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USE OF E-LEARNING PLATFORMS IN THE TRAINING OF PROFESSIONALS

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Abstract

Digital educational environments that offer adaptability, accessibility, the potential for simulation-based learning, and automated progress monitoring are progressively mitigating the constraints of traditional training models that predominantly emphasize face-to-face interaction. The objective of this study is to evaluate the efficacy of contemporary e-learning platforms in the training of professionals engaged in the field of critical infrastructure, taking into consideration regulatory, technological, and organizational factors. The study utilized a mixed methodology, encompassing a survey of 47 representatives of educational and government institutions; a comparative analysis of five digital platforms (Moodle CLMS TsNTU, Microsoft Learn for Educators, CISA Virtual Learning Portal, OPSWAT Academy, NSDC-authored courses); and a content analysis of the functional components of the learning environment (availability of cyber ranges, SCORM support, micro-credentials, language adaptation, and Learning Analytics). The findings revealed that the most pronounced positive influence on the quality of the educational process stemmed from the availability of adaptive simulators, Ukrainian-language content, and analytical tools for tracking the results. The scientific novelty of this study lies in the formulation of a comprehensive model for assessing the effectiveness of digital educational platforms grounded in an interdisciplinary analysis, which combines regulatory requirements, technological readiness, and pedagogical practices. Prospects for further research encompass the development of national criteria for the accreditation of online courses within high-risk sectors, the establishment of an integrated repository of simulation training materials, and the experimentation with hybrid training models predicated on adaptive scenarios and cyberfields.

Keywords: E-learning; Critical infrastructure; Cybersecurity; Training of professionals; Virtual cyber training ground

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UTILIZAÇÃO DE PLATAFORMAS DE APRENDIZAGEM ELECTRÔNICA NA FORMAÇÃO DE PROFISSIONAIS

Resumo

Os ambientes educativos digitais que oferecem adaptabilidade, acessibilidade, potencial para aprendizagem baseada em simulação e monitorização automatizada do progresso estão progressivamente a mitigar os constrangimentos dos modelos de formação tradicionais que enfatizam predominantemente a interação face a face. O objetivo deste estudo é avaliar a eficácia das plataformas de e-learning contemporâneas na formação de profissionais envolvidos no domínio das infra-estruturas críticas, tendo em consideração factores regulamentares, tecnológicos e organizacionais. O estudo utilizou uma metodologia mista, englobando um inquérito a 47 representantes de instituições educativas e governamentais; uma análise comparativa de cinco plataformas digitais (Moodle CLMS TsNTU, Microsoft Learn for Educators, CISA Virtual Learning Portal, OPSWAT Academy, cursos de autoria do NSDC); e uma análise de conteúdo dos componentes funcionais do ambiente de aprendizagem (disponibilidade de gamas cibernéticas, suporte SCORM, microcredenciais, adaptação linguística e Learning Analytics). Os resultados revelaram que a influência positiva mais pronunciada na qualidade do processo educativo resultou da disponibilidade de simuladores adaptativos, de conteúdos em língua ucraniana e de ferramentas analíticas para acompanhar os resultados. A novidade científica deste estudo reside na formulação de um modelo abrangente de avaliação da eficácia das plataformas educativas digitais, assente numa análise interdisciplinar, que combina requisitos regulamentares, preparação tecnológica e práticas pedagógicas. As perspectivas de investigação futura incluem o desenvolvimento de critérios nacionais para a acreditação de cursos em linha em sectores de alto risco, a criação de um repositório integrado de materiais de formação em simulação e a experimentação de modelos de formação híbridos baseados em cenários adaptativos e cibercampos.

Palavras-chave: E-learning; Infra-estruturas críticas; Cibersegurança; Formação de profissionais; Campo virtual de ciberformação

USO DE PLATAFORMAS E-LEARNING EN LA FORMACIÓN DE PROFESIONALES

Resumen

Los entornos educativos digitales que ofrecen adaptabilidad, accesibilidad, potencial para el aprendizaje basado en la simulación y seguimiento automatizado del progreso están mitigando progresivamente las limitaciones de los modelos de formación tradicionales que enfatizan predominantemente la interacción cara a cara. El objetivo de este estudio es evaluar la eficacia de las plataformas contemporáneas de e-learning en la formación de profesionales

dedicados al campo de las infraestructuras críticas, teniendo en cuenta factores normativos, tecnológicos y organizativos. El estudio utilizó una metodología mixta, que abarcaba una encuesta a 47 representantes de instituciones educativas y gubernamentales; un análisis comparativo de cinco plataformas digitales (Moodle CLMS TsNTU, Microsoft Learn for Educators, CISA Virtual Learning Portal, OPSWAT Academy, NSDC-authored courses); y un análisis de contenido de los componentes funcionales del entorno de aprendizaje (disponibilidad de gamas cibernéticas, soporte SCORM, microcredenciales, adaptación lingüística y Learning Analytics). Los resultados revelaron que la influencia positiva más pronunciada en la calidad del proceso educativo procedía de la disponibilidad de simuladores adaptables, contenidos en ucraniano y herramientas analíticas para el seguimiento de los resultados. La novedad científica de este estudio radica en la formulación de un modelo integral para evaluar la eficacia de las plataformas educativas digitales basado en un análisis interdisciplinar, que combina los requisitos normativos, la preparación tecnológica y las prácticas pedagógicas. Las perspectivas de investigación futura abarcan el desarrollo de criterios nacionales para la acreditación de cursos en línea en sectores de alto riesgo, el establecimiento de un repositorio integrado de materiales de formación en simulación y la experimentación con modelos híbridos de formación basados en escenarios adaptativos y cibercampos.

