The Use of Artificial Intelligence and Virtual Computer Laboratories to Develop Computer Science Education

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Abstract. This research introduces and evaluates a new method of teaching information and communication technology (ICT), which results in the active participation of the trainee in the sequential performance of laboratory exercises in the virtual environment. This training is carried out using a virtual educational platform - VLC. The proposed approach uses an innovative mechanism for controlling the training process, called a virtual tutor, whose task is to continuously monitor the trainee's progress and adjust the pace and level of subsequent laboratory tasks. The virtual tutor function is implemented using machine learning techniques and semantic networks. The proposed method allows the use of educational content management mechanisms, an object repository, and educational process maps. Similar studies on IT tools for e-learning are conducted to a large extent, but they often lack a holistic approach to the problem. Such aspects as career counseling in selecting an educational program based on the balance of the future trainee's competencies, individual course of study through selective selection of laboratory exercises, remote progress monitoring, and activation of people over 45 years of age constitute the innovative nature of the article. Study results prove the effectiveness of the new holistic VLC method.

Keywords: Virtual laboratories · Educational platform · E-learning · Artificial Intelligence in e-learning · Innovative teaching methods

1 Introduction

In order to ensure the effective functioning of the labor market, it would be necessary to ensure better adaptation of existing competence resources to market requirements and increase the demand for high competences. Considering the dynamic development of the ICT sector, it is recommended to create favorable conditions for the development of staff and new educational programs. Undoubtedly, modern e-learning methods can be used effectively in the process of staff

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development and balancing competencies in the so-called high-tech sectors, especially in ICT.

Distance learning is referred to as e-learning, e-education, or remote teaching. The latest advances in information technology are used in the e-learning process, and the transfer of teaching content and other information takes place mainly over the Internet. Online learning is becoming increasingly popular. The authors of the publications indicate that this is due to its independence from time and place, low costs, and wide educational opportunities [1]. Interfacing tools that improve interactions between students, teachers, and content are key factors influencing academic outcomes in e-learning [2].
Artificial intelligence (AI) has found wide application in almost all areas of life, including e-learning. Researchers emphasize that AI enables the rapid and efficient production of learning content as a response to the ever-increasing demand for flexible online learning [3].

This article mainly addresses the following research questions.

- What impact does the new proposed teaching method have on the training results of course participants? The authors respond to this by presenting a comparison of the results of a traditional postgraduate course and a course enriched with the use of an innovative educational platform, which is the proposed teaching solution.
- How do course participants perceive this method? This question is answered in the survey results from the participants.
- Does the proposed method facilitate a holistic approach to teaching, and if so, what are the contributing factors? The conclusions from the expert panel address this question.

Organizations involved in IT training can use these research findings to improve the quality of education and improve the planning, organization, and management of training courses.

2 Related work

Distance learning is becoming more and more popular every year, and the breakthrough was the coronavirus pandemic when it was necessary to adapt to the prevailing conditions.
Currently, three types of application software are used in distance learning:

- LMS (Learning Management System) – a system for administering, monitoring, and reporting learning progress, managing teaching materials and permissions, and registering users for courses [4];
- LCMS (Learning Content Management System) – a training content management system, which, in addition to the functionalities available within LMS, can create, edit, deliver, and manage teaching content; provides the ability to control the process of creating didactic content and its archiving [5];

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– VCS (Virtual Classroom System) – a system enabling management and conducting distance learning in synchronous ("online") mode. This solution includes several functions in the area of cooperation, communication and knowledge distribution [6].

Artificial intelligence and machine learning are widely used in education. Popular techniques include:

– Supervised learning, which personalizes the educational material and predict student progress. The algorithms most often used in supervised learning are decision trees, Support Vector Machines (SVM), and logistic regression [7].
– Unsupervised learning, which involves clustering topics and grouping students by learning style. The algorithms most often used here are: k-means clustering and Principal Component Analysis (PCA) [8].
– Reinforcement learning (RL), which may include educational games and learning systems (intelligent tutors) [9].
– Artificial neural networks in education are most often used to recognize speech and text or generate didactic content [10].
– Recommendation systems - are mainly used to recommend additional lessons or tasks [10].
– Predictive analytical models - mainly used to predict future events such as a student's exam result, problematic topics for a student, etc. [10]
– NLP (Natural Language Processing) - used mainly in language translation, text analysis and editing or educational chatbots [10].

