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USING THE STUDENTS' STATE INDICES FOR DESIGN OF ADAPTIVE LEARNING SYSTEMS

Abstract. The paper discusses what scientific ideas could be used to increase effectiveness of adaptive learning systems. Possibilities to use changes of learner's cognitive state indicators under influence of internal (heart rate and blood pressure) and external (speed and density of solar wind) factors are discussed. It is described experience of use of the learner's cognitive state assessment (accounting psychological, physiological and external parameters) to assess his/her cognitive changes over weeks. The experimental results demonstrated individual nature of subjects' psychological and physiological changes over observation time (1,5 month) and their relationship. The authors' approach is based on the model describing formation and functioning of the "functional system of cognitive activity". The question discussed is: what indices of a human performance indicators (behavioral, internal and/or external) could be useful for model construction? A human cognitive load can be under influence of different external and internal factors that can provoke his/her performance degradation. The results demonstrated the similar tendency for studied groups of subjects in previous studies: individual nature of changes of cognitive and physiological indices in day-to-day performance, as well as potentially significant influence of parameters of solar wind on them. As a result, such type of measurements of internal (physiological) and external (solar physics) parameters in combination with test performance indices could be used for assessment and prediction of effectiveness of cognitive activity, and adaptation of learning process according to the particularly learner's readiness to learn on a particular day and time. Different approaches and methods were proposed to take into account a human state, abilities, individual features to plan a human activity. Looking at learning as a type of activity in human-system integration, it is possible to consider today's learner as an operator-researcher who acts in digital environment. At the same time, a human and tools of activity need mutual adaptation in complex systems. Psychophysiological model of learning and cognitive abilities development could be a basis for more effective design of learning achievements, organization and process, their quality, namely for adaptive learning on the base of accounting a learner's current cognitive state indices. Those results could be applied in design of adaptive learning systems, as it was made for industry in the previous developments of the authors. Principles of use of student's state indices in adaptive learning systems are proposed.

Keywords: adaptive learning system; cognitive performance assessment; cognitive indices' variability; high school students.

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1. INTRODUCTION

It is recognized that changes in the forms, methods and means of education are accompanied by changes in the tools and means of education process, in interaction during the learning process [1], as well as by changes in the educational environment (from traditional to synthetic one [2]): direct dialogue, dialog in the digital space, blended communication [3], social networks [4], AR/VR [5] etc. However, the electronic environment creates not only new opportunities for work and learning [6], but also makes new demands and new features of a human behavior “in-loop” that needs mutual adaptation of tools and a human.

Statement of the problem. Looking at learning as a type of activity in human-system integration, it is possible to consider today’s learner as an operator-researcher who acts in digital environment [7, p.259], and both a human, and tools of activity need mutual adaptation in complex systems [8] depending on particular levels and types of automation [9, p.287]. At the same time, it is important to take into account the mental workload [10] of the human and the "cost" of the physiological support for his/her activity [11], as well as influence of external factors [12] that is recommended to take into account in learning process [13].

Analysis of recent research and publications. Global changes in education demonstrated significance of using information and communication technologies (ICTs) for effective teaching and learning [14]. Special attention was paid to differentiation and adaptive learning [15], especially in connection with the transition to the concept of lifelong learning [16]. To date, two approaches were formed to be used in adaptive learning/training: (1) evaluation of a student’s learning results (local/temporal) as a feedback for learning tasks for the next step [17], (2) bio-signals (f.e., from the brain [18] or vegetative nervous system [11]) during learning performance) and behavior including special test tasks [19] and modeling of human-automation performance [20]. Those approaches used *a posteriori* or *ex tempore* data and were not effective to predict current learning activity. Cognitive fitness-for-work assessment could be more effective for individualization of learning for a particular day, if it uses indices of a student cognitive level, his/her physiological state, as well as external physical parameters, included in an individual students’ model that should be adaptive and self-adjusted. Some researchers have demonstrated that effectiveness of mental performance (sensory-motor and simple calculation tasks) could be affected by weather parameters [12].