Palabras clave: E-learning; Infraestructuras críticas; Ciberseguridad; Formación de profesionales; Cibercampo de entrenamiento virtual

1. Introduction

The last decade has been marked by the swift proliferation of digital technologies within the educational sector, wherein e-learning platforms have emerged as key tools for the implementation of flexible, scalable, and competency-based learning (Kobysia et al., 2021). These systems amalgamate content management functionalities, interactive learning experiences, and performance tracking, gradually replacing traditional modalities of face-to-face instruction. Such transformations have engendered novel challenges for conventional educational paradigms, which now must guarantee mobility, continuity, and personalization of the educational experience, even amid crises such as the COVID-19 pandemic and full-scale warfare (Artyushin & Rudenko, 2023). Consequently, digital solutions must include considerations of accessibility, adaptability, and seamless integration into national educational frameworks. In this light, the Ukrainian experience exemplifies how e-learning has evolved into a robust infrastructure that facilitates distance learning, emergency retraining of personnel, and educational continuity under emergency conditions (Matviichuk et al., 2022). Virtual classrooms and asynchronous modules have rendered it possible to sustain student engagement and implement educational programs during the crisis.

Modern platforms, such as Moodle, Microsoft Learn, OPSWAT Academy, incorporate simulation modules, microcertification, and real-time analytics, rendering them indispensable tools for both theoretical and applied learning

(Plakhotnik et al., 2023). These features facilitate program modularity and the formalization of outcomes in sensitive domains, notably cybersecurity and critical infrastructure protection. Despite advancements, e-learning ecosystems continue to face challenges related to usability, mobile optimization, and technical support. Research indicates that numerous platforms are deficient in adapted interfaces and localized content, thereby diminishing accessibility for broad user groups (Banciu and Fodorean, 2022). A comparative analysis of these platforms reveals significant disparities in adherence to technical and pedagogical standards. While some systems endorse SCORM, multimedia components, and assessments, others are limited in analytical capabilities, consequently undermining teaching efficacy (Ouadoud et al., 2021).

In response to these challenges, certain academic initiatives have introduced simulation environments and interactive modules that increase learner motivation and facilitate the virtual practice of complex situations (Batirel et al., 2021). Such innovations enhance students' self-regulation and foster the development of practical skills. International experience corroborates the role of e-learning in overcoming barriers to educational access in regions constrained by limited resources or infrastructural challenges (Mashau and Nyawo, 2021). Digital platforms offer scalable solutions that can be tailored to local contexts and swiftly implemented across diverse audiences. Furthermore, e-learning assumes a strategic role in the cultivation of professional and technical competencies. The capacity to model production processes, monitor progress dynamics, and validate competencies renders these platforms indispensable within advanced training frameworks (Belhaj and Moundib, 2025). Global research underscores the necessity of aligning digital platforms with accreditation systems, labor market demands, and regulatory stipulations. In the absence of such coordination, educational platforms remain fragmented entities rather than integral components of a cohesive national strategy (Kumar, 2024).

The objective of this study was to evaluate the effectiveness of five representative e-learning platforms utilized for training professionals in sectors characterized by high levels of responsibility. The analysis focuses on three critical dimensions: the functional capacity of the platforms, their degree of institutional integration, and their compliance with regulatory requirements. The study combines an examination of platform specifications and user feedback to elucidate strengths and system limitations, as well as to develop recommendations for educational policy and practice.

Despite the acknowledged potential of digital platforms in facilitating professional training, there exists a notable deficiency in comprehensive research that offers replicable models for their integration into the training of professionals in sectors characterized by increased responsibilities. Predominantly, existing publications concentrate on delineating individual platform functionalities or extolling the overarching advantages of distance learning, without elucidating their efficacy against the backdrop of challenges such as resource scarcity, fragmented infrastructure, and regulatory incompleteness. At the same time, such conditions are typical of nations undergoing reform in the spheres of governance, defense, and education.

This study is driven by a distinct motivation and purpose. Its objective transcends merely showcasing the advantages of e-learning platforms; it aims to formulate a holistic, well-substantiated model for their application in training professionals engaged in critical infrastructure protection. The integration of empirical analysis derived from the experiences of five disparate e-learning platforms, coupled with a systematic examination of regulatory, technical, and pedagogical dimensions is an imminent feature of this approach.

Employing a mixed-methodology that includes a survey of stakeholders from educational and governmental institutions, a comparative evaluation of functionalities, and an analysis of components such as SCORM compatibility, language adaptation, Learning Analytics, and a simulated environment, that elucidates the strengths and significant limitations of current solutions. Notably, it was found that the presence of adaptive simulators and virtual cyber training grounds positively influences both satisfaction and learning efficacy, whereas the absence of Ukrainian-language content and limited integration with Learning Management Systems considerably undermine program effectiveness.

In light of the above, the creation of a replicable model for integrating e-learning platforms into the professional training system is key for enhancing the personnel's preparedness in critical sectors. The study proposes a theoretical framework, an assessment methodology, applied criteria for the accreditation of online courses, and the potential establishment of a unified national repository of simulation cases that fosters a sustainable, normatively aligned, and technologically flexible educational ecosystem.

In domains of strategic significance such as critical infrastructure protection, the digitalization of professional education necessitates fundamentally novel approaches to the training of professionals. Traditional pedagogical models, which predominantly emphasize face-to-face interactions and standardized curricula, are increasingly demonstrating their inadequacy in the face of rapid technological advancements, the fragmentation of educational resources, and the imperative for swift competency updates. This issue is particularly pronounced in fields that demand the capacity to operate effectively in crisis situations, a high degree of digital literacy, and expertise in simulation technologies.

Despite the proliferation of numerous e-educational platforms, their integration into the training of professionals in critical sectors remains constrained due to a number of factors. As Abumandour (2022) and Meng et al. (2023) elucidate, most platforms fail to account for the unique characteristics of professional activities in high-risk environments, exhibit inadequate adaptation to national regulatory frameworks, and frequently lack compatibility with public education systems for institutional integration.

