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Computer Modelling of Cognitive Processes

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Abstract—**Brief description of the author's results of development of cognitive processes (CP) computer modelling concept on the basis of improving the methodology and expanding the area of using computer-based testing technology in education is suggested. The fundamental heuristics for formalizing: the concept of degree of difficulty of test tasks (TT); the degree of confidence of individual's CP concept; the concept of stability modes of individual's CP and CP phases during the working time; the concept of the target level of the test session are presented.**

The heuristic algorithms of intellectual express and expanded analysis of the TT quality are developed. The algorithm of obtaining the cognitive individual's profile for formation and adequate interpretation of individual intellectual characteristics is offered. The concept of technical implementation of the CP computer model into the informational learning environment is formulated.

I. Introduction

BEGINNING of the XXI century represents a crucial stage in the development of education. In intellectually intense and fast-paced high-tech environment, with an excess of information, which has already exceeded the capacity of individual's perception of it, new approaches in teaching and educational technologies are necessary.

Due to the emergence of new trends in science up-to-date conceptual framework was born. Thus, the term "cognitive" (from the Latin word "cognition" – knowledge, perception), meaning "informative", "pertaining to knowledge," appeared in the sixties of the last century as a result of existence of a new paradigm in psychological research (cognitive psychology, cognitive science). In this paradigm special attention is paid to traditional cognitive processes (CP): perception, attention, memory, imagination and thinking etc. However, the cognitive approach is fundamentally different in a way that all of these processes are considered as components of the overall process of information exchange between the individuals during the learning.

Under the new conditions new learning technologies must be created – cognitive, i.e. ways, techniques, methods to ensure effective understanding by the individuals of information on the bases of unique indicators and characteristics of their CP. The task of great importance is to develop the modern methodologies of organizing individuals' learning and continuous monitoring and assessing of individuals' CP indicators, as well as of forming individual productive paths in the cognitive processes by means of introducing effective feedback systems via using the computer testing controlling methodology.

Recent scholarly research in the field of creating computer learning technologies can be divided into several categories:

Intelligent Tutoring Systems: information-reference systems; consultative type systems; intellectual training (expert-type tutoring) systems; accompanying type systems (e.g., ELM-ART-II, AST, ADI, ART-Web, ACE, KBS-Hyperbook, ILESA, DCG, SIETTE) [1].

E-Learning Management Systems elaborated the following SCORM standards, the specifications of the IMS Global Learning Consortium, and the Aviation Industry Computer-Based Training Committee (AICC) that regulate certain aspects of their development and use: the system's architecture and the system's interaction with outside systems; the ways of the learning system's interaction with learning resources; the presentation of courses' contents; the models of learning control; the testing algorithms and ways of presenting testing results (e.g., BaumanTraining, eLearning 3000, WebTutor) [2,3].

Diagnostic and Planning Expert Teaching Systems based on using the methodological tools of computer testing [4-7].

Despite the wide range of scholarly achievements and market offers in the field of computer learning technologies, all of them have a number of similar specifications:

a) The use of testing technology mostly for measuring students' learning individual achievements and the lack of methods for obtaining the specific characters of their individual intellectual activity and features of CP.

b) The necessity of development of the methods of intellectual diagnostics of test materials for increasing the quality of CP assessment.

c) The inflexible demands in most Ukrainian higher schools (HS) to the software required for their functioning and to the technical characteristics (in particular, the capacity characteristics) of computers, as well as to the speed and time of Internet resources use.

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The purpose of this paper is brief description of the author's results of development of CP computer modelling concept on the basis of innovative approaches to improving the methodology and expanding the area of using the computer-based testing systems (CBTS) technology. The paper is also aimed at the presenting the key aspects of developing the use of author's modelling propositions as an instrument for receiving and adequate interpretation of the set of quantitative and qualitative identifiers of individual intellectual characteristics of individuals.

II. Cognitive Process Computer Modeling Concept

The CP computer modelling concept suggested by the author is based on implementing the following functional components: the database, the expert system of integrated diagnostics and cognitive process control (the latter comprising the logical conclusion mechanism, the working memory, the knowledge base, as well as the explanation subsystem and the dialogue subsystem), control systems, and CBTS.

