Проаналізовано проблеми сучасних e-learning та обґрунтовано необхідність впровадження систем ергономічної якості. Обґрунтовано необхідність системного ергономічного аналізу для інформаційного забезпечення e-learning. Розроблено компонентні і морфологічні моделі e-learning як складної системи "людина-техніка-середовище". Результати дозволяють формувати інформаційне забезпечення адаптивних e-learning і сприяють пошуку ергономічних резервів діалогової взаємодії "людина-комп'ютер"

Ключові слова: e-learning, ергономіка, "людина-техніка-середовище", системний аналіз, електронний навчальний модуль

Проанализированы проблемы современных e-learning и обоснована необходимость внедрения систем эргономического качества. Обоснована необходимость системного эргономического анализа для информационного обеспечения e-learning. Разработаны компонентные и морфологические модели e-learning как сложной системы "человек-техника-среда". Результаты позволяют формировать информационное обеспечение адаптивных e-learning и способствуют поиску эргономических резервов диалогового взаимодействия "человек-компьютер"

Ключевые слова: e-learning, эргономика, "человек-техника-среда", системный анализ, электронный учебный модуль

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DEVELOPMENT OF MODELS FOR THE FORMALIZED DESCRIPTION OF MODULAR E-LEARNING SYSTEMS FOR THE PROBLEMS ON PROVIDING ERGONOMIC QUALITY OF HUMAN-COMPUTER INTERACTION

E. Lavrov
Doctor of Technical Sciences, Professor
Department of Computer Science
Sumy State University
Rymskoho-Korsakova str., 2, Sumy, Ukraine, 40007
E-mail: prof_lavrov@mail.ru

N. Barchenko
Senior Lecturer*
E-mail: barchenkonatalia@gmail.com

N. Pasko
PhD, Associate Professor*
E-mail: nbpasko@gmail.com

I. Borozenec
PhD
Department of Mathematical and Software of Automated Control Systems
Kharkiv National University of Air Forces
Sumska str., 77/79, Kharkiv, Ukraine, 61023
E-mail: semjab@mail.ru

*Department of Cybernetics and Informatics
Sumy national agrarian University
Gerasyma Kondratyeva str., 160, Sumy, Ukraine, 40021

1. Introduction

The widespread introduction of computer technology into all spheres of human activity radically changed the nature of people's activity. Revolutionary changes occurred not only in industry, agriculture and science, but also in educational system. Computerization of processes of attaining knowledge and skills touched upon many forms of learning (school, institute of higher education, factory, business company, self-instruction, retraining, qualification upgrading and others). The progress of technical facilities and new technological opportunities caused a splash of interest in the computerization of learning, thus, a new progressive concept of "lifelong learning" has taken root and has been widely spreading in recent years [1].

Electronics-based learning has passed a number of stages – from the "application of technical equipment for education" to contemporary distributed educational environments of universities, for example [2, 3], with the use of mobile devices [4, 5]. At universities, "online" and "blended" learning technologies are widely used [6, 7].

It involves enormous resources and unbelievable efforts from the teams of IT-specialists, instructors, scientists, directed at creating learning technologies of a new type, for example [3].

Although great advances have been made, however, according to some estimates, for example [8, 9], results received do not entirely meet expectations of the leading specialists.

The practice of a number of institutes of higher education indicates that learners do not want to work with non-adaptive systems, which do not meet their contemporary requirements and expectations. Even the most advanced technologies and devices, used without a comprehensive systems analysis, may lead to a decreased effectiveness. Some aspects of such problems are analyzed, for example, in [9, 10].

Even the problems of harmfulness of e-learning and new threats to humans that arise when it comes to special features of new information technologies are discussed in [11]. Thus, the relevance of the work is determined by the need for searching for ergonomic reserves to enhance e-learning effectiveness.

2. Literature review and problem statement

It is obvious that with the complication of automated information systems in the complex of general measures, directed toward effectiveness enhancing, the need of taking ergonomic measures and facilities is becoming increasingly important [12, 13]. The programs of ergonomic quality management [14, 15] are supposed to enhance reliability [17], usability [18] and to provide the optimum working conditions of operators [15, 19]. Furthermore, their introduction makes it possible to decrease stress probabilities [20] and hazards for the health of people [14, 21].

In this respect, the new methods that compliment the existing classical approaches of ergonomics have been developed in recent years:

– design of working conditions at work sites of operators [22, 23];

– ergonomic assessment [23, 24];

– design of algorithms of human-computer interaction [25];

– distribution of functions between operators [26, 27];

– optimization of group activity [28];

– predicting error-free of operators and risks of losses caused by unreliability [29];

– others (briefly described in [13, 14, 21]).

Many of these methods are expedient to use in the process of both designing and operation of e-learning, and in classical systems «human -technology-environment [30, 31].

However, the specificity of e-learning as a special system “human-technology-environment”, the elements of which are different from other types of systems [32, 33]:

– object of labor – information (learning content);

– implements of labor – software and hardware facilities of learning content delivery;

– labor product – new state of a human operator (new knowledge and skills);

– system of effectiveness assessment – through indicators of probability of achievement of assigned standards of knowledge and skills and a degree meeting “the expectations of learners” requires specific methods of providing ergonomic quality [21, 32].

Systems analysis of problems of human-computer interaction in the university learning environments, approaches to searching for ergonomic reserves for enhancing effectiveness and requirements for appropriate methods is presented in [34].