Authors have studied mental capacity to work of high school students in different weather types. It has been proved, that mental capacity to work of high school students varied in different weather types. The I type of weather was the most favorable for mental work for both boys and girls of senior school age. The III weather type was the worst for intellectual work. The possible increase of the compound sensory–motor reaction and decrease of the nervous processes functional mobility of high school students was revealed, when the weather became worse. It was stated, that in the III weather type perception, attention, memory and thinking of 15-17 years old students became worse in comparison with the corresponding data in the I weather type. But the weather type in that research was evaluated as a general qualitative assessment without specifying exactly which components exhibited the most significant influence. Besides, those results demonstrated influence of external factors on students' perceptual abilities, but more complex cognitive tasks performance (which is more typical for learning activity) has not been studied.

The purpose of the article. To describe experience of use of the ICT for student's cognitive state assessment (accounting psychological, physiological and external parameters) and principles of use of such an ICT in adaptive learning systems.

2. THE THEORETICAL BACKGROUNDS

Our approach is based on the model proposed and generally discussed earlier [21]. That model was a development of the basic idea of P.Anokhin concerned formation and functioning of the "functional system of cognitive activity". Besides, that learning activity could be analyzed as an operator work (of operator-researcher type), because students have to do with the objects of their activity (information, facts, knowledge) indirectly, using the information model of the learning process, especially in digital education [21]. Such type of activity has some features, namely, the conceptual model of activity (as result of a human psychological adaptation to the work) is formed by discrete comparison of the information obtained from the activity object with the current model. The result of comparison is used for the model correction, and the new model becomes the actual one at the next stage. As authors highlighted, "in general case, the conceptual model can be considered as an information stratum of professional activity, and physiological chain „afferent inputs – activity acceptor – physiological control – effectors - act" is an energetic stratum in this context. The goal of professional training is to form the conceptual model of activity of particular type, carrying out particular tasks" [21, p.406]. It means creation of „information contour" that exists and is maintained in activated state in carrying out process for purposeful activity and embraces afferent inputs (Figure 1), decision making block, activity acceptor and act program, as well as the object of activity (such an object is represented as information model in case of operator-watcher worked with technical units).

From this viewpoint, a human activity could be considered as a mediator between internal and external environment of organism, projection of structural-function specifics of professional homeostasis on a human activity. Output parameters of the activity program (activity effectors) stand in the information contour as parameters of capability.

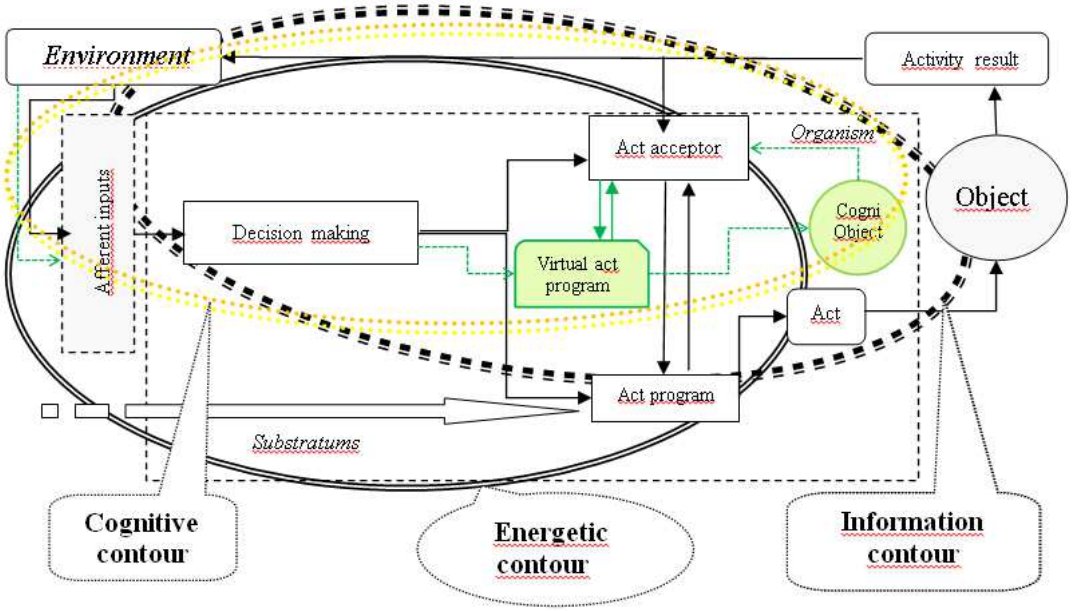

Figure 1. *Theoretical scheme of the functional system of learning activity, where regulation was divided into two contours – information and energetic ones. The third (cognitive) contour is associated with the "internal" activity (cited after [21])*

This theoretical model and the cognitive contour explain individual features of student's abilities to perform cognitive tasks and possible variations of the psychophysiological maintenance of this activity. This model can be used in ICT design and for students' abilities

assessment, monitoring of the intellect development on micro-age intervals, as well as for studying of students' cognitive stability under influence of education process.

