partnerships with industry and the public sector. Program flexibility, rapid responsiveness to technological change, personalized learning pathways, and the development of lifelong learning skills are also critical.

Conclusions. An analysis of practices at leading universities indicates that the integration of sustainable development into IT education is most often achieved not through a standalone "add-on" course, but through a systemic combination of content-related and organizational-pedagogical mechanisms embedded within educational programs. The most effective mechanisms for developing the professional competence of prospective IT specialists in the context of sustainable development include interdisciplinary modules, project-based learning (PBL), early engagement in research, partnerships with industry and social stakeholders, and the incorporation of "responsible computing" components (ethics, responsibility, and the societal impact of digital solutions). A common trend across the cases reviewed is the growing role of institutional support through the establishment of centers, laboratories, or cross-faculty initiatives that ensure continuity of change, accumulation of learning resources, coordination of projects, and scaling of successful practices. Effective competency development is associated with a shift from declarative inclusion of sustainability themes to engagement with authentic problems, where students must analyze context, constraints, risks, and impact metrics, and justify technical decisions. A further hallmark of mature approaches is alignment between learning content and assessment tools, including rubrics, portfolios, project defenses, and expert review, which make it possible to evaluate not only technical correctness but also the socio-environmental and ethical dimensions of digital products.

The results confirm the relevance of adapting international experience for Ukrainian educational programs by selecting reproducible mechanisms rather than replicating individual courses. Priority steps include modernizing disciplinary content, strengthening interdisciplinarity, implementing PBL and research tracks, and formalizing collaboration with industry and communities.

Future research should focus on developing a coherent framework for assessing sustainable development competencies in IT education and on empirically validating the effectiveness of the proposed mechanisms on a sample of Ukrainian higher education institutions.

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Стаття узагальнює міжнародний досвід (2020-2025) розвитку професійної компетентності майбутніх ІТ-фахівців у контексті сталого розвитку. Дослідження поєднує теоретичний огляд наукових джерел із контент-аналізом публічно доступних описів освітніх програм, курсів та інституційних ініціатив і застосовує порівняльно-педагогічний аналіз до цілеспрямовано відібраних кейсів у Північній Америці, Європі та Азії (зокрема MIT, Stanford, Cambridge, ETH Zurich, TU Delft, NUS, University of Tokyo). Порівняння дає змогу виокремити відтворювані підходи та регіонально специфічні акценти: міждисциплінарну інтеграцію інформатики з гуманітарними й соціальними науками; проєктне та проблемно-орієнтоване навчання, спрямоване на розв'язання реальних завдань сталого розвитку; раннє залучення студентів до досліджень і випускних (capstone) проєктів; інституційну підтримку через лабораторії/центри та партнерства з індустрією і громадянськими стейкхолдерами; інтернаціоналізацію через спільні програми та віртуальну мобільність; а також системний розвиток м'яких навичок, етичного мислення, принципів відповідального обчислення й відповідальності за суспільний вплив цифрових рішень. Результати показують, що сталість найефективніше інтегрується не як окремий «додатковий» курс, а як наскрізний компонент змісту й організації освітньої програми, узгоджений з інструментами оцінювання (рубрики, портфоліо, експертне рецензування та захисти проєктів), які дають змогу оцінювати не лише технічну коректність, а й екологічні, соціальні та етичні наслідки студентських продуктів і забезпечують простежуваність результатів навчання між модулями. Отримані висновки можуть бути використані для модернізації українських ІТ-програм шляхом адаптації відтворюваних механізмів (міждисциплінарність, проєктне навчання, дослідницькі траєкторії, партнерства) та уточнення рамки оцінювання компетентностей сталого розвитку в ІТ-освіті.

Ключові слова: *інтеграція в навчальні плани, ІТ-освіта, наскрізне впровадження сталості, проєктне навчання, міждисциплінарність, відповідальні обчислення.*

Дата першого надходження статті до видання: 20.02.2026
Дата прийняття статті до друку після рецензування: 27.03.2026
Дата публікації (оприлюднення) статті: 22.05.2026