Another considerable challenge is the lack of flexible mechanisms for the certification and acknowledgment of online learning outcomes within the formal educational landscape. For example, Liu and Yu (2023) and Gligorea et al. (2023) highlight that, despite the presence of advanced adaptive solutions, the majority of platforms prioritize individual learning experiences and do not facilitate integration with the learning management systems (LMS) utilized by employers or governmental agencies.

It is also imperative to acknowledge the inconsistent quality of content, namely a substantial portion of educational materials fails to meet cybersecurity standards, lacks localization in Ukrainian, and restricts domestic professionals' access to simulation environments. An analysis of OPSWAT Academy, CISA Virtual Learning Portal, and Moodle of the Central Ukrainian Technical University reveals that only a select few courses offer interactive engagement with risk scenarios, while the majority are confined to text or video formats without practical components.

In addition to technological and content-related challenges, organizational impediments obstruct the effective implementation of digital learning, in particular the absence of a unified strategy for the digital transformation of vocational education, insufficient awareness among educators regarding new tools, as well as limited funding for the development and maintenance of high-quality digital content.

To ensure the relevance and generalizability of the research findings, it is important to clearly define the target audience of the platforms being analyzed. This study examines platforms used by cybersecurity professionals, energy sector engineers, e-Health specialists, transport system technical administrators, and personnel responsible for operational resilience and emergency response. Such professional diversity requires adapted learning scenarios, different levels of digital training, and sector-specific competencies.

Furthermore, current e-learning platforms show insufficient attention to inclusion issues: most of them do not include adaptation tools for neuroatypical users, people with sensory impairments, or users with special educational needs. This limits the possibility of equal access to professional training and reduces the generalizability of the study findings.

Given the above, the core issue lies not solely in the technological inadequacies of individual platforms but also in the absence of a systematic approach to the integration of e-learning in the training of professionals within strategic industries. It is imperative to devise a comprehensive model for evaluating the efficacy of digital educational platforms that combines regulatory requirements, technological viability, institutional integration, and users' authentic needs. This study aims to bridge this gap by scrutinizing the factors that influence the effectiveness of digital learning, juxtaposing the functionalities of various platforms, and articulating recommendations for their adaptation within the framework of contemporary Ukrainian educational policy.

2. Literature review

In the scientific discourse of recent years, considerable attention has been devoted to scrutinizing the efficacy of e-learning platforms (ELPs) as tools for professional training in higher education. Abumandour (2022) delineates critical technical and organizational barriers to the implementation of Project-based Education Networks (PEN) in engineering education, highlighting the absence of simulation learning tools and the challenges educators face in

adapting to digital modalities. Accordingly, Meng et al. (2023) underscore the obstacles associated with the implementing project-based learning through PEN, emphasizing the necessity of institutional administrative support.

There is a growing interest in the intellectualization of educational environments. Liu and Yu (2023) advocate for the integration of artificial intelligence components into e-learning platforms to tailor learning experiences, construct adaptive routes, and enhance learning effectiveness. Similar themes resonate in the scholarship of Gligorea et al. (2023), who explore the potential of artificial intelligence in creating dynamic educational trajectories.

Against the backdrop of global transformations of the education system caused by the pandemic and digitalization, Fülöp et al. (2023) examine the challenges associated with sustaining the educational process in the conditions of the "new normal", emphasizing the significance of flexible certification forms. Kukkar et al. (2023) augment this perspective by establishing a correlation between the learners' emotional states and their success in PEN.

A notable domain is the continuous professional development of professionals. Shahzad et al. (2023) and Shahzad and Khan (2023) substantiate the efficacy of utilizing PEN in the ongoing enhancement of competencies among university library personnel. A related theme is explored by Abdur Rehman et al. (2021), who elucidate the challenges encountered in transitioning to fully distance learning through the lens of student experiences.

Several investigations have concentrated on the analytical potential inherent in digital platforms. Lin et al. (2023) propose a methodology for multilevel modeling of educational progress, which allows tracking individual trajectories. Wienand et al. (2024) consider the design of e-learning systems with regard to user requirements for corporate training on the SAP platform.

Considering regional characteristics, Adeniyi et al. (2024) juxtapose the experience of utilizing PEN in the United States and various African nations, highlighting pronounced disparities in accessibility, content localization, and governmental support. In the context of student motivation and performance, it is also worth mentioning the study conducted by Yang (2024), which concerned political education within universities.

What is more, a plethora of studies delve into the interdisciplinary applications of e-learning. For instance, López-Belmonte et al. (2022) and Huang et al. (2024) illustrate the assimilation of digital learning within visual arts disciplines and metaverse environments. Maqbool et al. (2024) and Dritsas and Trigka (2025) scrutinize innovative methodologies for collaborative learning in online spaces, encompassing fuzzy logic and cognitive interfaces. Notably, particular emphasis is placed on enhancing the efficacy of professional training through contextualization and a practice-oriented approach. In this regard, Ertl et al. (2025) underscore the advantages of case-based e-learning, which fosters cognitive engagement and cultivates decision-making competencies in intricate environments.

Thus, scholarly research substantiates that the application of clinically oriented scenarios within a digital context positively influences academic outcomes, particularly in fields where interdisciplinarity and realism of simulated situations are paramount (Ertl et al., 2025). In this vein, the study conducted by Vekaria et al. (2021) is pivotal, demonstrating the efficacy of training through the principle of "attack–defense by pretense," executed within a cyber-range bolstered by educational analytics. The authors articulate the significance of scenario-based training in a digital environment for the cultivation of reactive thinking amid cyber threats. From a systems perspective, Floros et al. (2025) propose a model for constructing training programs predicated on cyber training grounds, specifically designed for professionals in critical infrastructure. The said study is predicated on identified learning needs and accentuates the adaptability of the simulation approach.