3. METHODS

As it is known, a human cognitive load can be under influence of different external and internal factors that can provoke his/her performance degradation. Different approaches and methods are proposed to avoid this phenomenon that take into account a human state, abilities, individual features. Information from appropriate measurement could be used for prediction of a human-operator performance and functional state. In some tools, when such information is used in adaptive, especially in self-adjusted systems, the accuracy of prediction for an operator work efficiency and reliability can be very high (90-95%) in comparison with traditional methods and models [22].

The question arising from this can be formulated as follows: (1) What indices of a human acting (behavioral, internal and/or external) could be useful for model construction? (2) Which of them could be used for the individualization, differentiation and adaptive learning [23]. It is necessary to know what individual features of learners are sensitive to variations in internal and external influences on his/her abilities to perform cognitive tasks.

To answer this question, it was carried out the experimental research based on the use of the computer system SPFR (system of psycho-physiological research) to monitor the cognitive activity of high school students. The survey includes test task performance, blood pressure and heart rate before and after the test performance. The test block included:

Short-term memory test T2, where a table with 12 random numbers from 11 to 99 was presented to a subject. The number of correctly reproduced numbers was considered as a result.

Time perception test T3. The subject was proposed to press any key on the keyboard after the sound signal in 60 seconds (calculation of time is carried out without the use of wristwatch, etc.).

Activity and mood self-assessment test T4. This test is an abridged version of the Health-Activity-Mood test. The subject was proposed to give a subjective assessment of his/her state in 7-point scale for five pairs of questions-characteristics.

Numbers permutation test (combinatorial) in ascending T6 and descending T9 order. It consisted of a sequence of numbers (from 0 to 9) which were not repeated and placed in a random order. The task execution time was free.

Perception test T7. It consisted of a sequence of 7 numbers (from 0 to 7) which were not repeated and placed in a random order, but one number was missing. The task execution time was free.

In all tests we registered time of each task performance in milliseconds, correct (expected) and actual answers. The error was fixed if expected and real answer did not match.

Besides, we used a subjective state assessment of the examinees by means of the reduced variant of the test “General_state - Activity – Mood” (GsAM) at the beginning (indexed by "0") and at the ending of the test session (the indices of mood ***mood***, serviceability ***FfD***, attention ***atten***, anxiety ***anxiety***).

As indices of physiological “cost” of activity and the human state, we registered a heart rate ***HR*** and blood pressure (systolic ***ADs***, diastolic ***ADd***) by means of the digital blood pressure monitor Model LD11. The indices ***HR***, ***ADs*** and ***ADd*** we registered during 5 min prior to the tests beginning (index “0”) and 5 min after finishing (relaxation).

The data on influence of solar activity on a human health and some physiological systems are known, however results of study of cognitive activity associating with heliophysic parameters are not known in the scientific literature to date. In our preliminary

pilot researches, the precise connection between effectiveness of operator activity and parameters of a solar wind (SW) was revealed. With the purpose to study this phenomenon we registered indices of proton component of a solar wind: speed ***SWsp*** (km/s) and density ***SWden*** (proton/sм^3) downloaded from the Internet site NASA [24], as well as parameters of the geomagnetic field (GMF) - planetary index ***Ks*** and index of "equivalent amplitude" ***A***.

11 subjects participated in experiments, 3 times per week over 1,5 month. Variations of the cognitive test task performance (accuracy and reliability) over the research period were studied and compared with changes of psychological (memory and subjective test indices) and physiological indices, as well as parameters of the solar wind in the same days.

4. FINDINGS

Student's state indicators. Due to a number of reasons, not all subjects (high school children, volunteers) were able to take tests every day of experimental research within a specified period (more than one month). Complete data for making scientifically substantiated conclusions were obtained from the results of the testing of seven subjects.

Average time of test performance (***Tl6*** – test T6, ***Tl7*** – test T7), coefficient of variation (***cv6*** and ***cv7***, respectively), as well as reliability of test performance (***η6*** and ***η7***, respectively) demonstrate different nature of inter-individual variation in perceptual and cognitive test performance (Table 1). Lack of data for two first subjects in test T7 should be explained by the fact that this test has not been included in their task.