The new developed methods for e-learning improvement include:

– principles and technologies of designing interfaces [32, 35];

– principles of designing dialogue interaction [31, 32];

– ergonomic assessment of electronic educational modules [36–38];

– multilevel adaptation of e-learning to special features of a human-operator [39].

Solution of the problems of contemporary technologies of computer learning [34, 39], related to low adaptability to special features of learners, is proposed to be achieved by:

– creating a system of ergonomic certification and passportization of electronic educational modules [38];

– implementing special agent-managers [40], intended to realize the mechanisms of multilevel adaptation.

The capabilities of such intellectual agents include [34, 39, 40]:

1. *GroupTask1* – selection of optimum modality, convenient for a particular person (provides maximization of cognitive comfort).

2. GroupTask2 – operative correction of recommended algorithms of the human-computer interaction, considering:

– functional state of an operator;

– motivation of an operator;

– training level of an operator;

– special features of technical and software facilities, available time and other resources;

– interactive capabilities of electronic module;

– current self-control results and others.

In spite of the essential progress in development of mechanisms of such multilevel adaptation for e-learning, effectiveness of intellectual agents functioning is limited to the degree of development of information environment at an institute of higher education) (enterprise) [41]. Making optimum decisions in terms of management of ergonomic quality of dialogue interaction is finally determined by the existence of relevant data and knowledge in the system of information provision of e-learning [41].

It is clear that the problem of “Big Data in E-Learning” [42] is becoming obvious as far as ergonomic updating of learning processes is concerned.

The solution of this problem may be found if we use the methods of systems ergonomic analysis, developed in the functional-structural theory of ergotechnical systems. In the basic fundamental work [43], the concept of construction of formal models of human-computer system, relying on a number of special component and morphological structures, was developed.

Such systems models were previously constructed for automated technological complexes, meant for different purposes. Specific character of e-learning requires construction of new models, oriented to given subject area (based of the known theoretical and methodological results [43]).

Thus, the problem lies in formation of a set of systems of e-learning models, aimed at the solution of a series of problems of ergonomic provision of human-computer interaction processes in the information educational environment of an institute of higher education) (enterprise).

3. The aim and tasks of the study

The purpose of present work is development of a complex of formal mathematical models, which provide description of e-learning as a system “human-technology-environment” form the standpoint of the systems-ergonomic analysis. Such models are necessary for the formation of bases of theoretical and methodological provision of technologies for creation and implementation of data and knowledge bases, used for solving the problems of provision of e-learning ergonomic quality.

To achieve the set goal, the following tasks are to be solved:

– to form the structure of a complex of models of systems ergonomic analysis of e-learning as a system "human-technology-environment";

– to develop structures for component models, which describe the necessary entities of e-learning as a system "human-technology-environment;

– to develop structures for morphological models, which describe connections of different nature between the entities, described by the component models;

– to substantiate the expediency of using the developed models in e-learning.

4. Development of a complex of models of ergonomic analysis systems

4. 1. Formation of a set of necessary models

An analysis of information about the system, necessary for optimization of the dialogue interaction, enables us to make a conclusion that this information may be assigned with the help of two classes of structures: component and morphological. We introduce component structures to reveal the entities, necessary for describing the system while solving the optimization problem of dialogue interaction, and morphological structures to assign connections of different nature between the revealed essences [43]. A set of actual e-learning, as well as contemporary literary sources, were analyzed. This made it possible to form a complex of models of systems ergonomic analysis of MMS, which may be assigned by the scheme shown in Fig.1 and described by structural formula (1).