The technical framework is further enriched by the work of Angelogianni et al. (2021), which delineates specific requisites for cyber training grounds tailored for 5G environments. The authors formalize the criteria for interfaces, testing modalities, and security levels, thereby facilitating the adaptation of platforms to high-precision training objectives within the telecommunications sector. Within the framework of technical integration, the article by Ruano et al. (2023) holds significance, as it scrutinizes standards for interoperability between online laboratories and learning management systems (LMS). A particular focus is directed toward SCORM, LTI, and REST protocols that ensure seamless interoperability between content and platforms.

A distinct emphasis is placed on the use of artificial intelligence in digital educational environments. In a study by Murtaza et al. (2022), a systematic review of personalized e-learning systems grounded in AI is presented. The authors explore real-time analytics, recommendation models, chatbots, and cognitive adapters as means for increasing flexibility and learning efficacy, especially in adaptive settings.

Therefore, prior research has established a robust theoretical and practical foundation for examining the potential of e-learning platforms in the professional training of professionals. However, these studies infrequently address the institutional, regulatory, and organizational barriers that hinder the large-scale implementation of such platforms in sectors characterized by elevated levels of responsibility, including critical infrastructure protection. The proposed investigation aims to address this gap by integrating functional analysis, domain-specific expertise, and regulatory compliance assessment within a cohesive analytical framework tailored to the requirements of interagency collaboration.

Consequently, the evolution of scholarly approaches to the use of e-learning in professional training is delineated, their limitations are critically analyzed, and the necessity for a model that is not only technologically efficient but also institutionally relevant and resilient to regulatory changes is substantiated.

3. Method

3.1. Research stages

This study was carried out in three distinct stages and was aimed at elucidating the efficacy of utilizing digital educational platforms for the training of professionals engaged in Ukraine's critical infrastructure sectors, specifically in energy, information security, transportation, and healthcare. Particular emphasis was placed on the role of simulation tools, adaptive content, and the potential for integrating these platforms into internal professional training systems.

In the initial stage, a systematic analysis of the functionalities of five educational platforms employed for training within the specified domains was undertaken: Moodle CLMS (TSNTU), Microsoft Learn for Educators, OPSWAT Academy, CISA Virtual Learning Portal, and the National Cyber Training Ground established by the National Security and Defense Council of Ukraine.

The analysis encompassed criteria such as structural adaptability, availability of virtual simulators, adherence to SCORM/xAPI standards, support for learning outcomes analytics, language localization, as well as flexibility of learning scenarios.

The second stage included conducting a questionnaire survey of 47 respondents, comprising teachers, cyber defense engineers, pedagogical and methodological specialists, as well as digital content coordinators in critical infrastructure institutions.

The survey, administered through Google Forms, contained both closed and open questions regarding the experience of using educational platforms, implementation barriers, the learners' level of motivation, and the feasibility of certifying learning outcomes.

In the third stage, a comparative analysis of the findings was conducted alongside data from leading international studies, as well as a content analysis of the open-ended responses from participants, which facilitated the identification of semantic categories.

This process enabled the discernment of key patterns regarding the effectiveness of digital learning. Statistical analysis was performed using SPSS 28.0 software; Pearson coefficients were employed to examine the correlation between the frequency of platform usage and motivational indicators, while analysis of variance was utilized to identify significant differences among different categories of users.

Table 1 presents an analytical matrix for evaluating the effectiveness of e-learning platforms utilized in the training of professionals within the field of critical infrastructure.

Table 1. Analytical matrix for evaluating the effectiveness of e-learning platforms

EVALUATION CRITERIA	COMPONENT DESCRIPTION
Functionality	Modeling and simulation tools, content adaptation to professional specifics
Pedagogical effectiveness	Adaptability of the learning path, user-friendly interface, availability of integrated tests and self-assessment
Institutional integration	LMS compatibility, SCORM/xAPI support, standalone administration capability
Motivational and communication potential	Motivation for learning, feedback tools, the role of certificates in professional validation

Source: consolidated by the author drawing upon the results of their own research,

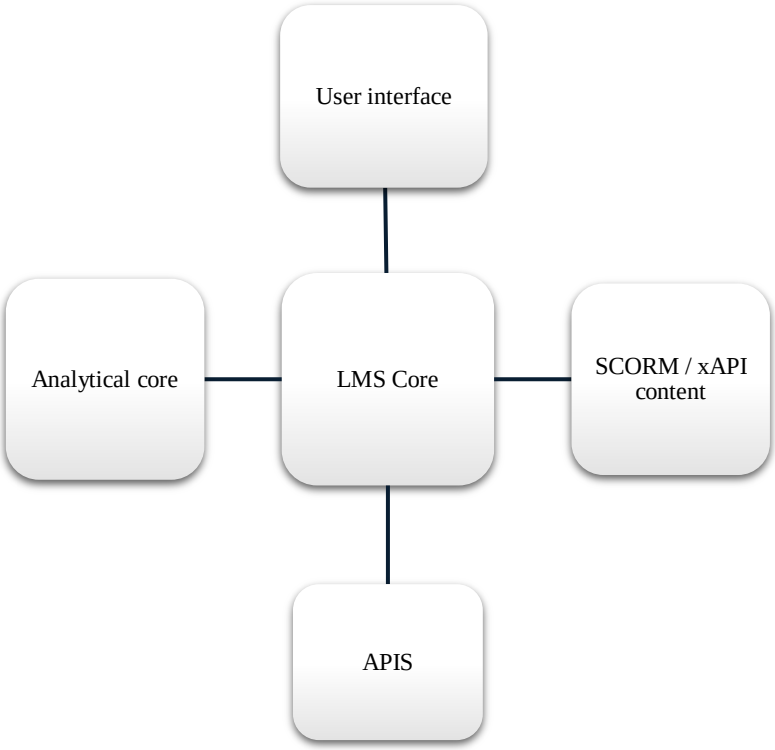
The matrix covers four major components: regulatory compliance (the presence of state or interdepartmental accreditation and course certification), technological readiness (SCORM support, availability of a mobile version, and data security), pedagogical adaptability (availability of simulators, simulation modules, and learning analytics systems), and organizational integration (capability to connect to Learning Management Systems (LMS), utilization within advanced training programs, and support for the Ukrainian language).