Comparison of effectiveness of T6 and T7 test performance demonstrated that perceptual test (T7) was significantly easier for subjects than the cognitive one (shorter test performance time and higher reliability). At the same time, it is necessary to note individual differences in performance of these tests by all subjects, especially high in T6.

Table 1

Average data of subjects' tests T6 and T7 performance

Subject	*Tl6,* ms	*cv6, %*	η6	*Tl7*, ms	*cv7, %*	η7
MAV	3403	53,04	0,94	-	-	-
SKI	5106	48,43	0,90	-	-	-
GBA	4067	93,6	0,79	2596	102,1	0,98
TAU	5880	116,7	0,82	1653	15,5	0,99
RVR	4779	102,6	0,91	2102	53,6	0,99
AMD	2052	39,86	0,96	1481	21,1	0,98
BVI	1564	32,2	0,72	3808	58,53	0,95

The results of tests performing of perceptual (T7) and cognitive types (T6 and T9) confirmed the fact stated in previous studies [25] regards changes of the effectiveness of tests performance (average time and reliability of test tasks for 3 subjects, as an example) during the month (Fig. 2). Besides, the changes had oscillatory nature, that may be explained by the effect of the education load, as well as the influence of circaseptanial (around weekly) rhythms.

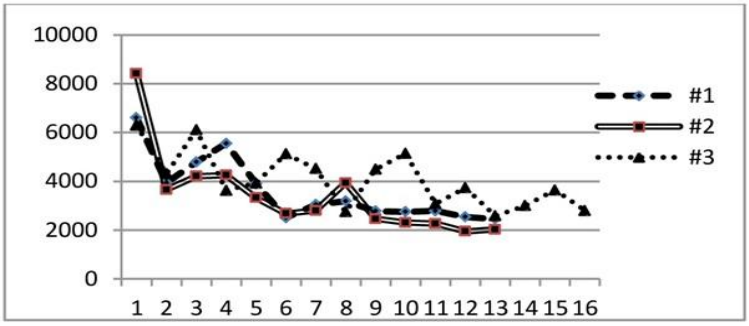

Figure 2. Average time of task performance (ms) on days of experiment, three subjects (#1, #2 and #3)

Analysis of the physiological maintenance (heart rate and blood pressure) has revealed individual dynamics for every subject as well (Fig.3).

External physical influences on subjects were evaluated by parameters of solar wind. Changes of ***SWsp*** and ***SWden*** had different nature over time of investigation, but coincided (in picks) with changes of test performance (Fig.4). Because days of test performance could be different for subjects, the figure 3 shows ***SW*** only changes for subject #3.

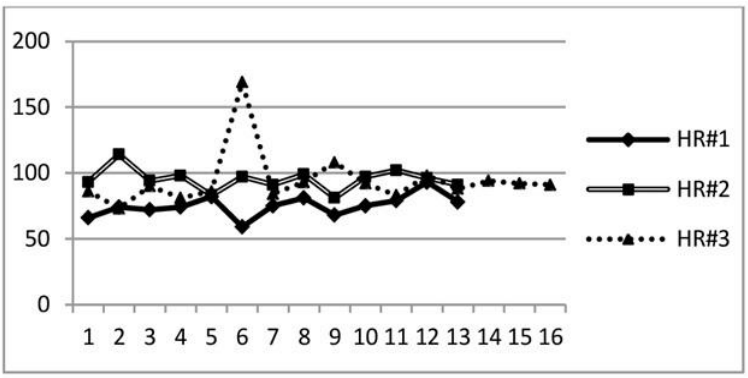

Figure 3. Average heart rate (per min) on days of experiment, the same subjects (#1, #2 and #3)