In the educational process, it is also worth looking at pedagogical theories. We can mention the following:

– Constructivism - involves engaging students by constructing their knowledge after interacting with the environment or their experiences. The emphasis here is mainly on practical tasks, promoting student engagement [11].
– Connectivism - this is a theory that says that learning is a network process. The emphasis here is on interaction with other students, experts, and digital resources. The approach promotes the ability to use information and technology and personalized learning [11].
– Cognitive Load Theory – a theory that discusses the internal, external, and useful load in the learning process. According to this theory, students should engage in activities that deepen the deeper processing of valuable information. The aim here is to reduce external load, i.e. unnecessary knowledge, and optimize internal load by adapting the material to the student's level [12].

The key component that integrates the methods, techniques, and tools used in e-learning is the educational platform. This platform facilitates the continuous management of the teaching process and allows the modular expansion of the content accessible to students. Educational platforms are widely used for teaching at national universities. For example, Moodle, a product based on the GNU GPL license, is implemented in Poland universities, for example, at the

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Gdańsk University of Technology [13], Ukraine universities [14], or the Peru National University of San Agustín (UNSA) [15]. Similarly, the ILIAS platform, also based on the GNU GPL license, is used in many universities, even African ones, ensuring the development of African students despite many adversities [16]. The ILIAS platform is gaining popularity in countries of the European Union. This platform supports the administration of various university study programs and facilitates the management of e-learning courses [17]. In addition to ILIAS, other educational platforms such as Claroline, Chamilo, Docebo, and ATutor are also widely used [18]. These are just a few examples of how software can be used to bridge distances and teach despite war or pandemics. However, research has identified several shortcomings in traditional educational platforms, such as insufficient user engagement, lack of integration with other systems, high costs for material development, a need for greater motivation, and a prolonged duration of learning [19].

Other authors highlight that a significant advantage of Artificial Intelligence in e-learning is its ability to personalize the content for each learner [20]. This contrasts with traditional e-learning systems, where only difficulty levels are defined and all students at a particular level use the same instructional material [21]. To effectively utilize AI in e-learning, it is essential to develop a comprehensive and personalized e-learning framework. Unfortunately, many of the currently proposed solutions lack this holistic approach [22]. To establish a personalized learning system, various IT challenges must be addressed [23]. Machine learning (ML) and deep learning (DL) models can be used effectively to match appropriate learning materials to individual learners according to their competencies [24]. Furthermore, the algorithm should be trained and updated in real-time [25]. Another key aspect is analyzing the learning preferences of the course participants, which should be included in the recommendation system [26]. The key dysfunctions of existing educational platforms include lack of interactivity (the software only acts as a repository of static documents), the level of training not being adjusted to the competency profile of individual participants, problems with understanding the names and messages used in the graphical user interface, and the lack of specialist solutions dedicated to the needs of the ICT sector. The response to diagnostic dysfunctions of classic solutions [27] is a research and development program, the result of which was the development of an innovative educational platform.

3 Materials and Methods

The following section describes the implementation of the project, which was the source of obtaining data for the research. It also describes the innovative VLC method proposed by the authors of the article, as well as the importance of AI in this method. At the end of the section, methods for verifying the results used in the next section are proposed.

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3.1 Project Realization

The research was carried out as part of a project co-financed by the European Union. The aim of the project "Management of the transfer of information technology to enterprises" [28] - was to educate and prepare staff - specialists with interdisciplinary knowledge in the field of information technology (e-business, IT systems supporting knowledge management) and skills in the field of managing this category of enterprise. This aim was achieved by organizing postgraduate studies "Management of IT projects in the e-business environment" and "Knowledge management using modern technologies and information systems". The strategic criterion of the project was the professional activation of people over 45 years of age. The project was divided into five stages shown in figure 1. The project preparation process (stage 1) included analyzing the training