Each component was evaluated on a scale ranging from 0 to 2 points, where 0 signifies absent, 1 denotes partially implemented, and 2 indicates fully implemented. The maximum cumulative score attainable was 24. This methodology permitted a quantitative comparison of various platforms in terms of their readiness for use in training of professionals in critical industries.

Figure 1 illustrates the architecture of a prototypical e-learning platform, with the LMS (Learning Management System) core at its nucleus, facilitating the management of the educational process.

Four principal modules are interconnected: a user interface through which the platform's functionalities are accessed; a SCORM/xAPI content module tasked with the integration of standardized educational materials; an analytical core that processes educational data and generates comprehensive reports; and an APIS (Application Programming Interface) that enables interaction with external information systems.

Figure 1. Architecture of a typical e-learning platform with an LMS core and key functional modules.



Source: consolidated by the author.

This structure served not so much as an object of direct testing, but as a logical framework for describing the components that were evaluated within the study – in particular, the platforms' ability to integrate, support for adaptive content, the presence of rating systems, data security, and of interaction.

This structure functioned not merely as an object of direct examination, but as a conceptual framework for articulating the components that were assessed within the study, specifically, the platforms' capacity for integration, their support for adaptive content, the existence of rating systems, data security measures, and the ease of user interaction. Thus, the technical model ensured the integrity of the comparison approach and allowed the interpretation of the obtained data in relation to specific elements of the digital infrastructure.

3.2. Sampling

Five electronic educational platforms employed in professional training within the critical infrastructure domain were selected for experimental evaluation: Moodle CLMS (TSNTU), Microsoft Learn for Educators, OPSWAT Academy, CISA Virtual Learning Portal, and the National Cyber Training Ground at the National Security and Defense Council of Ukraine. The criteria for the selection of these platforms encompassed: accessibility for Ukrainian users, the availability of well-structured cybersecurity courses, support for certification, and integration with systems for assessing learning outcomes. Each platform was examined as an individual analytical unit.

To facilitate a symmetrical assessment of their functionalities, controlled groups of users (comprising 8–10 individuals per platform) with comparable levels of qualifications and experiences in utilizing digital educational tools were established.

A total of 47 participants were engaged in the testing procedure, representing five institutions dedicated to training personnel in critical infrastructure sectors. Their role was to evaluate the platforms within a standardized training scenario, which ensured the comparability of results across parameters such as functional completeness, methodological relevance, technological compatibility, and organizational accessibility.

3.3. Tools

– Survey: a structured questionnaire was devised on the Google Forms platform, encompassing both quantitative and qualitative questions. The questionnaire addressed four principal domains: platform accessibility, functionality, adaptability to user needs, and effectiveness in the practical application of acquired knowledge.

– Content analysis: a comprehensive examination of the functionality of five e-learning platforms (Moodle CLMS TsNTU, Microsoft Learn for Educators, CISA Virtual Learning Portal, OPSWAT Academy, NSDC authored courses) was conducted, with a focus on the integration of cyber ranges, micro-credentials, language localization, SCORM compatibility, and learning analytics.

– Peer-review method: three independent experts in the field of cybersecurity and digital education evaluated each platform based on the following criteria: interactivity, content relevance, incident modeling support, and institutional integration.

– Analytical matrix: presented in tabular form, Figure 1 delineates four key assessment parameters: (1) organizational accessibility, (2) functional completeness, (3) methodological efficiency, (4) technological compatibility. For each platform, the level of implementation in each category is assessed on a scale from 1 to 5 points.

– SPSS (v.26): utilized for the statistical analysis of questionnaire data, particularly for constructing profiles of platform efficiency and calculating coefficients of variation across diverse respondent categories.

The application of this comprehensive suite of tools facilitated not only a quantitative assessment of platform effectiveness but also a qualitative comparison according to parameters that are critically important for the training system.

The study further categorized platforms based on technical architecture, standards compliance, and integration capabilities. Table 2 presents the key parameters utilized for technical typology.

Table 2. Typology of educational platforms by architectural and functional parameters

PLATFORM	CLOUD ARCHITECTURE	SUPPORTED STANDARDS	API TYPE	INTEGRATION WITH LMS
Moodle CLMS (TSNTU)	Installed locally	SCORM, xAPI	REST API	Built-in LMS
Microsoft Learn	Cloud (Azure)	SCORM, LTI	Microsoft Graph API	Through external integrators
OPSWAT Academy	Air-gapped (isolated environments)	ISA/IEC 62443, SCORM	Closed API	Limited (via API requests)
CISA VLP	Cloud (on Canvas LMS)	SCORM, LTI, ADA compliance	Canvas API	Native Canvas integration
National Cyber Range	Hybrid architecture	SCORM, proprietary modeling protocols	Internal API + REST	Partial (through gateways)

Source: consolidated by the author based on the technical documentation of the platforms, the results of expert evaluation and their own functional analysis.

The utilization of this set of tools facilitated not only the execution of cross-platform comparisons but also the formulation of a technical and methodological efficiency map, which can serve as a guiding framework for the implementation of analogous solutions in the training of professionals within critical industries.

