# Cognitive Abilities' Research Technology as a Tool for STEM-Education

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**Abstract.** The paper discusses an experience to develop and use research ICT for STEM education in an out-of-school educational institution, namely science and mathematics, with involving high school students into different projects, namely to study cognitive abilities variance over month. Experimental research was carried out in after school time with volunteers who performed series of cognitive tests of predefined type 2 or 3 days per week with registering physiological indices, as well as indices of solar physics, namely solar wind. Real new scientific results were obtained and were discussed. The experience obtained in the research allowed for one of the co-authors to prepare the scientific project presented at the INTEL ISEF Eco contest. That research was planned to be continued as regards experiments series with the same and new subjects, and involvement of new researchers and preparation of new projects in the fields as psychology, as astrophysics, physiology, human behavior and mathematics.

**Keywords:** human abilities, development, learning environment, tools, STEM.

## 1 Introduction

The reform of school education worldwide takes place in the direction of transition from the classroom to the mixed form, in which the share of independent and project-oriented work is constantly increasing [9; 2]. This is necessary in terms of both the ability of students to self-study and the ability to perform search-and-research activities with the obtaining of practical results with special attention to key competences [10]. Specialists of the psychological and pedagogical sphere highlight the necessity of forming a person at the beginning of the XXI century [3; 6] with such professional skills as: informational literacy, inventive analytical thinking, quick search and processing of information, innovative thinking style, effective communication, project and team work, problem solving, ability to take responsibility, high productivity, and life competencies [ 9]. As the task of the European Commission is to ensure that Europe and the EU member states are competitive, the main task is to organize training in order to meet the challenges of the 21st century in the field of education in four areas: learning to learn, learn to act, learn to live together with others, to learn the practice of being [9].

Accordingly, the importance of information and communication technology (ICT) for education and training [3], especially considering that research activity of any kind, requires the ability to process a large amount of information, to analyze the data obtained and provides it correctly using the appropriate and modern ICTs, including for education purpose [14]. As a result, the special significance of ICT is acquired in STEM-oriented education [17], when the ability to work on collaborative projects in on-line and off-line modes, as well as the use of cloud computing technologies allow real scholarly research of students together with scientists and students. In this way, the conditions are created to avoid "gaps" between school and university studies, as well as practical work.

Young people are prepared for life and activity in the knowledge society, in the conditions of global informatization [3] and understanding of the interdisciplinary problems of the study of human and society, especially accounting new needs such as lifelong learning [8] and growing importance of social networks [12]. Every successful solution in this field is the important step of mankind to the future [10], when a human should meet requirements of old and new technologies, especially in transportation [4] and emergent fields [19]. Unfortunately, science and research are not included in school curriculum. So the scientific component of STEM education can be used and accessed for young researcher at extramural institutions, f.e. as the Kyiv Palace of Children and Youth.

The purpose of the article is to describe the experience of using ICTs for research work as a tool for STEM education.

## 2 Method

The methodological basis of the research is a methodology and methods of designing computer systems for assessing suitability of a person to cognitive activity [7], which can be used as a system of professional selection for operator professions [for example, 4] or for carrier guidence, and systems for psychophysiological research [5], which can be used to study psychophysiological features as adults in general [13], and young people [11], as well as adolescents [5]. In this study, the basic scientific provisions previously developed have been adapted to use the relevant ICTs in rela-tion to the high school students [5] as a tool for young researchers to get experience in science in real research with the particular goal and aim to prepare the project for the international contest.

Longitudinal experimental research was based on the use of a computer system SPFR (system of psycho-physiological research) to monitor the cognitive activity of high school students [3; 20]. The survey includes test task performance, blood pressure and heart rate before and after the test performance. Electropuncture diagnostics (**EPD**) by Nakatani [15] was conducted after the test session for each subject.

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. Where the subject was proposed to press any key on the keyboard after the sound signal through 60 seconds (calculation of time is carried out without the use of wristwatch, etc).

Activity and mood self-assessment test T4. It's an abridged version of Health-Activity-Mood test. The subject was proposed to give a subjective assessment of his/her state in 7-point scale, giving answers on five pairs of questions-characteristics.

Numbers permutation test (combinatorial) in ascending order T5. It consisted of a sequence of numbers (from 0 to 9) which were not repeated and placed in a random order. Task execution time was fixed and calculated individually for each subject according to the results of the training test.