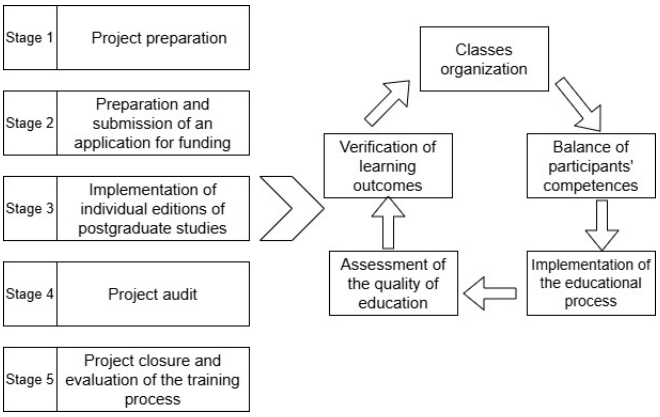

Fig. 1. Management cycle of an educational project co-financed by the European Union (source: own elaboration)

needs of future participants, formulating the goal and scope of the project, and defining the target group. The work related to the development of the project funding application (stage 2) included: formulating the concept of education for postgraduate studies in the IT and management profile, conditions of participation, recruitment rules, organization of the educational process, and rules for verification of education results. As part of the project, the postgraduate studies "IT project management in the e-business environment" and "Knowledge management using modern technologies and information systems" were organized and conducted in a total of fourteen editions (stage 3). Within the fourteen editions, 560 people were trained over three years. It is worth highlighting that, in addition to meeting the substantive criteria, the organization implementing the project was required to professionally activate people over 45 years of age, as well as to observe the principle of equal opportunities for women and men in the recruitment process. In each edition of the postgraduate studies, the conditions

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for participation were higher education, and the requirement was for at least 60% of women and at least 15% of people over 45 years of age. The participants showed similar characteristics, most of them were directly or indirectly related to IT. Some of them managed projects, others were analysts, still others were testers, there were also those who worked, for example, in accounting, but used data from IT systems as end users. They were certainly not programmers, but they had professional experience and an understanding of various data and processes. Their goal was to change the industry or use acquired skills in IT projects of which they were members. The turnover among instructors over the 3 years was insignificant.
The third stage of the project was cyclical. It included: the preparation of a training schedule within the individual editions of studies, development (verification) of syllabuses of didactic classes, recruitment of lecturers, promotion, recruitment and qualification of candidates, balance of participants' competencies, implementation of didactic classes, assessment of the quality of teaching and verification of education effects. As part of the project, systematic research was conducted on the analysis and evaluation of the competencies acquired by the participants. The last two stages focused on project audit and evaluation.

3.2 VLC Method Characteristic

The innovative educational platform, "Virtual Computer Laboratories" (VLC), is the result of this paper. This package includes tutoring software that supports the teaching of ICT technologies. It features typical modules specific to LMS, LCMS, and VCS software, while also introducing completely new functionalities. These include career counseling to help students select an educational program based on their competencies, personalized study paths through the selective choice of laboratory exercises, and remote progress monitoring. The individualization of the curriculum is based on the level of advancement, adapted to the specific topic determined by the system based on the tasks performed by the student. For example, for people who have basic skills in designing database systems, it is reasonable to reduce the number of exercises intended to learn the basics of SQL semantics and syntax. In return, these people may be offered advanced exercises in the field of client-server application programming, during which it will be possible to extend the classic elements of the SQL language course. In other words, the traditional concept of teaching ICT technologies containing the classic division of the group type: "basic group / advanced group" will be replaced by the method of creating original laboratory class paths.
The VLC educational platform uses virtual machines to simulate database servers and data warehouses for laboratory exercises. These exercises consist of a project description, a scenario, and step-by-step instructions. Students interact with virtual application servers, which allows them to continuously verify and control their work in a professional database management system environment. Tasks include configuring roles and authorizations, writing T-SQL scripts, and managing data migration in distributed systems. The platform provides real-time feedback on exercise performance.