3.4. Formalized model for evaluating platform effectiveness

To ensure the coherence and uniformity of the approach to the comparative analysis of educational platforms, the study devised a formalized model of performance assessment that entails the systematic progression of information through three interconnected levels: user, platform, and analytical. The model is manifested in the form of a flowchart that reflects the rationale behind collecting, processing, and interpreting the results stemming from interactions with the platforms (Figure 2).

Figure 2. Model for evaluating the effectiveness of digital educational platforms

Source: consolidated by the author.

The platform evaluation model is predicated based upon three levels. At the user level, educational interactions are documented: training (participation in courses, engagement with simulations) and feedback (filling out questionnaires, facilitating the assessment of behavioral responses and subjective perceptions). The platform layer encompasses the technical ecosystem, integrating content, simulators, SCORM/xAPI formats, and analytics, where user interaction data is systematically recorded. At the analytical level, generalized metrics are computed — most notably, the integral performance indicator (IRS) as well as motivation and adaptability indices, which are derived from the results of the analytical matrix and statistical analysis.

4. Results and discussion

4.1. Overall platform readiness index

The first stage of quantitative analysis allowed us to calculate the readiness index (Integrated Readiness Score, IRS) for each of the five platforms under study: Moodle CLMS (TSNTU), Microsoft Learn for Educators, OPSWAT Academy, CISA Virtual Learning Portal and the National Cyber Range of the National Security and Defense Council of Ukraine. The calculation was carried out by aggregating the estimates of the four components of the matrix (see Table 1) by the formula:

$$\mathrm{IRS} = \frac{FC+ME+TC+OA}{4} \quad (1)$$

Where FC – functional completeness, ME – methodological efficiency, TC – technological compatibility, OA – organizational accessibility.

Each component was rated on a five-point scale, which allowed for standardization of comparisons and identification of best practices. The results are presented in Table 3.

Table 3. Comparative evaluation of platforms by matrix components

PLATFORM	FC	ME	TC	OA	*IRS*
Moodle CLMS (TSNTU)	3.2	3.8	4.0	4.5	3.9
Microsoft Learn	4.2	3.5	4.7	3.9	4.1
OPSWAT Academy	4.8	4.6	4.5	4.3	4.6
CISA VLP	3.9	4.1	3.8	3.6	3.9
NSDC Cyber Range	3.5	3.7	3.3	4.6	3.8

Source: Consolidated by the author based on the survey results and expert assessments.

As can be seen from Table 3, the highest average score was received by OPSWAT Academy (*IRS = 4.6*), which is due to a wide range of cyber simulations and support for international standards (NIST, ISA/IEC 62443). Microsoft Learn ranked second due to its highest technology compatibility score (4.7), including integration with Azure Active Directory and SCORM/xAPI compatibility. The strongest component of Moodle CLMS is organizational accessibility (4.5) owing to open source and the possibility of deep customization for the needs of higher education institutions.

4.2. Differentiation of indicators by industry

To determine the extent to which platform effectiveness and motivational characteristics depend on industry specifics, a one-way analysis of variance was conducted. The result $F(3, 43) = 4.82$; $p < 0.01$ indicates statistically significant differences between the four critical infrastructure sectors. The summarized data are presented in Table 4.

Table 4. Average platform performance scores and user motivation levels by industry

SECTOR	AVERAGE EFFICIENCY SCORE	USER MOTIVATION LEVEL, %
Cybersecurity	4.3	86
Energy	3.9	81
Transport	3.7	74
Healthcare	3.5	69

Source: consolidated by the author based on the survey results (N = 47).

Within the four sectors examined, distinct disparities emerge in both the comprehensive score of platform efficacy and the participants' motivational levels (see Table 1). Cybersecurity continues to dominate, with the highest average score of 4.3 and a motivation index of 86%. This score can be attributed to the consistent utilization of OPSWAT Academy and the National Security and Defense Council's national cyber training ground, where professionals engage in ICS/SCADA incident simulations and receive training on SOC simulators. In addition, correlational analysis substantiates a strong association between the frequency of simulation usage and the perceived utility of the content ($r = 0.74$; $p < 0.01$), underscoring the decisive role of practical simulators in sustaining high motivation.

In the energy sector, the average score of 3.9 reflects the good adaptability of Moodle CLMS and Microsoft Learn to regulatory courses (NAPSG, ISO 55001). Nonetheless, the absence of Ukrainian-language technical documentation and the partial duplication of English-language materials reduce the motivation index to 81%.

The transport sector exhibits a moderate level of efficiency (3.7) and motivation (74%). The interviewed experts emphasize the necessity for simulations concerning supply chain continuity and emergency response, whereas the CISA VLP currently provides a limited array of relevant cases. This limitation is evident in a lower methodological relevance score (3.4), which subsequently undermines user engagement.

The healthcare sector recorded the lowest ratings (3.5; 69%), primarily due to a deficiency of clinically oriented simulations available in the Ukrainian language. It was noted by the participants that the English-language content of Microsoft Learn and CISA VLP requires adaptation to align with national e-Health standards and evidence-based medicine protocols. The scarcity of thematic simulators and the low methodological efficiency (3.2) correlate with a decline in motivation ($r = 0.61$; $p < 0.05$), which is indicative of an urgent need to broaden the industry-specific content.

4.3. Correlation analysis of the relationship between platform characteristics and engagement

To elucidate the in-depth statistical relationships among individual e-learning parameters, correlation analysis employing the Pearson coefficient was conducted. The findings are encapsulated in Table 5, which demonstrates the interconnections among technological, methodological, and behavioral characteristics.

Table 5. Correlations between platform characteristics and user engagement

PAIRS OF PARAMETERS	*R*	*P*
Frequency of use ↔ Satisfaction	0.71	< 0.01
Technological compatibility ↔ Involvement	0.68	< 0.05
Methodological efficiency ↔ Motivation	0.65	< 0.05

Source: consolidated by the author drawing upon the results of their own study (n = 47, SPSS v.26).