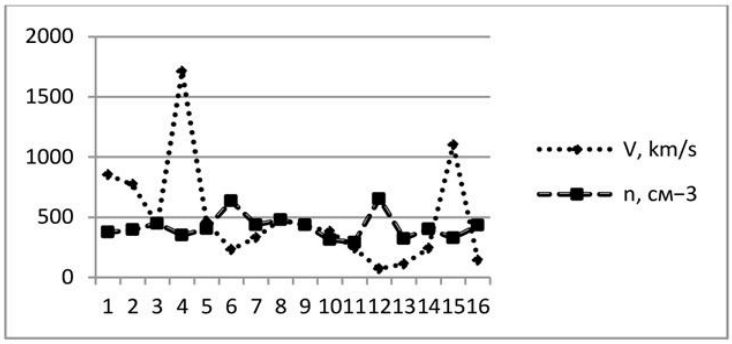

Figure 4. Indices of solar wind on days of experiment, subject #3

Regression analysis of the effects of autonomic regulation (on the parameters of the heart rate and blood pressure), the features of the nervous system and external factors (solar wind speed and density of its proton component at the time of testing) revealed their high correlation with tests performance rate and reliability in cognitive tests after selection of three the most informative independent variables according to the standard procedure (standard package STATISTICA 5.1, a stepwise regression analysis): coefficient of multiple correlation R of the test rate “M” (the index corresponds to the test number) and reliability “R”: R6 = 0.7

... 0.93 ($p < 0.01$), R9 = 0.95 to 0.97 ($p < 0.001$), R6r = 0.88 ... 0.91 ($p < 0.01$), R9r = 0.95 ... 0.97 ($p < 0.01$).

These results have confirmed our previous findings for students and adult professional scientists and programmers. It was quite unexpected, because physiology parameters of adolescents were known as unstable ones. However, our results demonstrated clear that general tendency was similar for all observed groups of subjects: individual nature of changes of cognitive and physiological indices in day-to-day performance, as well as potentially significant influence of parameters of solar wind on them. As a result, such type of measurements of internal (physiological) and external (solar physics) parameters in combination with cognitive test performance indices could be used for assessment and prediction of effectiveness of cognitive activity, and for adaptation of learning process according to individual readiness to learn of a particularly learner on a particular day.

Principles of use of student's state indices in adaptive learning systems. Modern changes in education are aimed at individualization of learning. The natural solution to this problem is to adapt the learning to the needs and abilities of each student. Respectively, adaptive learning systems (ALS) have a special place among educational ICTs, and the student's state information (SSI) can increase the efficiency of the ALS. Such a tool for education gives new opportunities as follows:

- maximal flexibility of education programs: a student can choose courses, teachers, time of active work, etc.;
- individualization of education process: re-allocation time and education resources in dependence on a student's individual psychophysiological possibilities to make this process more intensive and to give equal opportunities for both common people and people with disabilities;
- the choice of the optimal learning continuation is made *before* learning process in contrast with traditional ALS's based on a student achievements *after* results obtained.
- the ICT used in experimental research can be a part of the ALS (in-build or state-alone application). Principles of the SSI use in adaptive learning systems have been developed:
- individual "norm" of psychophysiological indices used for SSI assessment;
- psychophysiological indices of the student should be associated with his/her current state;
- information concerned physical environment of learning process is highly recommended;
- psychophysiological test control should be exercised with the data collected in the system database using adaptive model;
- adaptive algorithm of learning session is based for choosing an optimal workload for the particular student.

According to schedule, before the learning session, the student performs a cognitive test with the computer sub-system and got (as a result) a time and type of his/her effective work with the learning tools for the current day. This recommended time could be coordinated with the student's supervisor and the real time could be changed by the ALS.

These proposals can help a student to make a decision what type of work in particular day is preferable accordingly to his/her cognitive state:

- to take lectures,
- to work in interactive mode with computer,
- to work in interactive mode with a teacher,
- to make applied tasks,
- to work in library,

- to work in Internet,
- to perform individual tasks,
- to work with computer modeling,
- to delay an active form of teaching for another time.

We strongly believe that such an adaptive learning can improve effectiveness of education and increase a learner inquiry. This reliance is based on the experience of using systems for pre-shift control of the operators' performance in emergent industries, and those computer systems used the same cognitive test, as in our research.

As it was demonstrated [22], the human-machine system control was achieved by use of the system for day-to-day control (monitoring) of an operator's state, which was affected by a set of major factors, determining readiness of the operator to work: professional knowledge and skills, conditions of equipment controlled by the operator, operator functional state, and parameters of environment. Those factors could be described by their parameters, which superposition affected target parameters of the system (effectiveness and/or reliability of professional performance).

