Intelligent Adaptation Method for Human-Machine Interaction in Modular E-Learning Systems

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Abstract. The article describes ergonomic problems in e-learning systems. A new method for ensuring ergonomics of electronic educational resources, including ergonomic expertise and multilevel adaptation to the capabilities of trainees was developed. A model approach based on an anthropocentric concept is proposed, which takes into account the requirements of system analysis for the e-learning system as a man-machine complex, namely: multivariance and detailing of the functional structures of the dialogue man-machine interaction in the learning process; parameters, preferences and conditions for individual operators working with the system; the possibility of dynamic optimization of human-machine interaction in real time, providing mechanisms for multi-level adaptation to the human operator.

Keywords: Ergonomics, E-learning, An algorithm of activity, Optimization of activities, Human factor, Human-machine, Effectiveness

1 Introduction

The widespread introduction of computer technology into all spheres of human activity radically changed their nature. Revolutionary changes have taken place not only in industry, agriculture and science but also in the education system. Computerization of the acquisition of knowledge and skills has affected many forms of education (in schools, universities, industrial enterprises, commercial firms, self-training, retraining, advanced training, etc.). The progress of technical facilities and new technological opportunities have caused a surge of interest in new computerized tools and methods of training. In recent years a new progressive concept of “lifelong learning” has emerged and spread widely [1].

E-learning has evolved through a number of stages – from the “use of technical tools for instruction” to the use of modern distributed educational environments of universities (for example [2, 3]) in the educational process, using mobile devices [4, 5]. In universities, “online” and “blended” learning technologies are widely used [6, 7].

At the same time, huge resources and incredible efforts of teams of IT specialists, teachers, and scientists are spent to create learning technologies of a new type [3].

There has been, indeed, enormous progress in enriching the educational process with new methods of training using technical and electronic means. However, according to some estimates [8, 9], the results of cognitive activity of trainees in the learning process do not quite meet the expectations of leading specialists.

The practice of a number of universities shows that trainees cannot fully interact with non-adaptive learning systems that do not meet the modern educational needs and expectations of trainees. Even the most advanced technologies and devices introduced into the learning process haphazardly can lead to a decrease in the efficiency of cognitive activity, and sometimes to the complete failure of the idea of computerization of education. Some aspects of such problems have been analyzed in [9, 10].

Even the problems of harmfulness of e-learning and new threats to humans arising in connection with the peculiarities of new information technologies are discussed [1-9].

Thus, the practice of using e-learning tools faced the need to search for ergonomic reserves to enhance the effectiveness of e-learning methodology and the wider use of modern SMART technologies.

Progress and strong competition in providing information and computer services for legal entities and individuals in local and global networks exacerbate problems of quality and operational services. Huge efficiency reserves are in the modern arsenal of ergonomics methods [1–6].

2 Literature Review and Problem Statement

It is obvious that as automated information systems become more sophisticated in the complex of general measures aimed at increasing the efficiency of the learning process, the need for ergonomic measures and tools also increases [12-17]. Ergonomic quality management programs [12] are designed not only to improve reliability [17] and usability [13], to ensure optimal working conditions for operators [14] but also to reduce the likelihood of stress [12] and threats to human health [14, 15].

Over the past years, in addition to the existing classical ergonomic approaches, new techniques have been developed in these respects:

- designing working conditions at the operator's workplaces [22, 23];
- ergonomic expertise [10-12];
- designing algorithms for human-machine interaction [19-25];
- distribution of functions between operators [24, 25];
- optimization of group activities [17, 24];
- forecasting error-free operation of operators and the risks of losses from unreliability [12];
- others (briefly described in [12, 13]).

Many of these methods are appropriate to use in designing and running e-learning systems as classical "man-technology-environment" systems [30, 31].

However, the specifics of e-learning systems as a special "person-technology-environment" system, the elements of which differ from other types of systems, should be noted [1, 2, 23]:

- subject of labor – information (educational content);
- tools of labor – software and hardware for the delivery of educational content;
- product of labor – a new state of the trainee – the human operator (new knowledge and skills);
- system of performance evaluation – through indicators of the likelihood of achieving specified levels of knowledge and skills (using the specified resources and environmental characteristics) and the degree of compliance of use and interaction with the "students' expectations".

