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PEDAGOGICAL CONDITIONS FOR DEVELOPING DIGITAL COMPETENCE OF FUTURE IT SPECIALISTS IN VOCATIONAL COLLEGES THROUGH STEAM TECHNOLOGIES

Abstract. The article substantiates the pedagogical conditions for developing the digital competence of future IT specialists in professional colleges through STEAM technologies. It shows that the rapid digitalization of society, and the IT sector in particular, creates the need to train specialists capable of effectively applying digital tools, modeling technological processes, working with data, and creating innovative products. It is determined that digital competence has a multidimensional structure that includes cognitive, technological, communicative, project-based, artistic, and ethical components, whose development becomes possible through the targeted integration of STEAM technologies into professional training.

The article reveals the content of five pedagogical conditions: motivational and value-based support of professional training; activation of independent learning activities through innovative forms and methods; integration of STEAM technologies into the curriculum to develop algorithmic, engineering, systemic, and design thinking; creation of a modern STEAM-oriented educational environment; implementation of a system for diagnostics, monitoring, and reflective–analytical support of digital competence development. It is proven that the implementation of these conditions ensures a practice-oriented character of learning, strengthens learners' intellectual autonomy, promotes their ability for innovative activity and professional mobility, enables the integration of engineering, IT, and design solutions, and ensures a high level of readiness for work in multidisciplinary teams.

The conclusion highlights that the systemic integration of STEAM technologies into professional education forms a strong foundation for preparing competitive IT specialists capable of acting effectively in a dynamic digital environment.

Keywords: digital competence; STEAM technologies; STEAM education; professional training of IT specialists; professional college; digital transformation; pedagogical conditions; digital educational environment; learner; design; artistic competencies.

ПЕДАГОГІЧНІ УМОВИ ФОРМУВАННЯ ЦИФРОВОЇ КОМПЕТЕНТНОСТІ МАЙБУТНІХ ФАХІВЦІВ ІТ-ГАЛУЗІ В ПРОФЕСІЙНИХ КОЛЕДЖАХ ЗАСОБАМИ STEAM-ТЕХНОЛОГІЙ

Анотація. У статті обґрунтовано педагогічні умови формування цифрової компетентності майбутніх фахівців ІТ-галузі в професійних коледжах засобами STEAM-технологій. Показано, що стрімка цифровізація суспільства й ІТ-сфери зокрема зумовлює потребу в підготовці фахівців, здатних ефективно застосовувати цифрові інструменти, моделювати технологічні процеси, працювати з даними та створювати інноваційні продукти. Визначено, що цифрова компетентність має багатовимірну структуру й охоплює когнітивні, технологічні, комунікативні, проєктні, мистецькі й етичні компоненти, розвиток яких можливий за умови цілеспрямованого впровадження STEAM-технологій у професійну підготовку.

Розкрито зміст п'яти педагогічних умов: мотиваційно-ціннісного забезпечення професійної підготовки; активізації самостійної навчальної діяльності через інноваційні форми й методи; інтеграції STEAM-технологій у зміст навчання для розвитку алгоритмічного, інженерного, системного та дизайн-мислення; створення сучасного STEAM-орієнтованого освітнього середовища; упровадження системи діагностики, моніторингу та рефлексивно-аналітичної підтримки розвитку цифрової компетентності. Доведено, що реалізація цих умов забезпечує практико орієнтований характер

навчання, посилює інтелектуальну автономію здобувачів освіти, сприяє формуванню здатності до інноваційної діяльності та професійної мобільності, дає змогу вільно поєднувати інженерні, IT та дизайнерські рішення, а також забезпечує високий рівень готовності до діяльності в мультидисциплінарних командах.

Зроблено висновок, що системна інтеграція STEAM-технологій у професійну освіту створює підґрунтя для підготовки конкурентоспроможних IT-фахівців, здатних ефективно діяти за умов динамічного цифрового середовища.

Ключові слова: цифрова компетентність; STEAM-технології; STEAM-освіта; професійна підготовка IT-фахівців; професійний коледж; цифрова трансформація; педагогічні умови; цифрове освітнє середовище; здобувач освіти; дизайн; мистецькі компетентності.