A. The Database Structure

The database of the computer model is designed for storing:

– the structured learning content (LC), presented in the following systemically coordinated forms: brief textual notes of lectures for individuals' self-studying before the actual in-class teaching/learning starts $Teach^1$ (contain the basic notions, definitions, laws, examples, and algorithms of situational knowledge use from the course); slide-notes of the lecture materials for demonstrating and discussing directly in the in-class teaching/learning process – $Teach^2$; laboratory assignments – $Teach^3$; testing materials for assessing the degree of individuals' CP – $Teach^4$.

– reference and factual information about the syllabus, the number of individuals, the distribution of academic hours and learning units between in-class and out-of-class (independent) individuals' work;

B. Knowledge Base Structure

The core of the expert system of integrated diagnostics and cognitive process control is the knowledge base designed for storing: expert knowledge and the acquired analytically knowledge.

The foundations of expert knowledge are the author' research results in the area of computer testing methodology improvement and the development of intellectual instruments for supporting decision-making in what concerns the CP analysis. There are the following heuristics:

a) Reference time T_{ni} is the objective tool of complex quantitative formalization (scaling) of the degree of difficulty: the statement and visual representation of TT; the TT itself causes the timetable for task processing; the technology of entering the results of CP.

b) The degree of mismatching in factual and reference time for solving the TT – dynamic coefficient $D^f_{i=}t^f_i/t^n$, – demonstrates the objectivity of determined indicator of degree of difficulty of the TT – R_i.

c) The complex indicator of the degree of confidence of CP and the probability of guessing the correct solution is the correlation coefficient K_i between series of factual T_{fi} and reference time T_{ni} spent on correct result of cognitive processing of TT. The value of T_{ni} is determined after check testing of a group of experts [8].

d) The interpretation of the normalized K_i ranges may be the following: an individual with high level of the confidence solves the TT at steady pace ($K(t^*, t^f) \geq 0{,}5$); in the behavior of an individual, who has middle level of CP confidence, there are "gaps" in the problem domain's assimilation and uncoordinated pace of solving the tasks ($0{,}3 \leq K(t^*, t^f) < 0{,}5$); the individual, whose CP level is low, may try to guess the correct decision ($K(t^*, t^f) < 0{,}3$).

e) The concept of modes of stability of CP is a consequence of entering the concept of interpretation of the CBTS and individuals as a dynamic system. In this regard, the interpretation of equilibrium (EM) and periodic (PM) modes of the individual's CP may be the following [9]: EM corresponds to the situation, which is characterized by in-time constancy CP during the testing session; the PM is characterized by fluctuations in the CP individual's entropy as a result of changes in the level of complexity of TT.

f) In the author's interpretation the EM of CP is quantitatively identified by $K(t^*, t^f) \geq 0{,}5$ and PM – by $K(t^*, t^f) < 0{,}5$.

g) The concept of the CP phases is defined as a set of functional states of an individual during the test session: the primary reaction – short-term of reduction of the actual level of confidence and precision of CP; overcompensation and compensation – gradual improvement and stabilization of indicators of confidence and precision of CP; subcompensation and decompensation – reduction of actual level of confidence and accuracy of CP.

h) The concept of the informativeness level is considered on the basis of quantification of the effectiveness of test performance.

i) The concept of the target level $TL_i = f(U_j, P_j, Z_i)$ is considered on the basis of scaling the TT by: TT forms U_j (from lowest to highest: with only one correct answer; closed form of TT with multiple choice; matching TT; open form of TT with sequence-setting); boundary probability (P_j) of guessing the correct solution of TT; cognitive process difficulty levels Z_i (from lowest to highest: recognition and presentation; reproductive replay; productive replay).

j) The efficiency of CP testing is increased due to determining the consecutive order of giving TT in accordance with the decrease of their target level [10].