The presence of such special elements of the system requires special methods to ensure ergonomic quality [18-19], as well as the introduction of modern SMART technologies.

A systems analysis of the problems of human-machine interaction in university learning environments, approaches to finding ergonomic reserves for increasing efficiency and requirements for appropriate methods was carried out in [20, 23].

In this regard, the purpose of this work is: to describe the concept and system of methods necessary to ensure the ergonomic quality of e-learning.

3 Results

3.1 Sample of Main Tasks for Improving E-Learning

To determine the need for research, interviews were conducted among students [35] who study using electronic educational environment of the university.

Very often a student gives up his studies because "he does not get what he expects from the system". This applies to local systems, and especially to distance learning systems.

The main complaint of students to the existing means of e-learning (ergonomic defects) are:

- complexity and inflexibility of manipulating learning technology (34.3%);
- low conformity of information modality to styles and ways of user perception (21.1%);
- limited ability to change complexity (12.4%);
- difficulty of predicting learning outcomes (11.1%);
- poor adaptability for work with mobile devices (10.9%);
- lack of self-test technology and explanatory component (7.1%);
- others (3.1%).

The results of the studies confirm the thesis that a dialogue based system is effective only when it provides what the user expects from it, which explains the need for transition in the learning process to new adaptive technologies of human-machine interaction.

3.2 The Basic Concept. Justification of Requirements for Research Methods. Simulation of Human-Computer Interaction Analysis

The following variants of the concept of the relationships between the “man” and “technology” elements are formulated in relation to the concept of “system”:

- system-technical approach – the system is considered as consisting only of technical elements, and the person is considered as a factor in the environment;
- equal element approach – the system is considered as consisting of the equivalent “man” and “technology” elements;
- human-system approach – a person is the main element of the system, whereas technology is the “means of labor” subordinate to him;
- narrow anthropocentric approach – the system is considered as consisting only of the “man” elements without taking into account the “technology” elements;
- narrow technical approach – the system is considered as consisting of technical elements, and the person is not taken into account.

It is obvious that for the tasks of this research, it is necessary to focus on the human-system approach.

Within the framework of this concept, a functional-structural theory (FST) was created to describe the process of functioning and the evaluation of efficiency, quality, and reliability of functioning on its basis. The process of functioning is supposed to mean “the aggregate of actions of ergatic elements and operations performed by non-ergatic elements, united in a single purposeful sequence due to the managing and supporting activity of ergatic elements that form a coherent logical-temporal sequence from the disconnected nomenclature of individual functions that is stable to disturbances and leads to the achievement of the specified goal (or goals) of functioning”.

General requirements to mathematical models of the working process are formulated as follows:

- the model should cover both the main and auxiliary working processes of the “man-technology-environment” system;
- the choice of level of the description language of the working process must correspond to the semantic level of the simulated processes;
- the language should be sufficiently formalized for unambiguous perception on the computer;
- the model should combine the capabilities to describe and evaluate the working process;
- the alphabet of the language describing the working processes of the “man-technology-environment” system should consist of functional elements and be as simple as necessary, but capable to describe specific features of all sub processes of the working process.

In the works on ergonomic design, a systematic approach is adopted to determine the range of indicators of the workflow, according to which the resulting ergonomic quality is efficiency, i.e. ability of the system to reach the ultimate goal, i.e. to get a product of specified quality under given conditions.

The processes of dialogue based interaction in e-learning system can be described by a number of formal systems:

- logical systems (formal grammars, Petri nets, logical automata, event algebras, logical schemes of algorithms, etc.);
- algebraic systems (Markovian and semi-Markov processes, semi-Markovian service networks, etc.);
- language-algebraic systems (networks of precedence, PERT, GERT, MKP networks, functional networks).

Comparative analysis of main methods of describing and evaluating the dialogue based interaction in the e-learning system gives the opportunity to conclude that the concept of SMART systems, the methodology of intelligent data analysis and the apparatus of functional networks are to the greatest extent consistent with the requirements of this study [17-19].

The most convenient algorithmic activity modeling way is functional-structural theory (FST) of ergotehnical systems (ETS) by A. I. Gubinsky [17]. The description of elementary actions of operators is carried out with the help of standard functional units (TFU). A complete list of TFU is given in [17]. The functional network (FN) that describes the activity of the human-operator is built from these TFU. Mathematical models for accurateness and run-time estimation are obtained for typical functional structures (TFS). These models are used to evaluate the entire FN. The estimation is carried out by the method of folding (reduction) FN [17].