INTRODUCTION

The problem formulation. In the current context of deepening digital transformation across the economy, society, and the educational sector, the issue of developing digital competence among future IT specialists in professional colleges emerges as strategically significant. The modern labor market demonstrates a consistent demand for professionals capable of working effectively in information-rich environments, applying digital technologies for communication, data processing, production process modeling, information flow management, and solving complex professional tasks. Within this framework, digital competence is viewed not merely as an instrumental characteristic but as an integral component of an IT specialist's professional culture, encompassing cognitive, technological, communicative, social, and ethical dimensions.

Given this context, STEAM technologies – which integrate scientific, technological, engineering, and mathematical approaches–serve as a powerful methodological resource for modernizing professional training. They support the development of algorithmic, engineering, and systemic thinking, the ability to work with digital models, analytical tools, and simulation environments, and contribute to shaping innovative skills that are essential for the competitiveness of IT professionals in a globalized digital space.

The relevance of this issue intensifies alongside the digitalization of vocational education in Ukraine, where there remains a lack of coherent conceptual and technological approaches to integrating STEAM into the training of future specialists in professional colleges. As a result, a significant gap emerges between the needs of the IT industry and the actual level of digital preparedness among learners. According to S. Sevastyanova, in the modern educational environment «digital competence is the foundation for creating and implementing new educational technologies that transform traditional learning models and require adaptation to the conditions of «digital life»» (Sevastyanova, 2024, pp. 41– 42). This observation highlights the necessity of forming students' digital readiness not only at the level of mastering tools but also at the level of strategic capability for professional growth amid constant technological change.

Scientific studies confirm that the effectiveness of developing digital competence directly depends on specific pedagogical conditions. Among the key ones are: motivational and value-based support of learners' professional training grounded in STEAM-oriented educational practices; activation of independent learning activities in the process of studying informatics disciplines through innovative forms, methods, and digital tools; integration of STEAM technologies into the content of professional training to develop algorithmic, engineering, systemic, and design thinking in future IT specialists; creation of a modern STEAM-oriented educational environment within the professional college; and the implementation of a system for diagnostics, monitoring, and reflective–analytical support of learners' digital competence development. In professional colleges focused on practical training, the absence of these conditions leads to insufficient development of programming skills, engineering thinking, digital communication, and cybersecurity–competencies that form the core of contemporary professional preparation for IT specialists.

Therefore, the systemic implementation of STEAM technologies as a tool for developing the digital competence of future IT specialists is an essential prerequisite for modernizing the content and methods of vocational education. This approach ensures alignment with global educational trends, strengthens the practice-oriented nature of the learning process, and enables learners to acquire a comprehensive set of competencies necessary for effective performance in a high-technology digital environment.

Analysis of recent research and publications. The digitalization of the educational space has become one of the key vectors of educational development and an active subject of scientific inquiry. The methodological foundations of digitalizing the information and educational environment of vocational institutions have been explored by A. Hurzhiy, V. Radkevych, and M. Pryhodii; digital tools in Ukrainian vocational education–their historical evolution, implementation features, and prospects–have been examined by N. Marchuk. In the works of Ukrainian researchers such as V. Bykov, O. Budnyk, M. Dereniuk, O. Dzhogolyk, O. Kondur, N. Nychkalo, T. Paska, L. Prokopiv, S. Sysoieva, V. Stynska, O. Tsiuniak and others, digital technologies are viewed as a strategic resource for modernizing professional training. Scholars emphasize that digital tools and technologies are becoming decisive for improving the quality of learning, enhancing professional mobility, and strengthening the competitiveness of future specialists, which underscores the need to develop a coherent system of relevant skills and practices.

A significant contribution to the study of digital competence development has been made by N. Borozenets, M. Sevastyanova, O. Spirin, I. Shyshenko, Yu. Shcherbyna and others, who emphasize the importance of developing learners' digital skills, interpreting them as a necessary prerequisite for sustainable societal development and the innovative renewal of the educational sphere.

The issue of STEAM education in the training of specialists under conditions of digital transformation has been highlighted by O. Buriak, K. Kravchenko, T. Kravchenko, O. Mysiuk, V. Saiko and others, while the theoretical

foundations of monitoring the development of a STEAM-oriented educational environment have been explored by N. Soroko, O. Shymon and others.