The Expert Block of the Knowledge Base includes the knowledge about subject area and the control knowledge:

a) The Algorithms of TT Quality Analysis:

– Heuristic Algorithm of the TT Quality Q_i Express Analysis. Presupposes the methodology of stage-by-stage guaranteed acquisition of a complete testing results' matrix from two incomplete matrices – the results of preliminary and final testing in the framework of one class period [10];

– Heuristic Algorithm of Expanded Analysis and of Improving the TT Quality Q_i. Includes possibility of establishing the fact (1) and assuming the ways of eliminating the "problematic" character of TT. This algorithm is based on entering the indicator of dynamic coefficient D^f_i in accordance with the following rule [11]:

$$\begin{array}{l} \text{if } Low_F \le Low_R \text{ and } High_F \ge High_R, \text{then } PROBLEM_v = -1 \\ \text{if } High_F \le Low_R \text{ and } Low_F \ge High_R, \text{then } PROBLEM_v = +1 \\ \text{else } PROBLEM_v = 0 \end{array} ,(1)$$

where $D_{Ri} = \{Low_R, High_R\}$ is the boundary percentage of individuals, whose factual time of TT completion does not meet the reference one ($D^f_i \neq 1$).

b) The Algorithms of Adaptive Sequence of Distributing TT in order of decreasing the target level TL_i. This algorithm determines the necessity of transition λ to the next TL (2) in the conditions of surpassing the value of the boundary percentage G_{gi} of correct answers to TT as compared to the factual G_{fi} percentage. In the opposite case, this algorithm determines the necessity of terminating the testing procedure [12]:

$$\chi = \begin{cases} 0, \text{if } G_i^f < G_i^n \Rightarrow R_i = R_i - 1 \\ 1, \text{if } G_i^f \ge G_i^n \Rightarrow \text{Stop} \end{cases} \quad (2)$$

c) The Algorithm of Cognitive Individual's Profile (CP_PROFILE) obtaining:

– in the author's interpretation CP _PROFILE is a set of specific specifications describing: modes (MODES) and phase (PHAZES) stability of CP ; informativeness level (IL) of problem-oriented knowledge of individuals:

CP _PROFILE= <MODES> & <PHAZES> & <IL> (3)

– via using a statistical series of reference and actual time of CP of TT: processing transfer function charts for groups of individuals with a stable EM and PM of cognitive processes and individual "pictures" – structure of the time distribution (TD) during the test session and the intensity (high, middle or low frequency of correct answers) within the phase – of phases can be obtained (Table I). It helps to identify differences between individual's behaviour concerning the specificity of CP.

TABLE I.
SPECIFICATIONS OF THE INDIVIDUAL INTELLECTUAL PROFILE OF CERTIFIED INDIVIDUALS

MODES	Equilibrium mode of CP					Periodic modes of CP									
PHASES	High confidence level of CP					Middle confidence level of CP					Low confidence level of CP				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
TD (%)	5	87		8		20	60		20		10	70			20
Intensity	h	h	h	h	h	h	m	m	h	h	m	l	l	l	m
Explorations	Steady CP. Stable behavior within the fixed working time					Periodic state of CP. Insufficiently stable behavior within the fixed working time					Unstable state of CP. Insufficient level of knowledge				

– in accordance with algorithm of adaptive identification of the IL the formation of a quantitative assessment test perfomance (effectiveness) is carried out taking into account minimization of the impact of guessing on the objectivity of test results interpretation [8, 13] (Table II).

TABLE II.
THE ALGORITHM OF ADAPTIVE IDENTIFICATION OF IL

Levels of CP Confidence	**Expert Conclusion**	**Algorithm of Identifying the IL**
Low	Short time spent for solving difficult TT and long time spent for solving simple TT	$IL_k = \sum_{i=1}^{n} \left(S_i * \frac{t_i^f}{t_i^n} \right)$
Moderate	Only exceedingly prompt responses entail a "penalty"	$IL_k = \sum_{i=1}^{n} S_i * \frac{\sum_{i=1}^{n} t_i^f}{\sum_{i=1}^{n} t_i^n}$
Medium or High	Rational distribution of time for solving between difficult and simple TT	$IL_k = \sum_{i=1}^{n} S_i$

The Block of Knowledge Acquired by the Expert System in an analytical way comprises:

1. Knowledge about the current state of the CP: the individual's indications of CP, obtained on the bases of CP_PROFILE; the indications of learning content quality Q_k; the information about individual learning paths Din_k.
2. Actualized knowledge about the subject area – the dynamic boundaries.
3. Control knowledge which is a collection of algorithms for processing the database statistics and of control knowledge of the expert part of knowledge base that is launched by the mechanism of logical conclusion for acquiring new knowledge.