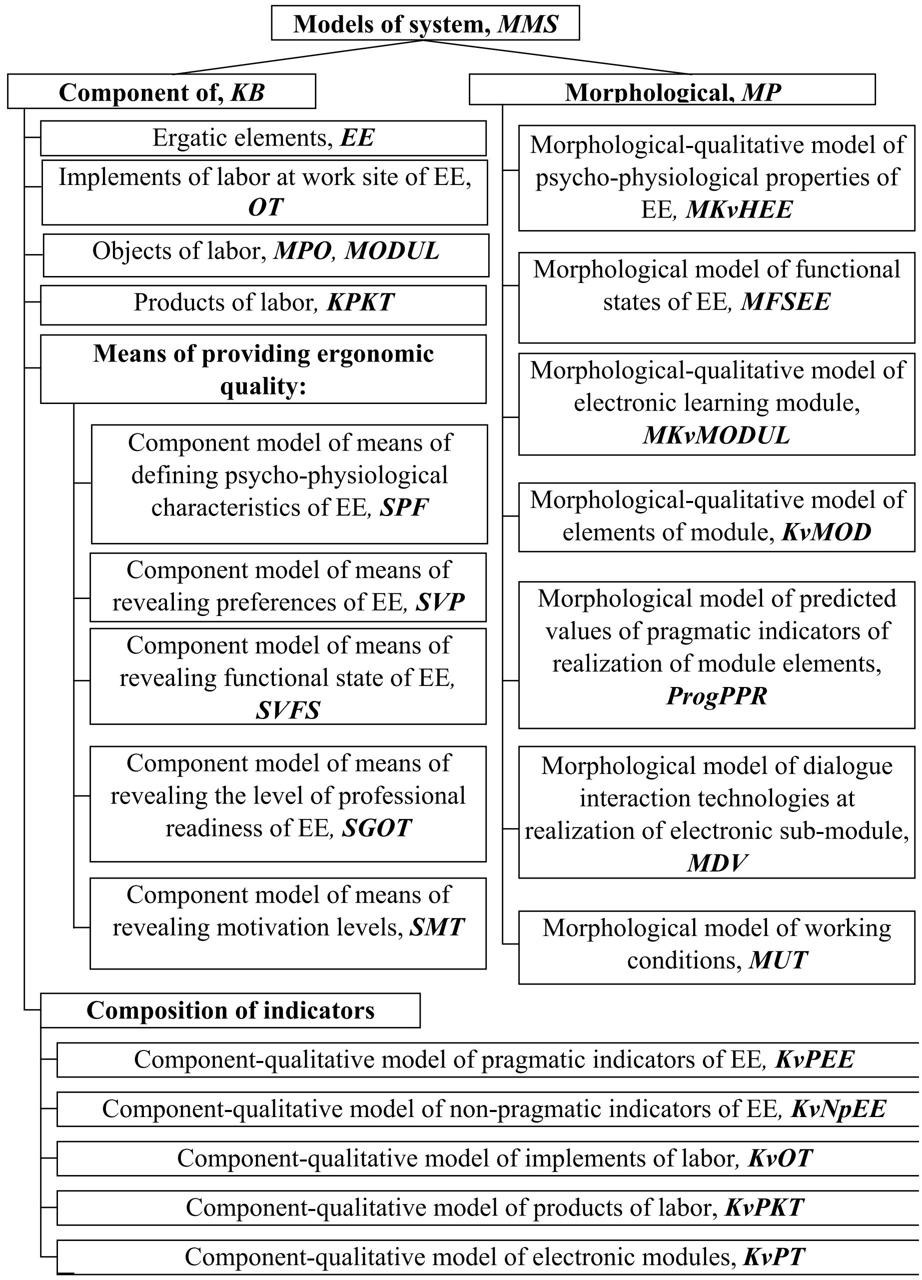

Fig. 1. Structure of complex of models of systems ergonomic analysis

$$MMS=\langle EE,OT,PO,MODUL,KPKT,SPF,SVP,SVFS,SGOT,SMT,EREM,KvPEE,KvNpEE,KvOT,KvPKT,KvPT,MKvHEE,MFSEE,MKvMODUL,MKvMOD,ProgPPR,MDV,MUT\rangle. \quad (1)$$

Further, we will determine the structures of all necessary models.

4. 2. Development of structures of component models

Component model of ergatic elements (EE). The model assigns a unique identifier to each human operator who works in the system (we further call it EE).

$$EE=\langle \{INStud_i;FioStud_i\} \mid i\in\{1,2,...,KEE\}\rangle, \quad (2)$$

where $INStud_i$ is the identifier of the i-th EE; $FioStud_i$ is the first name, the second name and surname of the i-th EE; KEE is the number of EE.

Component model of implements of labor. It describes the components of software, technical support, and means of communication, used while working in the system

$$OT=\langle SW,TO,SK\rangle, \quad (3)$$

where SW is the model of software:

$$SW = <\{idSW_i, NameSW_i, NasnSW_i, TipSW_i\} \big| i = 1,2,...>;$$

$idSW_i$ is the identifier of i-th software; $NameSW_i$ is the name of the i-th software; TipSWi is the purpose of the i-th software; TipSWi is the type of the i-th software; TO is the model of technical support:

$$TO = <\{idTO_i, NameTO_i, TipTO_i\} \big| i = 1,2,...>,$$

where $idTO_i$ is the identifier of the i-th technical support; $NameTO_i$ is the title of the i-th technical support; $TipTO_i$ is the type of the i-th technical support; SK is the model of means of communication:

$$SK = <\{idSK_i, NameSK_i, TipNet_i\} \big| i = 1,2,...>,$$

where $idSK_i$ is the identifier of the i-th means of communication; $NameSK_i$ is the title of the i-th means of communication; $TipNet_i$ is the type of the i-th means of communication.

Component model of subject area. The model determines the enumeration of learning themes for each subject area:

$$MPO = <\{Po_i, \{tema_{ij}\} \big| j \in \{1,2,...,KT_i\} \big| i \in \{1,2,...,KPO\} >, \quad (4)$$

where PO_i is the subject area; $tema_{ij}$ is the j-th theme of the i-th subject area; KT_i is the number of themes of the i-th subject area; KPO is the number of subject areas.

Component model of elements of module. It describes the structure of educational module.

$$\begin{aligned} &MODUL = <\{id\,mod_i, \{PO_k, \{tema_{kj}\} \\ &\big| j \in \{1,2,...,KT_k\} \big| k \in \{1,2,...,KPO\}, \{PMod_{il}, \\ &\{Sr\,mod_{iln}\} \big| n \in \{1,2,...,KSr_{il}\}, \{Sd\,mod_{ilk}\} \\ &\big| z \in \{1,2,...,KSd_{il}\}, Pr\,uk_{il}\} \big| l \in \{1,2,...,KP\,mod_i\} >, \end{aligned} \quad (5)$$

where $idmod_i$ is the identification of the i-th module; PO_k is the k-th subject area; $tema_{kj}$ is the j-th theme of the k-th subject area; KT_k is the number of themes of the k-th subject area; $PMod_{il}$ is the first sub-module of the i-th module; $Srmod_{iln}$ is the n-th self-control of the first sub-module of the i-th module; KSr_{il} is the number of variants of self-control of the first sub-module of the i-th module; $Sdmod_{ilk}$ is the z-th means of “finishing” of additional learning (in terms of [43] – “finishing”) of the first sub-module of the i-th module; KSd_{il} is the number of means of “additional learning” of the first sub-module of the i-th module; $KPmod_i$ is the number of sub-modules of the i-th module; $Pruk_{il}$ is a sign of existence of means of controlling the quality level (provides a possibility of changing learning technologies depending on the current level of the learning quality) of the first sub-module of the i-th module, $Pruk_{il}$ {0,1}.

