**Virtual Laboratories – an Effective Tool For E-Learning**

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**Abstract:** The paper discusses the issues of creation and research of computer systems for automation and control of technological processes and productions, as well as modern technologies of virtual laboratories. The use of software models and real equipment with remote access, followed by integration into a single virtual educational environment, is being considered.

**INTRODUCTION**

Currently and in the near future, virtual laboratories will be one of the main tools for e-learning in the humanities and technical disciplines. Modern information technologies offer extensive opportunities and tools that significantly enrich and complement the traditional learning process. Virtual laboratories are defined as a type of interactive multimedia objects with diverse content, including text, hypertext, graphics, images, animation, video, etc.

The Industry 4.0 strategy provides for the intensive development of the digital society as a whole and, in particular, innovative educational technologies. Currently, when it comes to innovation in education, e-learning and mobile learning are usually understood as modern forms of distance learning. It should be emphasised that engineering knowledge and skills are acquired not only in lectures but also in practical classes. The latter is possible in laboratories equipped with testing and research facilities for the relevant engineering discipline, where students can work with the theoretical material presented in the lecture course. As a rule, equipping and maintaining such laboratories requires a significant investment of time and money. In addition, a laboratory for a specific discipline must be available in all universities where that discipline is taught. Another significant disadvantage of these laboratories, which can be called real, is the workload of one such laboratory, which is at least 30 hours, multiplied by the number of subgroups in the corresponding stream. The solution to this situation is to create virtual laboratories. Once created and tested, a virtual laboratory, unlike a traditional one, becomes available daily and hourly from any computer connected to the Internet. The availability of virtual laboratories is also a prerequisite for the transition to distance learning in this engineering speciality

**MAIN PART**

This paper analyses virtual laboratories as one of the key tools for e-learning in higher education. In this regard, it is necessary to emphasise the relevance of restoring and developing engineering training, the importance of which has grown significantly in recent years.

Returning to the issue of virtual laboratories as a fundamental means of e-learning for academic disciplines, it is necessary to classify virtual laboratories into the following types: simulator-based virtual laboratories, virtual laboratories with real equipment, and hybrid virtual laboratories. [1]

Simulator-based virtual laboratories are computer systems that simulate objects, environments or situations that are the subject of observation, research and experimental activity, providing students with unlimited access and the ability to actively control the experiment in a highly interactive information environment. This allows learners to apply trial and error methods, track the process, detect errors and successfully complete the experiment.

Virtual laboratories with real equipment are often implemented in the form of real equipment with remote access via the Internet. They are used to expand access to equipment, which is itself a limited resource. As a rule, this equipment is too expensive to reproduce or access to it is restricted for security reasons. In this case, a virtual laboratory can be viewed as a complex of hardware, software and methodological tools that enable remote automated laboratory and experimental research to be conducted directly on physical objects. [4]

Hybrid virtual laboratories are a combination of the two previous types. In this type, one part of the experiment is conducted on real equipment, and the other part is conducted using software products. In laboratories of this type, the most common tasks are related to measurements that are performed on real objects, and then the collected information is processed using software tools.

A comparative analysis of virtual laboratories shows that there are a number of accessible virtual laboratories developed and used by various organisations. Some of them are based on real equipment, others use simulators, and still others successfully combine these two approaches.

Software models allow experimental conditions to be reproduced quickly, economically and with minimal resource expenditure. The number of instances of a software virtual laboratory is virtually unlimited. There are areas where it is impossible to physically represent the relevant level of decomposition of the object under consideration. This often applies to the object itself. When it comes to visualising the blocks of modern microprocessors, the only option here is undoubtedly to use software laboratories. The main disadvantage of such laboratories is the discrepancy between the results of virtual experiments and the real behaviour of the simulated object. [5] On the other hand, trainees are placed in an artificial environment and have no idea about the real process of setting up, performing, and adjusting the experiment. This factor is a prerequisite for difficulties in the subsequent work of trainees with real objects.

Maintaining a software lab is basically just about looking after the servers that store and access the software, unlike a lab with real equipment, where there are extra bits that need physical space, electricity, and extra maintenance.

On the other hand, if expensive laboratory equipment is available, remote access allows this equipment to be used optimally and provides access to a larger number of students. It should not be overlooked that, unlike testing software code on a simulator/debugger, running it on a real platform gives a much clearer picture of the behaviour of the real system, especially in the context of real-time process control.

The use of a laboratory with real equipment expands the possibilities for coursework and research without requiring the physical presence of students in the laboratory facilities.[2]

During theoretical research, similar solutions were found for using interactive multimedia environments in information technology education: Learning Content Development System (LCDS), a system for creating educational content from Microsoft; and products for developing computer skills from ‘Edimite’.