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The project work was focused on the following:

- Development of a new method of teaching ICT technologies, the result of which is the active participation of the course participant through sequential performance of laboratory exercises in the virtual environment. The mechanism for controlling the training process (virtual tutor) will activate subsequent laboratory tasks (educational objects) according to the current progress of the trainee and the assumed goals and effects of education (educational process maps). The adopted methodological concept of teaching advanced ICT technologies and the platform architecture therefore exclude passive participation of the course participant.
- Application of knowledge engineering systems for the development of an intelligent tutor mechanism: The research was initiated by the analysis and assessment of the possibilities of using machine learning techniques and semantic networks to implement a virtual tutor mechanism. As part of the project, a model of information flow, decisions, and control between logically and physically related educational objects (educational process maps) was developed. The possibility of a graphical representation of the educational process map using open standards was also provided including XHTML (Extensible HyperText Markup Language), SVG (Scalable Vector Graphics), and SMIL (Synchronized Multimedia Integration Language).

3.3 The Impact of Artificial Intelligence in VLC Method

Training materials are stored as educational objects, each with metadata that defines the relationship between course elements, including descriptions, complexity, recommendations, and assessment criteria. These objects are linked to their predecessors and successors, allowing the creation of personalized educational process maps. The VLC platform prototype includes tools for searching, selecting, and filtering educational objects, as well as analyzing their effectiveness for specific courses. Educational objects are described using XML, and their specifications will be freely available to future course creators.

Virtual Tutor is a mechanism controlled by artificial intelligence. Before starting to work on the VLC platform, the virtual tutor function was temporarily dormant, and the configuration of the provided content was the default (all participants used the same content). After starting to work in the platform, the output data from the individual platform modules were the input data for the AI as part of training the model. Each thematic part of the course was divided into tasks, and after training in each part, the student had to take a test to move on to the next part. The student's identifier, task number, and test result were the training data for the AI as part of the virtual tutor. These results could be binary (0 or 100% for the task) or represent the ratio of correctness of task performance according to the programmed evaluation criteria. After going through the first part of the course in the full thematic scope, the training of the output data from the partial tests was carried out. The algorithm assigns the results of the exercises to thematic parts to propose appropriate tasks in the

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second part of the course. If the student demonstrates a good level of knowledge in a given subject area, tasks in this area will appear less frequently in the future. Similarly, if the algorithm identifies a subject area as problematic for the student, it is practiced by selecting more frequent tasks in this area. The next partial tests are further data training for the model, so that the student receives content appropriate to his level. Of course, course elements with which the student copes well also appear in the course, but with a much lower frequency than standard, so that the student can consolidate a given issue and not forget about it. The virtual tutor has information on the specific subject area of the tasks (type/subtype) and information about their level of difficulty. A system implemented in this way allows you to focus only on the essential elements.

The virtual tutor also works with course moderators, who can introduce their own cognitive rules based on their expertise and learning goals. This allows for the creation of personalized courses that align with both the mentor's goals and the learner's competencies.

Supervised learning techniques were used through the implementation of semantic networks to classify the students' questions and answers in a given area into a specific level of advancement. In addition, reinforcement learning was used so that the system could dynamically decide what material to offer the student at a given time. The system is designed to learn which activities bring the best results for a specific student and dynamically adapt the tasks to their needs.

3.4 Methods of Verifying Educational Results

The verification of the results after the project implementation was carried out in three ways:

- The most measurable verification method was the quantitative method, comparing the course results to the results of a previous year's course with the same thematic structure but without the support of the VLC method. The students were given an exam task that consisted of creating a database system for any company. The task included: formulating the purpose and scope of the project, specification of requirements, implementation of the physical model of the database, and the construction of T-SQL scripts (views, data validation rules, triggers, stored procedures, transactions). The exam project task was mandatory for all participants in studies. It was verified and evaluated by lecturers and external experts. An average of the student's grades was taken and compared with the average of the student's grades from the previous year. In general, the study involved 192 people - 96 students from 8 random laboratory groups in the academic year before the new method was implemented and 96 students in the academic year after it was implemented. In the previous year (before the VLC implementation), there were 63 women and 33 men, while in the following year, 65 women and 31 men. The number of people over 45 years of age - 32 and 37 people, respectively.
- A survey was conducted among the course participants and conclusions were drawn. This survey was conducted using the in-depth interview method.