Component model of products of labor. It gives enumeration of knowledge and skills on the themes of subject area.

$$\begin{aligned} &KPKT = <\{PO_k, \{tema_{kj}, Zn_{kj}, Um_{kj}\} \\ &\big| j \in \{1,2,...,KT_k\} \big| k \in \{1,2,...,KPO\} >, \end{aligned} \quad (6)$$

where PO_k is the k-th subject area; $tema_{kj}$ is the j-th theme of the k-th subject area; Zn_{kj} is the knowledge on the j-th theme of the k-th subject are; Um_{kj} are the skills on the j-th theme of the k-th subject area; KT_k is the number of themes of the k-th subject area; KPO is the number of subject areas.

Component model of means of defining psycho-physiological characteristics of EE (PPCEE). The model describes the set of means for defining psycho-physiological characteristics. It establishes a link between a psycho-physiological characteristic and the means, defining it.

$$\begin{aligned} &SPF = <\{INSpf_i, NameSpf_i, \{PSpf_{ij}\} \\ &\big| j \in \{1,2,...,KPS_i\} \big| i \in \{1,2,...,KPF\} >, \end{aligned} \quad (7)$$

where $INSpf_i$ is the identifier of the i-th means of defining PPCEE; $NameSpf_i$ is the name of the i-th means of defining PPCEE; $PSpf_{ij}$ is the j-th indicator of the i-th PPCEE; $PSpf_{ij} \in PFH$; KPS_i is the number of all indicators of PPCEE; KPF is the number of means of defining PPCEE.

Component model of means of revealing preferences of EE. The model describes the means for revealing preferences and indicators of EE and preference indicators of the EE, revealed by this means.

$$\begin{aligned} &SVP = <\{INSvp_i, NameVp_i, \{PSvp_{ij}\} \\ &\big| j \in \{1,2,...,KPVP_i\} \big| i \in \{1,2,...,KVP\} >, \end{aligned} \quad (8)$$

where $INSVp_i$ is the identifier of the i-th means of revealing the EE preferences; $NameVp_i$ is the name of the i-th means of revealing the EE preferences; $PSvp_{ij}$ is the j-th indicator for the i-th means, $PSvp_{ij} \in PMOD$; $KPVP_i$ is the number of all indicators of the EE preferences, revealed by the i-th means; KVP is the number of means of revealing the EE preferences.

Component model of means of revealing functional state of EE. The model gives enumeration of means for defining a functional state of EE.

$$SVFS = <\{INSfs_i, NameSfs_i \big| i \in \{1,2,...,KSFS\} >, \quad (9)$$

where $INSfs_i$ is the identifier of the i-th means of revealing the functional state of EE; $NameSfs_i$ is the name of the i-th means of revealing the functional state of EE.

Component model of means of revealing the level of professional readiness of EE. The model gives enumeration of means for revealing the level of professional readiness of EE.

$$\begin{aligned} &SGOT = <\{INSgot_i, NameSgot_i, InUgot_i \\ &\big| i \in \{1,2,...,KGOT\} >, \end{aligned} \quad (10)$$

where $INSgot_i$ is the identifier of the i-th means of revealing professional readiness to learning; $NameSgot_i$ is the name of the i-th means of revealing professional readiness to learning; $InUgot_i$ is the integral level of professional readiness to learning, revealed by the i-th means; KGOT is the number of means of revealing professional readiness to learning.

Component model of the means of revealing motivation levels. The model gives enumeration of means for revealing motivation levels of EE.

$$\begin{aligned} &SMT = <\{INSmt_i, NameSmt_i, \{PSmt_{ij}\} \\ &\big| j \in \{1,2,...,KPMT_i\} \big| i \in \{1,2,...,KMT\} >, \end{aligned} \quad (11)$$

where $INSmt_i$ is the identifier of the i-th means of defining motivation of EE; $NameSmt_i$ is the name of the i-th means of defining motivation of EE; $PSmt_{ij}$ is the j-th indicator for the i-th means, $PSmt_{ij} \in MMT$; $KPMT_i$ is the number of all indicators of motivation for the i-th means; KMT is the number of means of defining the motivation level of EE.

Component-qualitative model of pragmatic indicators of EE. The model defines probability-temporal indicators of quality of performing the learning process of EE.

$$KvPEE=<\{B,Mt,Dt\}>, \quad (12)$$

where B is the probability of successful completion of the learning process; M_t is the mathematical expectation of time of the learning process fulfillment; D_t is the dispersion of time of the learning process fulfillment.

Component-qualitative model of non-pragmatic indicators of EE. The model defines the composition of the EE characteristics, which are revealed for defining individual preferences, psycho-physiological characteristics, functional state, motivation and level of readiness for learning.

$$KvNpEE=<\{PMOD,PFH,\{PFS,VPfs\},\{MMT,VMmt\},\{InUGot,VUGot\}\}>, \quad (13)$$

where PMOD is the set of characteristics of preferable modalities of the EE; PFH is the set of psycho-physiological characteristics of the EE; PFS is the indicator of functional state; VPfs is the range of values of functional state; MMT is the level of the EE motivations; VMmt is the range of values of motivation level; InUGot is the integral level of professional readiness for learning of EE; VUGot is the range of values of the level of professional readiness for learning of EE.