AIM AND TASKS RESEARCH – to substantiate the pedagogical conditions for developing the digital competence of future IT specialists in professional colleges through STEAM technologies.

RESEARCH METHODS

In the course of the study, a set of scientific and pedagogical research methods was used, namely:

Theoretical methods: analysis (of psychological-pedagogical, scientific-methodical, and regulatory literature on digital competence, STEAM education, and professional training of IT specialists); synthesis (generalization of theoretical approaches to the structure of digital competence and STEAM integration); comparison and classification (juxtaposition of international and national models of digital competence–DigComp, DigCompEdu, and Ukrainian concepts); modeling (theoretical substantiation of pedagogical conditions for developing digital competence in professional colleges).

Empirical methods: pedagogical observation (identifying features of students' learning activities in a STEAM-oriented environment); analysis of students' work products (STEAM projects, digital developments, results of independent and project-research activities).

RESULTS OF THE RESEARCH

Digital competence is a concept largely introduced by European policy documents, having then emerged as a research topic of the moment (Zhao et al., 2021). It was introduced by Ferrari (2013) with the publication of the DigComp framework, which served as basis for several other digital competence frameworks developed by the European Commission, such as DigComp for Consumers (2016), DigCompOrg (2017), DigCompEdu (2017), and the newest version DigComp 2.2 (2022), to cite a few

Since the concept of digital competence is actively developed and refined in European and global scientific discourse, there are multiple definitions of «digital competence" that reflect different emphases–from technical skills to integrated cognitive, social, and professional abilities, including:

- an integrated capability combining knowledge, skills, attitudes, cognitive abilities, and conscious strategies necessary for the effective, safe, and ethical use of ICT and digital media to solve professional tasks, communicate, and create and share information content (Ferrari, 2012, p. 30);
- confident, critical, and responsible use of and interaction with digital technologies in learning, professional activities, and social communication, based on the integration of relevant knowledge, skills, and attitudes (Vuorikari, 2022);
- an individual's ability to use ICT responsibly and consciously, to interact effectively with digital technologies in learning and professional activities, and to purposefully improve their own knowledge and skills to ensure successful lifelong development (Sevastyanova, 2024, pp. 41–42);
- an integral professional-personal characteristic of a specialist, reflecting their ability to design the educational process using digital technologies (Shcherbyna, 2023, p. 258);
- an individual's ability to use digital technologies confidently and competently in areas such as professional activity and employment, education, leisure, and civic engagement, which is essential for participation in everyday socio-economic life (Spirin, 2025, p. 62).

Digital competence is regarded as a core professional characteristic for future IT specialists, as it ensures their readiness to work effectively with technological, project-engineering, artistic, and organizational-management components of professional activity. For an IT specialist, digital competence encompasses not only mastery of tools and technologies but also the ability to critically assess their application, understand the impact of chosen technological solutions on product quality, user experience, and the effectiveness of team collaboration.

Within the structure of digital competence for future IT specialists, key elements include technical skills, algorithmic and systems thinking, the ability to integrate digital tools into software development processes, and awareness of pedagogical and methodological aspects of teamwork, mentorship, and mutual learning. Acting as a leader or member of an IT team, a future specialist fosters the digital competence of colleagues by guiding productive collaboration, knowledge exchange, and the implementation of innovations.

Based on the synthesis of the presented definitions and considering the specifics of the professional activity of future IT specialists, the category «digital competence of an IT specialist" is defined as a multidimensional system of knowledge, skills, abilities, and value orientations that combines technological, cognitive, communicative, project-based, artistic, and ethical components, ensuring the specialist's capacity to act effectively, creatively, and responsibly in the digital society and professional sphere.

The outlined characteristics of digital competence for future IT specialists highlight its multidimensional nature and key role in professional training. Understanding its structure, content emphases, and functional significance makes it possible to identify the specific pedagogical conditions under which it can be developed most effectively.

Therefore, substantiating the pedagogical conditions that ensure the purposeful, phased, and effective development of digital competence in future IT specialists in professional colleges through STEAM technologies becomes a key methodological task of the study.

The first pedagogical condition is the motivational and value-based support of learners' professional training through STEAM-oriented educational practices.