C. The Concept of Technical Implementation of the CBTS

The CBTS presupposes the implementation of a number of technological and methodological solutions. The first of them is the most effective integration into the informational learning environment of the majority of Ukrainian HS by means of using MS Office as an instrumental base for creating a unified up-to-date system of controlling the teaching/learning process.

The second one is placing the repository of the LC on a powerful (possibly distant) server in the Internet network with the aim of eliminating the limitations of technical characteristics in those computers that most HS in the country are equipped with.

The third is the use of such regimes as short-time deliveries of LC from the server; e-mailing by using wireless connections or the internal network; mobile (distant) regime of system's work. These regimes are used for ensuring economy and efficiency of network resources [14].

D. Cognitive Model Control Algorithm

The developed methodology of CP computer modelling presupposes completion of the following principal control iteration stages [15]:

1. The Teacher, in advance of the next class, uses the control system for:

a) Formulating a request to the LC repository on the distant server as to compiling a set of learning units $Teach_z$.

b) Fine-tuning of the CBTS by indicating: the maximum number of points to be scored for every testing session (TS); the number of TL to be used in the TS; the modes of user's actions limitations: the possibilities for an individual to choose the order of TT and of returning the TT within test session.

c) Tuning the short-term connection with the Internet via a radio modem for transmitting the required LC $Teach_z$ to individuals.

2. Before coming to their class, individuals need: to get acquainted with the LC of the first form $Teach^1_z$; to take preliminary testing with using $Teach^4_z$; by means of tuning the short-term connection with the Internet – to transmit results of their testing to the control system.

3. On the basis of the Adaptive Methodology of Learning Process Individualization the following steps are implemented: multi-aspect diagnostics of the CP level with taking into account the quantitative and qualitative learners' intellectual characteristics; intellectual support of decision-making as to adaptive regulation of the structure and content of class work in accordance with the expert recommendations formulated in the knowledge base. Those recommendations allow:

a) Determining the most efficient conditions forms (group, individual autonomous, creative, calculative, research, or team learners' work) for individual cognitive processes.

b) Determining the learning elements requiring specific forms of cognitive processes (generalization, recapitulation, practical examples).

c) Automated tuning of $Teach^2_z$ or $Teach^3_z$ with recommendations as to mandatory consideration, possible consideration, or lack of necessity for consideration of qualitative results of students' acquisition of certain LC.

4. At the end of the class students have the final testing. As a result, information is collected and transmitted into the intellectual knowledge base.

III. Conclusion

Scientific novelty and practical value of the suggested CP computer modelling concepts, which allow to improve the CBTS-methodology and develop indicators of individual's intellectual activity and features of CP, are attested to and confirmed by the patents of Ukraine [8, 10-12, 14, 15]. The model has been introduced into the teaching practice of the Department of Economic Cybernetics and Mathematical Methods in Economics at Alfred Nobel University, Dnipropetrovs'k, Ukraine.

References

[1] Brusilovsky, P. Adaptive and intelligent technologies for Web-based education. In C. Rollinger and C. Peylo (Eds.). Konstliche Intelligenz, Special Issue on Intelligent Systems and Teleteaching, No. 4, pp. 19-25, 2004.

[2] Advantages and Disadvantage of Distance Learning. Education as a Road to Success. Ufa, 2010 (the original is in Russian).