The set of characteristics of preferable modalities of the EE are determined by formula:

$$PMOD=<\{Pmod_j,VPmod_j\}\big|j\in\{1,2,3,4\}>,$$

where $Pmod_j$ is the name of the j-th characteristic of preferable modalities of EE; $VPmod_j$ is the range of values of the j-th characteristic of preferable modalities of the EE.

The set of psycho-physiological characteristics of the EE is determined by formula:

$$PFH=<\{Npfh_j,Vpfh_j\}\big|j\in\{1,2,...Kpfh\}>,$$

where $Npfh_j$ is the name of the j-th psycho-physiological characteristic of the EE; $Vpfh_j$ is the range of values of the j-th psycho-physiological characteristic of the EE; Kpfh is the number of psycho-physiological characteristics of the EE.

Comp*onent-qualitative model of implements of labor*. The model describes the characteristics of implements of labor, used in the system

$$KvOT=<\{idOt_i,NameOt_i,TipOt_i,\{Pk_{ij},Val_{ij}\}\big|j\in\{1,2,...,KPK_i\}\big|i\in\{1,2,...,KOT\}>, \quad (14)$$

where $idOt_i$ is the identifier of the i-th implement of labor; $NameOt_i$ is the name of the i-th implement of labor; $TipOt_i$ is the type of the i-th implement of labor; Pk_{ij} is the j-th characteristic (quality indicator of the i-th implement of labor); Val_{ij} is the value of the j-th characteristic of the i-th implement of labor; KPK_i is the number of all quality indicators of the i-th implement of labor; KOT is the number of implements of labor.

Component-qualitative model of products of labor. The model determines the set of probability-temporal indicators of products of labor. Students' knowledge and skills on the themes of a subject area are assessed by these indicators

$$KvPKT==<\{prob_i\}\big|i\in\{1,2,3,4,5,6\},\{\{Mtk_{kj},VMtk_{kj}\},\{Dtk_{kj},VDtk_{kj}\}\big|j\in\{1,2,...KT_k\}\}\big|k\in\{1,2,...KPO\}>, \quad (15)$$

where $prob_i$ is the name of the i-th probability indicator ($prob_1$="probability of successful completion of test control", $prob_2$="probability of successful completion of test control with the grade "excellent", etc.); Mtk_{kj} is the indicator "mathematical expectation of time of successful completion of test control" on the i-th theme of the k-th subject area; $VMtk_{kj}$ is the range of permissible values of indicator Mtk_{kj}; Dtk_{kj} is the indicator "dispersion of time of successful completion of test control" on the j-th theme of the k-th subject area; $VDtk_{kj}$ is the range of permissible values of the indicator; KT_k is the number of themes on the k-th subject area; KPO is the number of subject areas.

Component-qualitative model of electronic modules. The model defines the composition of quality indicators of learning modules, used for conducting the ergonomic assessment.

$$KvPT=<PX,PY,PZ,PV,MODAL,IPEK>, \quad (16)$$

where PX is the set of assessment of interface and navigation parameters (indicators of convenience of working with the keyboard and the mouse, intuitive clearness of navigation, convenience of working with table of contents; PY is the set of evaluated parameters of slides quality (quantity of material on a slide, uniformity of slides layout); PZ is the set of evaluated text parameters (readability of a text, observance of layout logic); PV is the set of the evaluated parameters of visual environment (observance of proportions, color layout, arrangement); PMK is the set of evaluated multimedia components (validity of application, correspondence to the text material, quality of execution); MODAL is the set of evaluated parameters of information modality (degree of presence of a text component, an audio component, a graphic component, a video component); IPEK is the integral indicator of the module quality ("does not meet the requirements", "finishing is necessary", "meets requirements").

$$PX=<\{px_i,Valpx_i\}\big|i\in\{1,2,3\}>,$$

$$PY=<\{py_i,Valpy_i\}\big|i\in\{1,2\}>,$$

$$PZ=<\{pz_i,Valpz_i\}\big|i\in\{1,2\}>,$$

where px_i is the name of indicators of the interface assessment; $Valpx_i$ is the range of permissible values of the interface assessment; py_i is the name of the indicators of assessment of the slide parameters; $Valpy_i$ is the range of permissible values of indicators of assessment of the slide parameters; pz_i is the name of indicators of text assessment; $Valpz_i$ is the range of permissible values of indicators of text assessment.

$$PV=<\{pv_i,Valpv_i\}\big|i\in\{1,2,3\}>,$$

$$PMK=<\{pm_i,Valpm_i\}\big|i\in\{1,2,3\}>,$$

where pvi is the name of visual assessment parameters; Valpvi is the range of permissible values of indicators of assessment of the visual environment; pm_i is the name of indicators of multimedia components assessment; $Valpm_i$ is the range of permissible values of indicators of multimedia components assessment.

$$MODAL = < \{mod_i, Valmod_i\} | i \in \{1,2,3,4\} >,$$

where mod_i is the name of information modality assessment; $Valmod_i$ is the range of permissible values of information modality assessment.