The analysis elucidated a significant positive correlation ($r = 0.71$; $p < 0.01$) between the frequency of engagement with educational platforms and the overall degree of satisfaction with the educational experience. This suggests that consistent interaction with platforms that offer robust functionality and adaptable content fosters a lasting sense of usefulness and efficacy among users, which, in turn, encourages their continued involvement in the learning process. Furthermore, a noteworthy relationship was established between the technological compatibility of the platform - specifically, SCORM/xAPI support,

mobile accessibility, and integration into Learning Management Systems (LMS) – and the level of student engagement ($r = 0.68$; $p < 0.05$).

This underscores that flexibility and technical integration facilitate ease of use, lower the barriers to entry, and cultivate a favorable environment for continuous professional development. Additionally, a significant association was identified between the methodological effectiveness of the content – characterized by structure, availability of self-assessment, adaptive testing - and the respondents' motivational indicators ($r = 0.65$; $p < 0.05$). Therefore, a competently and thoughtfully constructed course, even in the presence of limited technical resources, can serve as a potent catalyst for enhancing internal motivation to learn. Summing up, the identified correlations underscore that the holistic quality of the platform, encompassing both technical and pedagogical dimensions, exerts a direct influence on the users' key behavioral responses.

4.4. Qualitative analysis of open ended responses

Content analysis of 102 open-ended comments elicited from respondents during the survey enabled us to delineate five key categories of challenges and requirements associated with the utilization of educational platforms within critical infrastructure sectors. The most frequently articulated necessity pertains to industry simulations (48% of mentions), including the modeling of emergency power outages in the energy sector, logistics disruption scenarios in transportation, and clinical simulators in healthcare. Following closely is the issue of limited language localization (43%), which engenders obstacles for users unfamiliar with technical English terminology, particularly in platforms such as Microsoft Learn and CISA VLP.

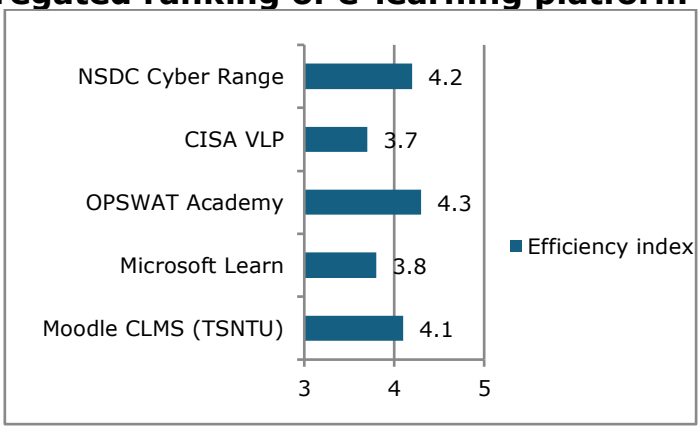
The third most prevalent category is certification disparity (37%), characterized by the varied recognition of digital certificates across different industries: notably, while OPSWAT courses are acknowledged within cybersecurity, they are not considered valid for advanced training in the healthcare sector. Further, an insufficient mobile optimization (29%) has also been a subject of criticism, particularly from learners situated in remote regions with restricted access to desktop devices. The fifth salient issue revolves around the absence of a unified registry of micro-credentials (24%), which complicates the integration of learning outcomes into national or intra-organizational systems for documenting professional competencies.

It is worth noting that respondents affiliated with government institutions expressed favorable evaluations of the NSDC national cyber training ground, commending its robust personal data protection measures and modular course architecture. However, they concurrently voiced concerns regarding the limited accessibility of content for non-government users. Also, a compilation of qualitative observations substantiates the findings of the quantitative analysis and delineates pathways for enhancing the institutional design of digital education in critical sectors.

4.5. Final ranking and key findings

Aggregated ratings derived from the IRS (Figure 3) underscore the preeminence of OPSWAT Academy and Microsoft Learn, with their cumulative scores surpassing those of Moodle CLMS by 15–18%. The deficiencies observed in Moodle and CISA VLP can be attributed to the absence of integrated cyber training environments and a limited scope for language adaptation. In contrast, the NSDC cyber training facility necessitates broader access for external users and the regular updates of its scenarios.

Figure 3. Aggregated ranking of e-learning platform effectiveness.



Source: consolidated by the author drawing upon the data obtained during the study.

As can be seen from Figure 3, the highest aggregated efficiency ratings among the examined platforms was attained by OPSWAT Academy, which garnered 22 points out of 24 possible. This achievement can be attributed to its exceptional functional completeness, methodological efficiency, and technological compatibility. The National Cyber Training Ground of the National Security and Defense Council of Ukraine secured the second position with a score of 21 points, primarily owing to its profound institutional integration and the presence of simulation modules. The Microsoft Learn for Educators and Moodle CLMS platforms achieved scores of 19 and 18 points, respectively, reflecting commendable adaptability and organizational accessibility, albeit with constrained flexibility in modeling. The CISA Virtual Learning Portal received the lowest rating of 16 points, a result attributable to the absence of localized materials and a low level of interactivity, a conclusion further corroborated by a qualitative analysis of open comments.

Overall, the study substantiated that the simulation component, comprehensive SCORM/xAPI compliance, and integrated analytics constitute the three principal catalysts for enhancing motivation and learning efficacy. Indeed, the platforms that incorporate these features consistently receive high evaluations, irrespective of the industry. On the other hand, obstacles persist in the form of fragmented language localization, the absence of a unified registry for micro-credentials, as well as insufficient mobile optimization.