[3] Chen, L., Wang, N., & Chen, H. (in press). E-learning in Chinese schools and universities. In J. Baggaley & T. Belawati (Eds.). Distance Education Technology in Asia (pp. 90-101). New Delhi: Sage. Retrieved from www.pandora-asia.org/downloads/Book-2/PANdora-book2_v6-Chap4.pdf as of December 12, 2009.

[4] Rybina, G.V. The development and use of integrated teaching expert systems in the teaching/learning process. In The Collection of Scholarly Papers from the Russian Scholarly-Methodological Conf*erence "Improvement of IT Specia*l*ists' in Applied Informatics* Training on the Basis of Innovative Technologies and E-*Learning"* (pp. 219-226). Moscow: MESI, 2007 (the original is in Russian).

[5] Ermolenko, O.B., Kovalyiov, V.I., Lysnoy, A.I., & Serkov, O.A. The Method of Designing the Adaptive Teaching/Learning System: Patent No. 3619U. Ukraine: 7G09B 7/07. Patent holder: Kharkiv Polytechnic Institute, No. 2004010029, 2004 (the original is in Ukrainian).

[6] Kudrjavcev, V.S., Waschik, K., Strogalov, A.S., Aliseytshik, P.A., & Peretruchin, V.V. The educational computer system of automatic machine type. In Problems of Theoretic Cybernetics (p. 111). Moscow: Publishing Center RSHU, 1996.

[7] Khmelyov, A.G. Neuronetwork technologies in the systems of automated checking of students' knowledge. In The Proceedings of the 16th All-Ukrainian Scholarly-Methodological *Conference "The Issues of Economic Cybernetics"* September 14-16, 2011 (pp. 120-125). Odessa, 2011 (the original is in Russian).

[8] Taranenko, I.K., & Rizun, N.O. The Meth*od of Measuring Learners'* Level of Knowledge in Computer Testing: Patent No. 51559. Ukraine: MPK G06F 7/00. Patent holders: Taranenko, I.K., & Rizun, N.O., No. u200913726, 2009 (the original is in Ukrainian).

[9] Rizun, N.O., & Taranenko, I.K. Receiving of the mathematical model of testee's intellectual activity with the use of statistical methods. System technologies. Regional Interuniversity Collection of Scientific Papers. – Issue 3(86). – Dnipropetrovs'k, 2013 (pp. 97-108). (the original is in Russian).

[10] Rizun, N.O., & Taranenko, I.K. The System of Teaching and Measuring the Quality of Test Materials: Patent No. 65657. Ukraine: MPK G06F 7/00. Patent holders: Rizun, N.O., & Taranenko, I.K., No. u201106558, 2011 (the original is in Ukrainian).

[11] Rizun, N.O. Heuristic algorithm for improving the technology of test task quality assessment. The Eastern-European Journal of Progressive Technologies. No. 3/11 (45), 40-49, 2010 (the original is in Russian).

[12] Kholod, B.I.,& Taranenko, I.K., & Rizun, N.O. The Method of Com*puter Testing of Students' Knowledge*: Patent No. 97149. Ukraine: G06F 7/04 (2006.01). Patent holders: Alfred Nobel University, Dnipropetrovs'k, No. a 2009 12950, 2012 (the original is in Ukrainian).

[13] Rizun N. Development of methods and models of inaccuracy minimization of the machine-to-human interaction in automated systems of professional readiness level diagnostics. Scholarly and Technical Journal "Nauchniy Visnyk NMU, No 2, 2013 (pp.17-25).

[14] Taranenko, I.K., & Rizun, N.O. The Mobile System of Teaching with Using Computer Testing: Patent No. 64481. Ukraine: MPK G06F 7/00. Patent holders: Taranenko, I.K., & Rizun, N.O., No. u201104361, 2011 (the original is in Ukrainian).

[15] Rizun, N.O., Taranenko, I.K., Tarnopolskyy, O.B., & Kholod, B.I. The System of Teaching/Learning with the Use of Computer Testing: Patent No. 64873. Ukraine: MPK G06F 7/00. Patent holders: Rizun, N.O., Taranenko, I.K., Tarnopolskyy, O.B., & Kholod, B.I., No. u201104040, 2011 (the original is in Ukrainian).