This condition involves creating an educational environment that fosters students' intrinsic motivation to master digital technologies through their practical relevance, professional value, and innovative potential. It is based on understanding motivation as a compensatory factor that ensures high productivity even with limited intellectual resources or foundational knowledge, guiding students toward success through cognitive-heuristic techniques (induction, deduction, heuristics) and cultivating an intrinsic need for the practical application of digital tools. In STEAM-oriented education, it serves as a system-forming component, engaging learners in intellectually rich activities, which is critically important for IT specialties that demand self-directed learning and adaptability (Sevastyanova, 2023).

Motivation, as a fundamental psychological determinant, defines the direction and persistence of educational activity, creating conditions for personal development and professional growth of the learner. Active engagement of learners in the educational process, manifested through various forms of academic involvement, serves as a key factor in enhancing the quality of learning and acquiring practical experience. A high level of engagement promotes deeper, conscious assimilation of educational content and the development of the ability to apply it in real professional contexts (Buriak, 2011).

STEAM technologies create a motivationally enriched educational environment by integrating computer science, mathematics, technology, engineering, and art into the solution of practical professional tasks, such as programming robotic systems, developing algorithms, designing digital prototypes, and analyzing data, thereby bringing learning into the realm of real professional relevance (Concept, p. 208). The use of simulators, virtual laboratories, and complex tasks models production processes, stimulating active problem-solving and the development of research initiative.

The practical implementation of such integration in professional colleges includes:

- the use of problem-oriented scenarios from real IT environments;
- the use of micro-didactic complexes, including training sessions with IT process simulations, hackathons for creating digital products, cybersecurity exercises, interdisciplinary quests, logic tasks (puzzles, mazes), and STEAM projects such as «Engineering Calculations + Python," which combine engineering, technology, data analysis, and creative components;
- the development of a positive attitude toward digital technologies, digital ethics, and responsibility;
- the use of suggestive methods ensures psychological comfort, reduces anxiety, and fosters self-reflection, creating favorable conditions for productive learning activities.

Thus, the motivational and value-based component facilitates students' transition from reproductive forms of learning to research and project-based activities, actively developing algorithmic, critical, and creative thinking, which forms the foundation for digital competence.

The second pedagogical condition is the activation of independent learning activities in the process of mastering informatics disciplines through the use of innovative forms, methods, and digital tools.

This condition encompasses the organization of an educational process that stimulates students' autonomy, responsibility, and intellectual initiative. It is grounded in contemporary principles of cognitive pedagogy, self-regulated learning theory (A. Zimmerman), principles of self-regulated learning (F. Vinn), cognitive and metacognitive processes in self-regulated learning (F. de Jong), motivation and self-regulated learning (P. Pintrich), social aspects of self-regulation (M. Pressley), and STEM education concepts, which view the learner as an active subject of knowledge capable of constructing new understanding through research, experimentation, and practical application of technological tools (Balashov, 2020, p. 52).

The activation of independent learning activities in the context of STEAM education is implemented through:

- the use of cognitive-heuristic techniques (inductive, deductive, heuristic strategies) that stimulate the independent discovery of patterns and principles of digital technologies;
- the use of integrative, game-based, and problem-solving methods (digital crosswords, cryptograms, simulation models, logical mazes) that develop analytical and algorithmic thinking;
- the implementation of project-research learning technologies, which involve the creation of prototypes, web products, software modules, micro-projects for data processing, and elements of machine learning;
- the use of innovative digital platforms, cloud services, and virtual laboratories for independent experimentation and modeling of complex technical processes (Marchuk, 2024).

These tools contribute not only to mastering the content of informatics disciplines but also to developing the ability for self-regulation, self-assessment, critical analysis of information, and responsible use of digital content and the online environment.

In the professional training of IT specialists, this approach facilitates the transition of learners from observation and imitation to independently creating digital products, thereby developing the cognitive, operational-technological, and reflective components of digital competence.

Thus, the activation of students' independent learning activities is an important pedagogical condition that ensures the stability, systematicity, and effectiveness of developing digital competence in future IT specialists in professional colleges through STEAM technologies, while promoting their professional adaptability and readiness to work in rapidly changing technological environments.