IPEK is the integral indicator of ergonomic quality, IPEK∈$\{e_1, e_2, e_3\}$, e_1="corresponds", e_2="finishing", e_3="does not correspond".

4. 3. Development of structures of morphological models

Morphological-qualitative model of psycho-physiological properties of ergatic elements. It contains the values of parameters of psycho-physiological properties of the EE.

$$MKvHEE = < \{idStud_i, PFH_i, PMOD_i\} >, \quad (17)$$

where $idStud_i$ is the identifier of the i-th EE; PFH_i is the set of psycho-physiological characteristics of the i-th EE.

$$PFH_i = < FPNS, VNS, SVI, DV, SPO, TNS, SLM, TM, SVG, SVT, NR, TNS, UT >,$$

where FPNS is the level of functional mobility of nervous system; VNS is endurance of nervous system; SVI is the ability of information perception; DV is the dynamic attention; SPO is the capability of three-dimensional operations; TNS is the type of higher nervous activity; SLM is the capability of logical thinking; TM is the temperament; SVG is the capability of perception of graphic information; SVT is the capability of perception of text information; NR is neuroticism; TNS is the type of nervous system; UT is the fatigue rate.

$PMOD_i$ is the set of characteristics of preferable modalities of the EE:

$$PMOD_i = < MOD_1, MOD_2, MOD_3, MOD_4 >,$$

where MOD_1 is the value of the parameter, which describes the verbal component; MOD_2 is the value of the parameter, which describes the audio component; MOD_3 is the value of the parameter, which describes the visual component; MOD_4 is the value of the parameter, which describes the kinesthetic component.

Morphological model of functional states of the EE.

$$MFSEE = < \{idStud_i; \{PFS_{ij}; T_{ij}\} | j = \{1,2,...,KMV\} >, \quad (18)$$

where T_{ij}∈T_{i0}, T_{i0} is the set of time moments of measuring functional states of the i-th EE. PFS_{ij} is the functional state of the i-th EE at time moment T_{ij}, PFS_{ij}∈{"permissible", "non-permissible", "indefinite"}.

Morphological-qualitative model of electronic learning module. The model contains the values of the results of ergonomic assessment of learning module quality.

$$MKvMODUL = < idMod; \{PO_k; \{tema_{kj}\} | j \in \{1,2,...,KT_k\}; \{px_i\} | i = \{1,2,3\}; \{py_i\} | i = \{1,2\}; \{pz_i\} | i = \{1,2\}; \{pv_i\} | i = \{1,2,3\}; \{pm_i\}; \{mod_i\} | i = \{1,2,3,4\}; e_i | i \in \{1,2,3\}\} >, \quad (19)$$

where idMod is the identifier of a module; PO_k is the k-th subject area; $tema_{kj}$ is the j-th theme of the k-th subject area; px_i is the i-th indicator of the interface assessment; py_i is the i-th indicator of assessment of slide's parameters; pz_i is the i-th indicator of test assessment; pv_i is the i-th indicator of assessment of visual environment; mod_i is the i-th indicator of information modality; e_j is the result of assessment (resolution on correspondence of a module to ergonomic requirements).

For example, indicators of interface assessment may be:

– px_1 is the indicator of convenience of working with a keyboard and a mouse;

– px_2 is the indicator of intuitive navigation clarity;

– px_3 is the convenience of working with the table of contents.

Indicators of quality of slides may be:

– py_1 is the amount of material on a slide;

– py_2 is the uniformity of slides layout.

Morphological-qualitative model of elements of module. It reflects the values of parameters of the elements of module and their probability-temporal quality characteristics.

$$MKvMOD = < idMOD_i; \{PO_k; \{tema_{kj}\} | j \in \{1,2,...,KPO\}, \{Pmod_{il}; Ur_{il}; MM_{il}; DM_{il}; \{Srmod_{iln}, K11_{iln}, K00_{iln}, MS_{iln}, DS_{iln}\} | n \in \{1,2,...,KSr_{il}\} >, \quad (20)$$

where $idMOD_i$ is the identifier of the i-th learning module; PO_k is the k-th subject area; $tema_{kj}$ is the j-th theme of the k-th subject area; KPO is the number of subject areas; $Pmod_{il}$ is th first sub-module of the i-th module; Ur_{il} is the number of complexity levels of the first sub-module; MM_{il} is mathematical expectation of fulfillment time of the first sub-module of the i-th module; DM_{il} is the dispersion of fulfillment time of the first sub-module of the i-th module; $Srmod_{iln}$ is the n-th self-control of the first sub-module of the i-th module; $K11_{iln}$ is the possibility of detecting an error by the n-th self control of the first sub-module of the i-th module; $K00_{iln}$ is the possibility of not detecting an error by the n-th self control of the first sub-module of the i-th module; MS_{iln} is the mathematical expectation of fulfillment time of the n-th self control of the first sub-module of the i-th module; DS_{iln} is the dispersion of fulfillment time of the n-th self control of the first sub-module of the i-th module; KSr_{il} is the number of self-controls of the first sub-module of the i-th module.