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Due to the lack of conditions for conducting in-depth surveys among all participants, a decision was made to conduct them in two random laboratory groups, which is why it was based on the answers of 24 random people - 13 women and 11 men. The purpose of this survey was to collect opinions about working with the VLC platform as a tool to supplement education in post-graduate studies. The survey included the following prompts:
  - List the advantages of the e-learning platform.
  - List the disadvantages of this platform.
  - How many hours did you spend using the platform during the course?
  - Do you intend to use similar educational solutions in the future?
- An expert panel composed of five professionally involved experts in conducting training in the broadly understood field of IT discussed the proposed method to allow for a holistic teaching approach and what makes it so.

4 Results

As mentioned in the previous section, the method was verified by analyzing an expert panel, student satisfaction surveys, and the final test results. The summary of this is given below.

4.1 Expert Panel Results

The result of the expert panel is that the fundamental advantages of the computer-aided teaching of computer science using the VLC educational platform prototype, proving its holistic approach to e-learning, include:

- Interactive implementation of laboratory exercise programs.
- Educational content management mechanism- object repository and educational process maps.
- Leverage of artificial intelligence in the teaching process (virtual tutor).

4.2 Satisfaction Survey Results

The survey, conducted with approximately 560 students over 3 years of post-graduate studies, highlighted the effectiveness of the virtual application server environment. Students appreciated the simplicity of using an IBM PC to work in a multi-user setting, process large data sets, and test program scripts and security. Interactive laboratory exercises allowed students to create a "skeleton" of their future system and formed the basis for design tasks. The VLC platform also supported error correction, enabling students to restore previous states and continue work, which was not possible in traditional courses, where errors could result in losing progress. Furthermore, respondents indicated that the greatest advantage of the proposed solution was the ability to create and test database systems without the need to install and configure the appropriate server infrastructure. This undoubtedly encouraged students to work on the VLC platform.

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The main drawback was the limited scope of teaching materials available in the prototype version of the platform. However, the students appreciated the ability to create and test database systems without the need for server setup. They were interested in using a similar platform for both IT and non-IT training. In general, the students spent about 50% of their education using the platform.

4.3 Exam Results

The results of course completion (Table 1) indicate the following:

- When analyzing the points for all elements of the completion, the average score increased by 16%, a median rise of 18%, and a mode increase of 12% compared to the previous year.
- Focusing on elements practiced more on the VLC platform, the average score rose by 24%, the median by 25%, and the mode surged by 66%.

A detailed analysis shows that results improved significantly (over 10%) in five of the eight aspects. Table 2 summarizes grades, and Table 3 lists the completion points. The results are as follows:

- construction of data correctness control mechanisms (rules, scripts) - by an average of 25%;
- creating data views based on a set of reference tables (views) - by an average of 27%;
- data processing methods using stored procedures and triggers - by an average of 21%;
- transaction management techniques - by an average of 19%;
- security procedures (authentication, authorization, access control) - by an average of 26%.

Table 1. General course completion results in points (source: own elaboration)

Result type	Each course parts		Trend	Parts of the course included in training within the VLC platform		Trend
	traditional course	trad. course + work in VLC		traditional course	trad. course + work in VLC	
Final points avg	75.36	87.71	116%	49.84	61.98	124%
Final points median	74.38	87.88	118%	49.50	61.88	125%
Final points mode	72.50	81.25	112%	38.50	63.75	166%

Based on the exam results, it can be concluded that people using the VLC platform obtained significantly better final grades. The results are correlated

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Table 2. Detailed course completion results presented through grades (source: own elaboration)

Criteria for evaluating course	Grades average		Trend	Grades median		Trend	Grades mode		Trend
	trad. course	trad. course + work in VLC		trad. course	trad. course + work in VLC		trad. course	trad. course + work in VLC	
Clarification of the project's purpose and scope, along with the specification of functional requirements	4.25	4.23	100%	4.00	4.00	100%	4	4	100%
Design of a physical database model (specification of tables and reference connections)	4.44	4.46	100%	4.50	4.50	100%	4.50	4.50	100%
Mechanisms for checking data correctness (rules, scripts)	3.83	4.77	125%	4.00	5.00	125%	3.00	5.00	167%
Perspectives (reporting based on a set of related data tables)	3.88	4.92	127%	4.00	5.00	125%	4.00	5.00	125%
Implementation of data processing mechanisms (stored procedures, triggers)	4.02	4.88	121%	4.00	5.00	125%	4.00	5.00	125%
Transactions	3.75	4.48	119%	4.00	4.50	113%	4.00	5.00	125%
Security procedures (authentication, authorization, access control)	3.48	4.40	126%	3.50	4.50	129%	3.00	5.00	167%
Project documentation (description of the physical model of the database and T-SQL scripts)	4.10	4.25	104%	4.00	4.25	106%	4.00	5.00	125%