The third pedagogical condition is the integration of STEAM technologies into the content of professional training to develop algorithmic, engineering, systems, and design thinking in future IT specialists.

This pedagogical condition involves the purposeful implementation of STEAM technologies (Science, Technology, Engineering, Art, Mathematics) into the content of professional training for future IT specialists, ensuring the comprehensive development of algorithmic, engineering, systems, and design thinking, as well as fostering the ability to create innovative digital products. According to the research by O. Stupak, the combination of technical and artistic competencies is a key condition for the effective preparation of specialists capable of working with 2D/3D animation, VR/AR technologies, multimedia tools, UX/UI design, digital content, and interactive environments (Stupak, 2024, p. 259).

The implementation of this pedagogical condition is carried out through:

- the implementation of interdisciplinary modules («Mathematics + Algorithmization," «Engineering Graphics + 3D Modeling," «Informatics + Digital Design");
- the organization of design thinking and digital prototyping environments;
- the execution of STEAM projects using VR/AR technologies, robotics tools, and multimedia and interactive visualization;

the use of digital fabrication (FabLab), cloud services, and professional platforms (Adobe Creative Suite, Blender, Figma, Unity, Unreal Engine, etc.).

Thus, the integration of STEAM technologies cultivates holistic digital thinking in learners, enabling them to seamlessly combine engineering, IT, and design solutions, while ensuring a high level of readiness to work in multidisciplinary teams. This aligns with global trends in the IT industry and design, where the universalization of professional roles and the ability to work with integrated digital products are key factors in a specialist's competitiveness.

The fourth pedagogical condition is the creation of a modern STEAM-oriented educational environment in professional colleges, which ensures students' practical, research, and innovative activities in the context of digital transformation.

The implementation of this pedagogical condition involves establishing a comprehensive regulatory and legal framework that institutionalizes the introduction of STEAM education in professional colleges. This includes reviewing existing and developing innovative educational standards capable of reflecting the dynamics of modern technological changes, the demands of the digital economy, and global labor market trends. Simultaneously, there is an urgent need to update the content of curricula to strengthen the project-research component, employ practice-oriented tasks, digital simulations, interactive models, and tools that develop learners' abilities for interdisciplinary integration, technological thinking, and professional autonomy (Gurzhiy, 2022).

An important system-forming factor in implementing the STEAM approach is the professional development of teaching staff in vocational education institutions. This involves the targeted enhancement of their professional competence in innovative educational technologies, STEAM pedagogy methodology, digital didactics, and the management of digital learning environments. A teacher's preparedness to design, implement, and provide scientific-methodological support for innovative practices determines the effectiveness of transformative processes and the quality of learners' digital competence development. At the same time, the STEAM approach emphasizes project-based and practice-oriented learning, extending beyond the traditional STEAM paradigm through the integration of humanities and artistic components. This integration fosters the ability to work under uncertainty, handle multidimensional problems, and generate unconventional solutions (Saiko, 2024, p. 51).

In the context of enhancing teachers' digital-methodological competence, technologies for intellectual development and methods of technical creativity play a significant role. They contribute to the formation of the ability to design innovative solutions, master new approaches to research and project-based activities, and realize the creative potential of future IT and telecommunications specialists.

The implementation of the STEAM approach also supports the development of a range of soft skills, including teamwork, providing constructive feedback, articulating and defending one's position, presenting project outcomes, and applying marketing elements in the promotion of technological products. A well-prepared teacher acts as a facilitator of digital learning, models educational situations, supervises projects, and ensures the effective implementation of STEAM integration.

The issue of modernizing the material and technical base of professional colleges is also highlighted through the creation of a high-tech educational space, which includes STEM/STEAM laboratories, engineering hubs, FabLab centers, digital workshops, and innovative coworking zones. Such an environment provides learners with access to modern software, digital platforms, robotics complexes, modeling tools, 3D prototyping, and data analytics resources (Kravchenko, 2025).

This pedagogical condition also involves expanding partnerships between colleges and IT companies, manufacturing enterprises, and research institutions through mechanisms such as dual education, internships, mentorship programs, joint research-engineering projects, and student participation in hackathons, engineering tournaments, specialized competitions, and startup schools. This form of collaboration strengthens the practice-oriented component of training, enriches learners' educational experience with real professional cases, and promotes the development of digital, engineering, algorithmic, and project-based competencies.