Morphological model of predicted values of pragmatic indicators of realization of elements of module. It determines the values of predicted probability-temporal quality indicators of realization by ergatic elements of the module's structural elements.

$$ProgPPR = < idStud_i; \{PO_k; \{tema_{kj}; \{idmod_{kjl}; \{pmod_{kjln}; \{B; M; D; T\}\} | n \in \{1,2,...,kpmod_{kjl}\}\} | l \in \{1,2,...,kmod_{kj}\}\} | j \in \{1,2,...,KT_k\}\} k \in \{1,2,...KPO\}\} | i \in \{1,2,...,KEE\} >, \quad (21)$$

where $idStud_i$ is the identifier of the i-th EE; PO_k is the k-th subject area; $tema_{kj}$ is the j-th theme of the k-th subject area; $idmod_{kjl}$ is the identification of the first module on the j-th theme of the k-th subject area; $pmod_{kjln}$ is the n-th sub-module of the first module on the j-th theme of the k-th subject area; B is the probability of successful completion of the learning process by the i-th EE of the n-th sub-module of the first module on the j-th theme of the k-th subject area; M is the mathematical expectation of fulfillment time by the i-th EE of the n-th sub-module of the first module on the j-th theme of the k-th subject area; D is the dispersion of fulfillment time by the i-th EE of the n-th sub-module of the first module on the j-th theme of the k-th subject area; T is the time moment of defining the current functional state of the i-th EE in the process of learning the n-th sub-module of the first module on the j-th theme of the k-th subject area; $kpmod_{kj}$ is the number of sub-modules for the first module on the j-th theme of the k-th subject area; $kmod_{kj}$ is the number of modules on the j-th theme of the k-th subject area; KPO is the number of subject areas; KEE is the number of ergatic elements.

Morphological model of dialogue interaction technologies at realization of electronic sub-module. The model describes the standard algorithms of electronic sub-modules realization, determined by the component model of the elements of a module *MODUL*. There may be several options of dialogue interaction in the course of electronic sub-module realization. The model is assigned as the formal model of the functional network [43]:

$$MDV =< \{P\bmod_{il}; \{Var_{ilj}, Mfs_{ilj}\} | j = 1,2,...nv_{il}\} | l = 1,2,..., KP\bmod_i >, \quad (22)$$

where $PMod_{il}$ is the first sub-module of the i-th module; $KPmod_i$ is the number of sub-modules of the i-th module; Var_{ilj} is the j-th variant of technology of dialogue interaction in the course of realization of electronic sub-module $PMod_{il}$; Mfs_{ilj} is the j-th formal model of the functional network (in terms of [43]) of the algorithm of interaction in the course of realization of electronic sub-module $PMod_{il}$; nv_{il} is the number of variants of technology of dialogue interaction in the course of realization of the electronic sub-module $PMod_{il}$.

Morphological model of working conditions. It reflects for each work site the values of the ergatic element of health and hygiene and psycho-physiological factors influencing the working conditions:

$$MUT =< \{RM_i; KT_i; IBO_i; \{TFak_{ij}; NFak_{ij}; ZFak_{ij}\} | j = 1,2,...nf_i\} | i = 1,2,...K_0 >, \quad (23)$$

where RM_i is the identification of the i-th working place; KT_i is the category of complexity for working site RM_i; IBO_i is the integral point assessment for work site RM_i; Nf_i is the number of influencing factors for work site RM_i; $TFak_{ij}$ is the type of the j-th influencing factor for work site RM_i; $NFak_{ij}$ is the name of the j-th influencing factor for work site RM_i; $ZFak_{ij}$ is the value of the j-th influencing factor for work site RM_i; K_0 is the number of work sites of a system.

4. 4. Using a complex of models of systems ergonomic analysis of e-learning

Component and morphological models of e-learning determine the concept of construction of data and knowledge bases of the learning control system and, therefore, provide:

– formation of source models for passportization of all elements of the human-computer system, including ergonomic evaluation of electronic learning modules;

– introduction of models of a learner, environment, object of labor, implements of labor and expected labor product, used by the program set “Agent-manager for e-learning” (Fig. 2).

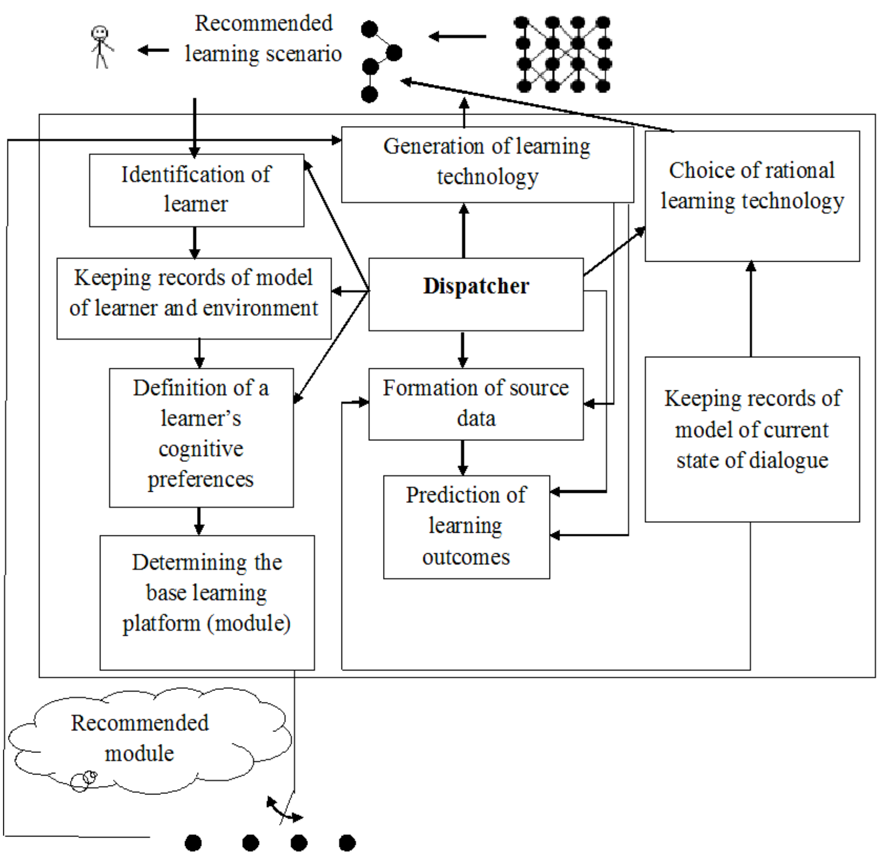

Fig. 2. Basic functional blocks and principle of functioning of agent-manager for e-learning