3.3 Justification of the Need for a Model Approach

The model approach based on an anthropocentric concept is proposed, which takes into account:

- the requirements of a system analysis of the e-learning system as a human-machine complex;
- multivariance and details of functional structures of dialogue based human-machine interaction in the learning process;
- parameters, preferences and conditions of particular operators working with the system;
- possibility of dynamic optimization of human-machine interaction in real time, providing mechanisms for multi-level adaptation to the human operator.

3.4 Approach to the Organization of Intelligent Agents for E-Learning. The Method of Multi-Level Adaptation

Adaptability problems of modern technologies and computer-based training methods [20, 23], namely limited adaptability to individual characteristics and educational needs of trainees are to be addressed in this study by:

- creation of a system of ergonomic certification of e-learning modules for computer training systems [20, 25];
- introduction of special intelligent agents-managers [20, 23], intended for mechanisms of multilevel adaptation of teaching aids to individual cognitive features of a trainee.

Among the capabilities of such intelligent agents, it is necessary to provide [20, 23]:

1. choice of the optimal modality (the form of presentation of educational information), convenient for a specific person (provides the maximization of cognitive comfort).
2. operative correction of the recommended algorithms of human-machine interaction, taking into account:

    - functional state of a trainee;
    - his motivation;
    - his preparedness;
    - details of technical and software tools, time and other resources available;
    - interactive capabilities of an electronic module;
    - current self-test results;
    - etc.

3.5 General Description of the Structure of Research in the Field of Ergonomic E-Learning Support

The development of the method and information technology of the intelligent adaptation of human-machine interaction in modular e-learning systems involves solving the following specific tasks that we solve:

- development of a technique and models of ergonomic expertise of electronic training modules used in the formation of the bases of educational resources of the educational environment of the university;
- development of a technique and models for the analysis of e-learning systems as human-machine complexes to form databases and knowledge systems required for information support of problems of intelligent adaptation of human-machine interaction;
- development of a technique and models for formal description of options for organizing human-computer interaction in the process of e-learning;
- development of a technique and models for evaluating the effectiveness of dialogue based interaction in modular e-learning systems, taking into account the characteristics of the human operator, the characteristics of the system and the characteristics of the environment;
- development of a multilevel adaptation method in modular e-learning systems, including mechanisms for selecting the optimal modality of electronic modules and constructing individual learning paths depending on the environment, as well as motivation, psychophysiological features, preparedness and condition of the trainee;

— development of information technology elements for the ergonomic provision of human operator activities in modular e-learning systems;
— approbation of technology and evaluation of the effectiveness of the method.

For the conditions of a particular university, these studies must be adjusted.

3.6 The Using of Information Technology. Approbation. Implementation

Based on the proposed methods, an information technology for managing e-learning has been developed. It includes:

— University Management Information System;
— information system for ergonomic expertise of electronic training modules;
— intelligent agent manager to manage the dialogue;
— and others.

Demonstration of ideas for an intelligent agent is shown in Fig. 1.