The comprehensive implementation of these elements creates an innovative STEAM-oriented educational environment capable of responding to the challenges of the digital economy, ensuring a high level of professional training, and promoting the development of digital competence in future IT specialists.

The fifth pedagogical condition is the implementation of a system for diagnosing, monitoring, and providing reflective-analytical support for the development of learners' digital competence.

The need to create a comprehensive system for diagnosing and monitoring students' digital competence is driven by current requirements for the quality of digital training for specialists and the priorities of the European Higher Education Area. Within the DigComp 2.2 framework, the European Commission emphasizes that the development of digital competence should be accompanied by regular assessment, which tracks student progress, identifies individual educational needs, and allows for the adjustment of learning trajectories (Vuorikari et al., 2022). According to the document, digital competence is a dynamic structure that requires continuous formative assessment through a combination of tests, self-assessment, portfolios, and activity-based tasks.

The issue of monitoring digital skills is also addressed in UNESCO studies, which emphasize the need for valid assessment systems capable not only of measuring outcomes but also of supporting learning through reflection, personalization, and individual guidance (UNESCO, Digital Literacy Global Framework, 2018). The document highlights that effective monitoring should encompass the cognitive, technical, social, and ethical components of digital competence.

According to N. Soroko's research, monitoring STEAM education is a systematic process of collecting, analyzing, and interpreting data on its status and development trends. It provides researchers, educators, and other stakeholders with the necessary information to make strategic decisions. Additionally, it should be noted that monitoring the development of STEAM education is a comprehensive process that gathers, analyzes, and interprets data on the state and dynamics of STEAM approach implementation in educational institutions.

The main monitoring objectives are:

- determining the level of integration of STEAM components into the curricula;
- analyzing the readiness of teaching staff to implement STEAM-based learning;
- assessment of material-technical resources and digital infrastructure;
- measuring the impact of STEAM education on learners' academic achievements and their motivation (Soroko, 2025, p. 65),

According to leading Ukrainian researchers (S. Ivanova, A. Kilchenko, O. Spirin, N. Franchuk), a key element in developing digital competence is also diagnostic and analytical support, as it allows for systematic assessment of students' knowledge, skills, and abilities through online testing and automated systems such as Kahoot! or Quizlet, providing objective feedback. This approach identifies gaps in IT specialists' digital skills and facilitates the adaptation of learning strategies to individual needs, thereby enhancing the effectiveness of professional training (Spirin et al., 2024, p. 95).

Thus, the system of diagnostics, monitoring, and reflective-analytical support is considered an integral structural component in the development of digital competence for future IT specialists. It ensures objectivity and systematic assessment, facilitates the personalization of the educational process, enhances motivation for independent development, and creates conditions for cultivating highly qualified, responsible, and competitive professionals in the digital field.

CONCLUSIONS AND PROSPECTS OF FURTHER RESEARCH

Summarizing the results of the theoretical analysis, it can be noted that digital competence of future IT specialists emerges as a multidimensional professional-personal construct, integrating technological, cognitive, communicative, design, and ethical components, and ensuring the ability to act effectively in the context of the digital economy and rapid techno-global changes. A set of interrelated pedagogical conditions for its development in vocational colleges through STEAM technologies has been substantiated: motivational and value-based support of professional training; activation of students' independent learning through innovative forms, methods, and digital tools; targeted integration of STEAM technologies into the professional curriculum; creation of a modern STEAM-oriented educational environment; and implementation of a system for diagnostics, monitoring, and reflective-analytical support of digital competence development. It has been demonstrated that the realization of these conditions ensures a transition from reproductive learning models to research and project-based activities, promotes the formation of algorithmic, systemic, and design thinking, strengthens students' active learning position, and enhances the alignment of educational outcomes with IT industry requirements.

The prospects for further research lie in the development of a structural-functional model for forming digital competence of future IT specialists in vocational colleges, in the empirical verification of the effectiveness of the outlined pedagogical conditions through pedagogical experiments, as well as in the creation of diagnostic tools for phased monitoring of the dynamics of digital competence formation at various stages of professional training.

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