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Table 3. Detailed course completion results in points (source: own elaboration)

Criteria for evaluating course	Max. points	Points avg		Trend	Points median		Trend	Points mode		Trend
		trad. course	trad. course + work in VLC		trad. course	trad. course + work in VLC		trad. course	trad. course + work in VLC	
Clarification of the project's purpose and scope, along with the specification of functional requirements	6.00	4.88	4.82	99%	4.75	4.75	100%	4.50	4.50	100%
Design of a physical database model (specification of tables and reference connections)	15.00	12.88	12.88	100%	13.25	13.25	100%	13.25	13.25	100%
Mechanisms for checking data correctness (rules, scripts)	20.00	14.49	18.32	126%	14.25	18.50	130%	11.25	17.50	156%
Perspectives (reporting based on a set of related data tables)	10.00	7.32	9.38	128%	7.63	9.38	123%	7.75	9.25	119%
Implementation of data processing mechanisms (stored procedures, triggers)	17.00	13.00	15.77	121%	13.00	15.75	121%	13.00	15.75	121%
Transactions	10.00	7.15	8.54	119%	7.25	8.75	121%	7.75	8.75	113%
Security procedures (authentication, authorization, access control)	12.00	7.89	9.97	126%	8.25	10.50	127%	6.50	11.00	169%
Project documentation (description of the physical model of the database and T-SQL scripts)	10.00	7.77	8.03	103%	7.75	8.13	105%	7.75	9.25	119%

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with the appropriate course elements that were provided on the VLC platform. The results of these elements that were not included in the platform did not change significantly.

An important observation is that all of the above criteria were practiced within the VLC platform using interactive training and in total consumed almost 94% of the time of the entire training module. This may indicate the effectiveness of the VLC platform in improving competencies.

5 Conclusion

In the author's solution - in addition to the classic functionalities of LMS, LCMS, and VCS software - mechanisms using artificial intelligence techniques were implemented for the selection of educational content depending on the didactic goals set by the mentor, as well as the competency profile of the trainee. The concept of "intelligent" selection of educational content using a set of cognitive rules (virtual tutor) and activation of people over 45 years of age is characterized by innovation to classic forms of teaching. Pilot studies show that platforms such as Moodle and ILIAS are commonly used for teaching materials, but lack interactivity. In contrast, VLC enables interactive laboratory exercises in a dynamic virtual environment, helping students design IT systems and ensuring correct execution. Unlike traditional LMS, LCMS, and VCS, VLC offers flexible course design by combining educational objects to meet specific training goals and trainee needs. Unlike traditional LMS, LCMS, and VCS platforms, the VLC platform allows for dynamic, adaptive course creation, such as designing an SQL course and extending it with advanced topics such as database server programming. It is worth recalling that a large number of stationary and on-line courses offered by commercial training companies are available on the market. However, to obtain real professional competencies, e.g. in the field of database system design, participation in a several-hour course or its online substitute is not enough. Acquiring ICT competency requires practice, performing a series of laboratory exercises, and multiple validation and testing of applications.
In summary, the new proposed teaching method:

- Has a positive impact on the quality of training, as evidenced by the course completion results;
- Is positively received by participants - as confirmed by the survey results;
- Enables a holistic teaching approach by interactive implementation of laboratory exercise programs, educational content management mechanism- object repository, educational process maps, and leverage of artificial intelligence in the teaching process.

In conclusion, tests of the educational platform prototype confirmed validity of the proposed teaching concept and set the directions for further work.
In the future, the following are planned: conducting research on the ergonomics of the graphical user interface, adapting the platform to the needs of people with disabilities following the Web Content Accessibility Guidelines, developing

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a commercial version of the software, increasing the number of available courses, and developing a manual for future training creators.

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