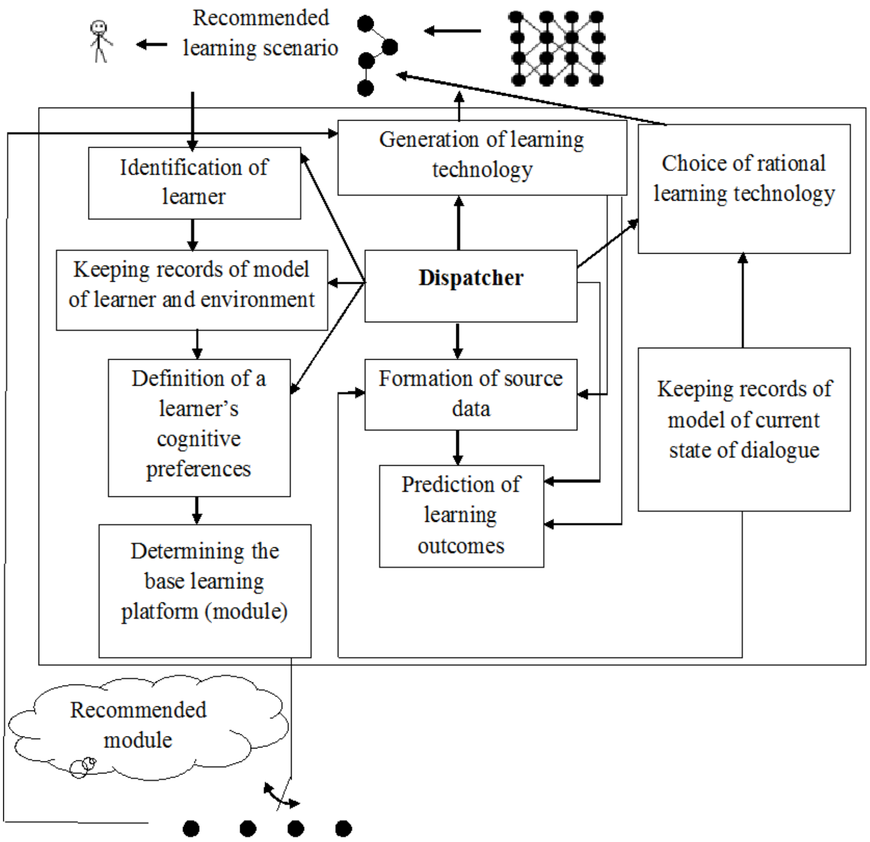

Fig. 1. Basic functional blocks and principle of agent-manager functioning for e-learning

The results were embedded in:

- Lomonosov Moscow State University,
- Belgorod Agrarian Academy,
- Sumy National Agrarian University,
- Sumy State University;
- Vinnytsia State Agrarian University,
- Kremenchug State Technical University,
- Ukrainian Engineering and Pedagogical Academy (Kharkov),
- Kharkiv National University of Municipal Economy,
- and other universities.

The intelligent agent-manager has the ability to integrate into any distance education management system.

3.7 The Effectiveness

Testing the effectiveness of ideas and methods was carried out for two types of distance education management systems:

- standard (for example, Moodle);
- unique university systems.

In both cases, the use of our ideas can significantly increase the adaptability of educational technologies.

Let's describe the effectiveness of the method for only one university – Sumy National Agrarian University, Ukraine (Experiments and efficiency analysis were carried out by N. Barchenko during the dissertation research (2015-2019) [26]).

The use of the agent-manager allowed the experimental group (the experiment was conducted [20, 26] under the guidance of N. Barchenko, S. Agadzhanova, N. Pasko, A. Tolbatov):

- to raise the average score from 72.32 to 81.43;
- to reduce the percentage of refusal to work with e-learning from 24.78% to 7.29%.

The results of the implementation of the system of ergonomic expertise in Sumy National Agrarian University (according to the data of N. Barchenko [20, 26]):

- the percentage of certified electronic modules increased from 5 to 85.4.
- the quality assessment of electronic modules (student survey - on a 100-point scale) increased from 37.7 to 83.8.

4 Conclusion

We have developed:

- a new method for ensuring the ergonomics of electronic educational resources, including ergonomic expertise and multilevel adaptation to the capabilities of trainees;
- elements of information technology to manage interaction in modular e-learning systems.

The obtained results contribute to the development of new SMART technologies and models of adaptive management of the electronic education system and enable the transition to the technologies of dialogue based interaction of a new generation. The social effect consists in a significant increase in the cognitive effectiveness and attractiveness of e-learning technologies. The economic effect is determined by the possibility to reach the following goals:

- improving quality of educational and cognitive activity;
- attracting categories and increasing the number of trainees.
- accessing new international markets for educational services.

The scientific novelty of the results is that, in contrast to the known results obtained earlier:

- in the general theory of adaptive control systems (A.I. Rastrigin, etc.), where in general a person is excluded from the review process;
- in the transformational learning theory (V.F. Venda, etc.), the theory of ergonomic provision of transport systems (E.V. Gavrilov, V.K. Dolya) and studies of many other scientific schools that do not provide the construction of functional models of human-computer interaction variants;
- in the framework of the functional-structural theory of ergotechnical systems of the scientific school, formed by A.I. Gubinsky, in which until now:
  - the task of adapting the information learning system to the human operator is not fully formulated;
  - the models of evaluation and optimization are oriented on an "average" operator;
  - a model of the human-computer information training system has not been built.

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