The results of the study substantiate that the utilization of e-learning platforms, particularly those incorporating elements of simulation and adaptive content, can serve as an effective tool for the training of professionals in critical sectors. Notably, the most pronounced integral efficiency indicators were detected within the cyber domain, which can be attributed to the availability of high-quality specialized platforms (e.g., OPSWAT Academy) and the use of ICS/SCADA simulators (Fülöp et al., 2023; Lin et al., 2023). This finding resonates with prior research that underscores the advantages of practice-oriented training in the field of cybersecurity (López-Belmonte et al., 2022).

Conversely, lower levels of satisfaction and motivation are evident within the healthcare and transportation sectors, corroborating the conclusions of Ertl et al., (2025), which suggest that language adaptation and the relevance of simulations are pivotal for the effective use of these platforms. Correlation analysis data reveal a significant positive association between the frequency of platform utilization and the degree of satisfaction, as well as between methodological efficacy and motivation ($r > 0.65$; $p < 0.05$). Accordingly, this reinforces the hypothesis regarding the critical significance of functional content richness in sustaining learning engagement (Huang et al., 2024).

Compared to prior works that predominantly concentrated on narrow subject analyses or technical descriptions of platforms, the proposed study adopts an integrated approach, enabling the consideration of institutional integration, certification validity, and technological compatibility of platforms within the realm of professional training (Adeniyi et al., 2024; Nouraey and Al-Badi, 2023). For the first time, five platforms were systematically assessed according to four components of the analytical matrix, facilitating not only their ranking by comprehensive score but also the identification of industry gaps in the implementation of digital solutions.

One of the limitations of the study is the restricted sample of respondents ($n = 47$), which precludes the generalization of findings to the entirety of the vocational education system. Furthermore, several platforms failed to provide comprehensive access to training modules, thereby constraining the depth of content analysis. Another challenge lies in the absence of a standardized mechanism for the exchange of micro-credentials, which hinders the formalization of learning outcomes within state qualification systems. Nevertheless, the paramount value of the study resides in the establishment of an operationalized model for evaluating digital platforms, tailored to the needs of critical infrastructure professionals. The proposed methodology bears significant practical implications for shaping educational policy in the context of digital transformation and sustainable development, thereby unlocking avenues for scaling to other industries and administrative levels.

5. Final considerations

The results obtained confirmed the feasibility and effectiveness of employing e-learning platforms in the training of professionals for Ukraine's critical infrastructure sectors. The proposed methodology, ranging from a

multifactorial evaluation of the functionalities of digital platforms to a correlation analysis of educational and motivational indicators, enabled the construction of a comprehensive model for assessing the effectiveness of e-learning, taking into account institutional, pedagogical, and technological dimensions. At the same time, the results showed that the effectiveness of the platform is closely related to the characteristics of the target audience: cybersecurity specialists, energy engineers, transportation system administrators, e-Health and emergency response workers have significantly different levels of previous digital training, specific cognitive requirements and professional scenarios. Therefore, platforms should meet not only general educational standards, but also the competency requirements of specific industries with increased operational risks.

The study found that the most effective platforms are those that offer simulation tools, SCORM/xAPI support, adaptability to industry-specific scenarios, and the capacity for integration into internal learning systems. Notably, OPSWAT Academy and the NSDC cyber range exhibited the highest values of the integral readiness index (4.3), which correlates with elevated motivational indicators among users within the cyber defense sector. On the other hand, diminished values of both functional and methodological implementations were observed in the healthcare and transport sectors, thereby constraining their practical application. These differences indicate that evaluating platform functionality should take into account the cognitive load inherent to the profession, as well as the level of realism and contextualization required to support decision-making under operational pressure.

The findings from the correlation analysis indicated the existence of stable relationships between the methodological effectiveness of the platform and the motivation level of the participants ($r = 0.65$; $p < 0.05$), as well as between the frequency of platform utilization and user satisfaction with the learning experience ($r = 0.71$; $p < 0.01$). This reinforces the central hypothesis of the study, namely that digital learning is efficacious only when the tools are both functionally and substantively relevant to users' professional needs. No less important is the aspect of accessibility: while some platforms offer Ukrainian-language content and basic usability features, most of them do not have adaptations for users with sensory impairments, neurodiversity, or the need for alternative learning formats. The lack of the ability to regulate cognitive complexity, multi-format presentation of material (audio descriptions, simplified visual routes, text alternatives), and inclusive navigation tools limits the participation of certain groups of professionals and reduces the overall sustainability of vocational training systems in critical sectors.

The scholarly contribution of the current study lies in the creation of an integrated analytical model for evaluating the effectiveness of e-learning platforms tailored for critical infrastructure, which possesses the potential for scalability across other sectors. For the first time, an analytical matrix has been developed that combines technological, methodological, motivational, and organizational components into a unified assessment framework, with the adaptability to align with the specifics of national educational programs. The inclusion of target audience characteristics and an accessibility component

significantly enhances the applied potential of the model, ensuring its use not only for comparative analysis of platforms, but also for the development of inclusive, industry-sensitive digital training strategies. Further applications of the model should include conducting standardized accessibility audits and cognitive profiling techniques to more accurately identify the educational needs of different professional groups.

At the same time, the study has a number of limitations that should be considered when interpreting the results. The relatively small sample size (n = 47) limits the representativeness of the findings for all critical infrastructure sectors, and incomplete access to the full functionality of individual platforms limited the possibilities for content analysis. In addition, the reliance on self-reported data poses a risk of response bias, especially when assessing motivation and subjective perceptions of usability.

Future studies should expand the sample of respondents, include experimental or observational methods to capture real behavioral indicators, and provide structured accessibility assessments to determine the suitability of platforms for users with different cognitive and physical characteristics. This approach will allow for a more accurate and multidimensional understanding of how e-learning solutions can be optimized for professional environments with increased risk.

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