An analysis of effectiveness is predetermined by the very technology of systems analysis, which provides data collection about all sessions of human-computer interaction in e-learning.

The use of the developed with the use of a concept of systems analysis of different elements of information support was studied throughout 1998–2016. This study was carried out within the framework of complex informatization [41] at more than 10 institutes of higher education of Russia and Ukraine (Kremenchug, Sumy, Vinnitsa, Kharkov, Belgorod, Moscow and others) and confirmed the constructiveness of the approach.

A comprehensive study of effectiveness was carried out within the framework of using a program set [44] for disciplines:

– "Artificial intelligence" [44, 45] at Sumy State University;

– "Information systems in management" at Sumy National Agrarian University in 2015–2017.

The use of agent-manager technology, based on the data and knowledge bases, formed with the use of the described approach, allowed us:

– to decrease probability of refusal from working session in e-learning from 0.271 (without using the system) to 0.093 (using the system);

– to increase the probability of successful completion of the session with the expected level of the evaluation of knowledge and skills from 0.707 to 0.901.

6. Discussion of the results of studying the task on formalized description of modular e-learning to provide for the ergonomic quality of human-computer interaction

The developed models make it possible to solve the problem of information provision of processes of ergonomic support of effectiveness of human-computer interaction in e-learning. The following processes are provided:

– formation of databases of electronic modules (formation of content), which meet ergonomic standards and requirements;

– operative control of a session of dialogue interaction in e-learning taking into account specific features of human operator (psycho-physiological, motivational, functional state and others), parameters of software and hardware means and the state of environment.

The proposed complex of models cannot claim to be comprehensive. It is obvious that there is a theoretical possibility of existence of "disregarded" types of systems with their specific features and emerging a new complex of problems of ergonomic provision, not considered earlier.

Moreover, the authors intentionally did not present already existing models, because the volume of material is limited. However, the developed methodology may be the theoretical basis for expansion, modification and upgrading the library of models.

In this case, this provides the possibility of:

– selection of optimum modality, which provides the maximum cognitive comfort;

– analysis of alternatives variants of operators' activity with electronic modules (complexity, dialogue organization, self-control technology and others), as well as their individual characteristics.

The possible limitations of the approach include relatively large labor intensity. Studies are useful only if preliminary work on "passportization" of electronic modules, software and hardware support of e-learning were performed, as well as all the necessary forms of testing and revealing preferences of learners.

Studies may be used for e-learning systems of modular type, employed at different institutions (schools, institutes of higher education, enterprises and others), in which rely on technology of common information space with the possibility of keeping the correspondent data bases. Results may be useful in contemporary distributed educational environment with the use of mobile devices, as well as when designing and providing "online" and "blended" learning technologies.

In future, the development of method is planned in direction of propagation of results on the e-learning systems of generating type. In such systems, there are no preliminarily formed modules, and alternative dialogue scenarios are formed in the process of learning by applying procedures of logical conclusion and methods of artificial intelligence.

7. Conclusions

1. We proposed the method of formal description of e-learning as a system "human-technology-environment", which provides ergonomic engineers, developers and managers of e-learning with unambiguously treated means of presentation of data and knowledge about the elements of the system and connections between them.

For the formalization, a concept of systems ergonomic analysis of the functional-structural theory of ergotechnical systems was used.

The authors formed the structure of the complex of models of systems ergonomic analysis of e-learning as a system "human-technology-environment".

A characteristic difference of the proposed methods from the previously developed approaches is the application of technology of systems ergonomic analysis to a new class of objects – e-learning with specific instruments, the object and the product of labor. In this case, characteristic features of a human operator as a learner, as well as contemporary technologies of constructing electronic learning modules and means of content delivery were taken into consideration.

2. The structures for component models, which describe the necessary entities of e-learning as a system "human-technology-environment", were developed. Their special feature is the existence of new models of means of e-learning ergonomic quality provision and models of description of e-learning specific components (ergatic elements, implements of labor, objects of labor, means of labor, composition of indicators for ergonomic design), which had not been previously described.

3. The structures for morphological models, which describe connections of different nature between the entities, described by component models, were developed. Their specific feature is the existence of required (fundamentally new) models, which describe states and dialogue interaction of ergatic and non-ergatic elements, which make it possible to form predicted values of the learning process quality.

4. Expediency of using the developed models in e-learning was substantiated and a method for using the developed formal models to construct the systems of ergonomic quality of e-learning was described. Practical significance is in the

fact that, based on the proposed formalisms, it is convenient to construct the information support systems of e-learning, oriented towards:

– ergonomic quality of the content;

– multilevel adaptation to the requirements of users and special features of the environment.

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