To maintain professional fitness-for-work of the operator at a required level, it was necessary to estimate and predict changes of his/her functional state daily and, if necessary, within a working day. The methodology developed was a synthesis of two systems. One system provided the choice of informative parameters of operator fitness-for-duty, and the other system provided automatic measurement of parameters and associated algorithms. Thus, in the methodological attitude, the approach assumed solving of two interconnected tasks: informative psychophysiological parameters selection and system engineering.

The fact of high and reliable relationship (revealed in our research) allowed assuming that parameters of the cognitive test organized in a similar way may be highly informative and reliable when used in the system for the daily check of operators' fitness-for-work.

Though those results concerned selective group of people (adults, men, professional operators-dispatchers), we have found in our current research quite similar facts: high relationship between indices of cognitive tasks performance and indices of physiological maintenance (related to functional state) as well as parameters of external environment. They could be used as informative psychophysiological parameters.

In the same time, technical solutions can be obtained, if we consider the pre-shift control of professional operators as "pre-mission" control of a learner with suggestions to him/her, what the best choice would be for the form of activity depending on the human current state accounting physiological and external factors.

In such a context, the functional states' assessment at the pre-mission control is based on the measurement of certain parameters describing regulatory realignments in the human organism. At the same time, use of the appropriate ICT allows to carry out psychophysiological (cognitive) test performance to receive operatively an estimation of the learner state and the prognosis of his/her fitness-for-work for the coming work activity. The opportunity of the pre-mission control is based on an assumption that, in regular modes of operation, the operator-researcher's (learner's, in our case) functional state within a working day varies to a lesser degree than within changes in a circannual rhythm and is determined by parameters of regulatory realignments in the organism by the moment of the start of activity. In that case, there is an opportunity to build the fitness-for-work prognosis based on the analysis of functional realignments changes in conditions of mental work modeling results of the psychophysiological test performance using an automated information system. And this prognosis could be used as a basis for adaptation of automated learning process.

5. CONCLUSIONS AND PROSPECTS FOR FURTHER RESEARCH

Digital life and activity gives new opportunities for people and new problems in different domains including education. Broader understanding of the promise and pitfalls of learning technologies and working (learning/teaching) environment in global education/development settings could be useful with special regard to the human as a subject in the system and to the collaboration of humans and technical, didactic and organizational subsystems.

Psychophysiological model of learning and cognitive abilities development could be a basis for more effective design of learning achievements [26], organization and process, their quality [27], namely for adaptive learning on the base of accounting a student's current cognitive abilities.

Principles of the student's state information's use in adaptive learning systems have been developed: individual “norm” of psychophysiological indices used for SSI assessment; psychophysiological indices of the student should be associated with his/her current state; information concerned physical environment of learning process is highly recommended; psychophysiological test control should be exercised with the data collected in the system database using adaptive model; adaptive algorithm of learning session is based for choosing an optimal workload for the particular student.

The further research is aimed to specify cognitive workload in particular types of learning and more accurate recommendations for them using indices of a student's current cognitive abilities.

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ВИКОРИСТАННЯ ПОКАЗНИКІВ СТАНУ УЧНІВ ПІД ЧАС ПРОЕКТУВАННЯ СИСТЕМ АДАПТИВНОГО НАВЧАННЯ

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Анотація. У роботі обговорюється, які наукові ідеї можуть бути використані для підвищення ефективності адаптивних систем навчання. Обговорюються можливості використання змін показників когнітивного стану учня під впливом внутрішніх (частота серцевих скорочень та артеріальний тиск) та зовнішніх (швидкість і щільність сонячного вітру) факторів на когнітивні показники. Описується досвід використання оцінювання когнітивного стану учня (з урахуванням психологічних, фізіологічних та зовнішніх параметрів) для оцінки та прогнозування його когнітивних змін для індивідуалізації навчання. Експериментальні результати продемонстрували індивідуальну природу психологічних та фізіологічних змін випробувачів протягом часу спостереження (1,5 місяця) та їх взаємозв'язок. Автори підходу ґрунтуються на моделі формування та функціонування «функціональної системи пізнавальної діяльності». Обговорюється питання: які показники діяльності людини (поведінкові, внутрішні та/або зовнішні) можуть бути корисними для побудови моделі? Пізнавальне навантаження людини може знаходитись під впливом різних зовнішніх та внутрішніх факторів, які можуть спровокувати погіршення продуктивності діяльності. Отримані результати показали, що загальна тенденція була однаковою для всіх спостережуваних осіб, як і в дорослих у попередніх дослідженнях: індивідуальний характер змін когнітивних та фізіологічних показників у повсякденній роботі, а також потенційно значний вплив на них параметрів сонячного вітру. Як результат, вимірювання внутрішніх (фізіологічних) і зовнішніх (геліофізичних) параметрів такого типу у поєднанні з показниками ефективності тесту можуть бути використані для оцінки та прогнозування ефективності пізнавальної діяльності та адаптації навчального процесу відповідно до індивідуальної готовності до навчання конкретного учня. Запропоновано підходи та методи з метою уникнення цього явища враховують стан людини, здібності, індивідуальні особливості. Розглядаючи навчання як тип діяльності в системі «людина-техніка-середовище», можна вважати, що сьогоднішній