LCDS is a full-featured tool for developing e-learning content (Microsoft Learning, 2011). The LCDS system is distributed free of charge and can be downloaded from the Microsoft website. It offers an extremely rich variety of patterns for creating different semiotic meanings to convey facts and basic concepts. However, this method of acquiring knowledge and developing skills and abilities in teaching students is not applicable for the following reasons: firstly, the ‘time’ factor of teaching is limited by a strict discipline schedule; secondly, the structuring of knowledge in adults is more subject to a deductive approach than an inductive one, since it is believed that metacognitive learning skills in adults are developed to such an extent that they allow for an intensive learning process. Bulgarian is not one of the twenty languages that LCDS can work with automatically. Additional corrections must be made ‘manually’. Elements that provide a high degree of interactivity in demonstrations and simulations must be created using specialised software outside the system and then integrated into it.

Multimedia development of educational content on information technology, suitable for both beginners and experienced users. Mastering individual elements involves interactive demonstration of actions followed by similar exercises, supported by supplementary information. The end of the demonstration is accompanied by sound and a step-by-step text algorithm. [3]

However, the system of introducing concepts is not structured, but moves directly to demonstrating activities. It is advisable to separate the demonstration of activities from independent study, and testing and assessment should be carried out not only through tests, but also through the completion of tasks in a simulated or real environment. For research purposes, the developed multimedia environment is used as a traditional computer-based form of training. When using multimedia for educational purposes, the perception and memorisation of information is only one of the necessary components of the process, and this is primarily due to its informative function of concepts and facts. The interpretation of concepts, the assimilation of their essential relationships and properties associated with the formation and application of skills could not take place solely at the information level. For a successful learning process in a supportive form, it is necessary for multimedia to provide ‘a formative and controlling function that can be combined in a single multimedia environment’. For the purposes of this article, e-learning can be defined as the procedural and functional unity between teaching and learning activities using various electronic means and technologies. E-learning is used in various forms of distance, open and blended learning. For the academic discipline of ‘Computer Technologies’, e-learning is intended for use in blended learning and to support traditional forms of learning.

In this context, the effectiveness of e-learning environments depends on their capacity to integrate instructional sequencing, learner interaction, and feedback mechanisms within a coherent pedagogical framework. A multimedia learning system should therefore be designed not merely as a repository of informational content, but as a structured didactic environment that supports cognitive engagement, guided practice, and performance-based evaluation. The separation of explanatory components, demonstrative activities, and autonomous learner actions enables a clearer alignment between learning objectives and instructional methods. From a pedagogical perspective, multimedia environments must support higher-order cognitive processes, including conceptual understanding, procedural knowledge acquisition, and the transfer of skills to novel contexts. This requires the implementation of interactive elements that allow learners to manipulate variables, test hypotheses, and observe the consequences of their actions in simulated or authentic scenarios. Such an approach enhances the internalisation of conceptual relationships and promotes active knowledge construction rather than passive information consumption. Furthermore, assessment within e-learning systems should be multidimensional and continuous, combining formative and summative components. Alongside conventional test-based assessment, task-oriented evaluation in simulated or real-world environments provides a more valid measure of learners’ competencies and applied skills. This alignment between learning activities and assessment criteria is essential for ensuring instructional validity and learning effectiveness. [4]

In the context of blended learning for the discipline of Computer Technologies, e-learning environments function as a complementary instructional medium that extends classroom-based instruction. They facilitate individualised learning trajectories, enable self-paced skill development, and support the consolidation of theoretical knowledge through practice-oriented tasks. Consequently, the integration of multimedia e-learning systems into traditional educational settings contributes to improved learning outcomes by reinforcing conceptual understanding and fostering sustainable skill formation.

In this sense, flexibility would allow training to be conducted at one's own pace, with changes to the training content being made once and becoming known to all training participants, which leads to savings.

Non-linearity should be implemented through the use of hypermedia elements that allow learners to follow an individual learning path and perform learning activities in a non-sequential manner.

Multimodality involves the formation of new concepts using various semiotic means. Interactivity provides control over teaching and learning processes as needed, with a full degree of automation.

The term ‘interactivity’ comes from English and means «interaction». While traditional education involves interaction between students and teachers, in the context of information technology education (or information technology education), the term undergoes modification, since interaction occurs not only between people, but also between ‘human’-‘computer’ and ‘human’-‘computer’-‘human’. E-learning, carried out with the help of interactive multimedia, provides opportunities for such interaction. Kadon, for example, regulates four levels of interactivity in human-computer relationships:

- first level: low interactivity: the user has virtually no control over interaction with the learning content. Interactivity at this level is primarily related to the user's ability to move forward and backward through the learning content.

- second level: moderate interactivity: includes the first level, but provides more opportunities to control the learning content. It may include audio support for the presentation of learning content. In terms of navigation, reciprocating movements, menus, branches, tables of contents and glossaries are used.