учень може вважатися оператором-дослідником, який діє в цифровому середовищі, причому як людина, так і інструменти діяльності потребують взаємної адаптації в складних системах. Психофізіологічна модель навчання та розвитку когнітивних здібностей може бути основою для більш ефективного проектування навчання, організації та процесу, їх якості, а саме для адаптивного навчання на основі врахування поточних когнітивних можливостей учнів. Ці результати можуть бути застосовані в ІКТ, які включають адаптивні системи навчання, використовуючи досвід попередніх промислових розробок авторів. Запропоновані принципи використання показників стану учня в адаптивних навчальних системах.

Ключові слова: адаптивна система навчання; оцінка пізнавальної діяльності; змінність когнітивних показників; старшокласники.

ИСПОЛЬЗОВАНИЕ ПОКАЗАТЕЛЕЙ СОСТОЯНИЯ УЧАЩИХСЯ ПРИ ПРОЕКТИРОВАНИИ СИСТЕМ АДАПТИВНОГО ОБУЧЕНИЯ

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Аннотация. В работе обсуждается, какие научные идеи могут быть использованы для повышения эффективности адаптивных систем обучения. Обсуждаются возможности использования изменений показателей когнитивного состояния ученика под влиянием внутренних (частота сердечных сокращений и артериальное давление) и внешних (скорость и плотность солнечного ветра) факторов на когнитивные показатели. Описывается опыт использования оценки когнитивного состояния учащегося (с учетом психологических, физиологических и внешних параметров) для оценки и прогнозирования его когнитивных изменений для индивидуализации обучения. Экспериментальные результаты продемонстрировали индивидуальную природу изменений психологических и физиологических показателей испытуемых в течение времени наблюдения (1,5 месяца) и их взаимосвязи. Авторы подхода основываются на модели формирования и функционирования «функциональной системы познавательной деятельности». Обсуждается вопрос: какие показатели деятельности человека (поведенческие, внутренние и/или внешние) могут быть полезными для построения модели? Когнитивная нагрузка человека может находиться под влиянием различных внешних и внутренних факторов, которые могут спровоцировать ухудшение продуктивности деятельности. Полученные результаты продемонстрировали, что общая тенденция была одинаковой для всех наблюдаемых лиц, как и у взрослых в предыдущих исследованиях: индивидуальный характер изменений когнитивных и физиологических показателей в повседневной работе, а также потенциально значительное влияние на них параметров солнечного ветра. Как результат, измерения внутренних (физиологических) и внешних (гелиофизических) параметров такого типа в сочетании с

показателями эффективности теста могут быть использованы для оценки и прогнозирования эффективности познавательной деятельности и адаптации учебного процесса в соответствии с индивидуальной готовностью к обучению конкретного ученика. Предложены подходы и методы, учитывающие состояние человека, способности, индивидуальные особенности. Рассматривая обучение как тип деятельности в системе «человек-техника-среда», можно считать, что сегодняшний ученик может считаться оператором-исследователем, который действует в цифровой среде, причем как человек, так и инструменты деятельности требуют взаимной адаптации в сложных системах. Психофизиологическая модель обучения и развития когнитивных способностей может быть основой для более эффективного проектирования, организации и процесса обучения, их качества, а именно для адаптивного обучения на основе учета текущих когнитивных возможностей учащихся. Эти результаты могут быть применены в ИКТ, включающие адаптивные системы обучения, как это следует из опыта предыдущих промышленных разработок авторов. Предложены принципы использования показателей состояния учащегося в адаптивных обучающих системах.

Ключевые слова: адаптивная система обучения; оценка познавательной деятельности; изменчивость когнитивных показателей; старшеклассники.

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