- third level: medium interactivity. This includes interaction with more complex information and allows for a higher level of control. Operations in a multimedia environment can be illustrated with graphics, video, animation, or a combination thereof. Modelling is part of the presentation of learning content. In addition, there is a quick response to user actions, which ensures that the learning material is remembered;

- fourth level: high interactivity: includes detailed presentation of educational information and allows complete control over the content of the course. Most tasks are demonstrated with full interaction and simulation. It includes all the interactive elements described in levels 1-3, as well as advanced branching capabilities using multi-level menus, complex animations and videos.

Communicativeness as a characteristic of interactive multimedia implies communication (through various media) between the learner and the electronic learning content, the teacher, and the author of the multimedia product as a dialogue between connections. [5]

The characteristics of interactive multimedia and the requirements for e-learning to achieve unity in teaching and learning can be combined by introducing an integrated multimedia learning environment, which we will refer to as the multimedia environment. In this study, the following working definition is used: A multimedia environment used in information and computer technologies in education is an integrated environment that performs all educational functions—informative, formative, and control—using various semiotic means (text, graphics, sound, video, animation, simulation of educational activities) and provides the user with a high level of interactivity and control.

Behaviourist theory is applied in the formulation of goals, the definition of concepts, and the formation and improvement of practical skills with support and encouragement.

Cognitive theory is implemented through a clear structure of learning content, determining the role of prior knowledge, the possibility of an unlimited number of repetitions of learning activities, and ensuring feedback on essential components of learning content.

This is linked to constructivist theory: learning at one's own pace; transferring knowledge not only through language, but also through the cognitive domain to ensure meaningful problem-solving activities; the ability to assimilate and accept new cognitive structures as a prerequisite for the dynamic interpretation of student experience [6-7].

**CONCLUSION**

The lack of virtual laboratories for basic disciplines significantly hinders the transition of students majoring in ‘Automation and Control of Technological Processes and Production’ to electronic forms of education. The availability of such laboratories contributes to the improvement of traditional forms of education and their integration with digital educational technologies.

Most existing virtual laboratories do not meet the requirement for interactive software models of all or key control and management devices and systems that are the subject of study in the relevant disciplines.

In particular, existing virtual laboratories lack models of processors with different architectures (battery, register and stack), which significantly hinders their detailed comparative study.

Well-known and accessible models of basic processor architectures do not illustrate their structure at the level of abstraction at which they are considered in specialised disciplines. These models are illustrative in nature, do not allow the degree of training of students to be determined, and do not provide useful information in the event of incorrect actions. In addition, they do not allow tracking and recording of the actions, behaviour, and results of the trainee's work, nor do they allow this information to be saved for further analysis. As a result, these virtual laboratories cannot be effectively used in the educational process for the relevant disciplines. [8-9]

The LabVIEW graphical development environment is widely used in remote access virtual laboratories. It is a powerful modelling tool that allows you to create virtual instruments using a graphical programming language and various component libraries. Along with modelling, the environment provides data acquisition, analysis, presentation and storage, virtual instrument control and measurement result analysis. However, this environment is more focused on modelling test and measurement instruments and systems and is mainly used in virtual laboratories in the fields of electrical measurement, electronics, automation and control. To overcome these limitations, it is necessary to develop a new generation of virtual laboratories focused not only on visualising operating principles, but also on the comprehensive development of competencies through interactive modelling, step-by-step verification of actions, and automated diagnosis of student errors. A key methodological requirement is the availability of parameterisable software and hardware models of basic control devices and computing nodes (including basic processor architectures — accumulator, register and stack) at a level of abstraction that corresponds to the content of the relevant disciplines. This ensures the comparability of architectural solutions, the transparency of command execution mechanisms, and the reproducibility of laboratory scenarios. From a didactic point of view, a virtual laboratory should support: (i) scenarios that simulate real engineering activities (design, configuration, debugging), (ii) formative assessment with feedback explaining the nature of errors and suggesting corrective actions, (iii) collection of digital traces of learning (logging of sequence of operations, execution time, typical difficulties) with the possibility of subsequent analysis and use for adaptive support. Such functionality allows a transition from ‘illustrative’ demonstrations to measurable learning outcomes and increases the validity of practical skills assessment in electronic and blended formats.

Despite the widespread use of LabVIEW in remote and virtual laboratories, its dominant focus on measurement and control tasks limits the ability to represent computing architectures and execution processes in detail at the level of micrological transitions, register operations, and stack mechanisms. Consequently, for disciplines related to computer system architecture and process automation, a promising direction is the development of specialised software benches that integrate with LMS and support standardised storage of results, analytical reporting, and model extensibility for educational purposes. Together, this creates the basis for the sustainable integration of virtual laboratories into the digital educational environment and improves the quality of training for students in the field of ‘Automation and Control of Technological Processes and Production.’

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