Numbers permutation test (combinatorial) in ascending order T6. The tasks were of the same type as in T5, but the task execution time was free.

In all tests we registered time of each task performance in milliseconds, correct (expected) and really entered answers. 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 and at the ending of the test session (the indices of mood **mood**, serviceability **FfD**, attention **atten**, anxiety **anxiety**) prior to the beginning (index "«0") estimated and upon finishing the tests performance.

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 - velocity **SWsp** (km/s) and density **SWden** (proton/см$^3$) on the data from Internet site NASA [15], as well as parameters of the geomagnetic field (GMF) - planetary index **Ks** and index of "equivalent amplitude" **A**.

## 3 Results and Discussion

### 3.1 Experiment methodology

It is generally acknowledged that the development of the technical basis for scientific research and, first of all, the expansion of the capabilities of computer technology, the transition to research networks and cloud technologies allows to increase the depth of analysis of the processes under study, the volume of research carried out, facilitates the transition from laboratory development to industrial products. This is especially noticeable in the sciences related to the study of human: psychology, physiology of

labor, medicine, and ergonomics. Over the past 10-15 years, the number of computer implementations of research techniques grew in geometric progression.

However, it has to be noted that in most cases, such developments are computer implementations of existing blank or hardware methods (tests) and do not take into account the fundamental psychological differences in the perception and reproduction of information in these ways. At the same time, ICTs can combine the research capabilities of laboratory development with the requirements of industrial psycho-diagnostic systems. The main condition for the realization of such a possibility – psycho-diagnostic technique should be implemented not as an abstract set of tests, but as a psycho-diagnostic system. In this case, systems for laboratory research and production can be considered as system objects of the same kind [18]. In accordance with the basic provisions of the general theory of systems and the basic law of system transformations after Yu.A. Urmantsev, such systems may undergo mutual transformation by means of changing one of the characteristics while preserving the other unchanged. Accordingly, ICT for research work (ICT-DR) in high schools has been created, that combined the assessment of students' abilities and determine their research potential, enabling them to carry out scientific projects both online and off-line [5].

It is generally recognized that intelligence as itself does not fully represent a human and is not a guarantor of its success in life. It is important to take into account that the joint use of psychotype and intelligence can allow to predict successfully the professional suitability of a human to certain mental professions [8], as well as his/her ability to form the functional system of activity [1].

### 3.2 Prior results of the ICT use

In a screening study with the help of the ICT developed, and in order to identify the dominant fields of intellectual activity of high school students (grades 8-11), there were selected students of the Kiev Palace for Children and Youth who tended to scientific, research, inventive and analytical activity. The students identified in this way were offered research projects, built on a more general project - the study of psycho-physiological features of the dynamics of cognitive abilities of senior pupils under the influence of educational load and external factors (solar activity, solar wind, atmospheric pressure).

Our preliminary results of the application of such a system proved its effectiveness and ease of use (the $9^{th}$ and $10^{th}$ grade students, 9 subjects, conducted daily research after the necessary training), which allowed building a general experiment, around which the projects were carried out [20]:

- Influence of student's chronotype on learning success.
- The influence of the solar wind on the human functional state.
- Link the speed of processing cognitive information with the success of learning.
- Impact of the geomagnetic field on human health.
- Modeling the emergence of bifurcations of the effectiveness of human mental activity in monotony conditions.

The aforementioned projects of students took part in research competitions of MAS, ICYS and INTEL ISEF in 2016. They received new scientific results, which allowed broadening the idea of psycho-physiological peculiarities of cognitive activity of a person for such an age group as senior pupils.

In particular, in the daily experiment, within the framework of two student projects, the influence of atmospheric pressure, solar activity and solar wind parameters on arterial pressure and on the heart rate of the test subjects in the experiment was revealed. The correlation coefficient of the velocity and density of the SW proton component and the arterial pressure was r = 0,5 ... 0,65 ($p \leq 0,5$), SW and the performance indicators r = 0,5 ... 0,6 ($p \leq 0,5$) , SW and subjective estimates of the state r = 0.6 ... 0.7 ($p \leq 0.5$). The most sensitive indicators were not always the same concrete ones in different subjects. In addition, one of the subjects was weather-sensitive (the correlation between systolic blood pressure and atmospheric exceeded 0.8). In addition, during the experimental study functional changes were detected from the cardiovascular system of two testers, which were not documented by medical examinations in a generally accepted way.

It was revealed that the average time of test tasks performing in the "free" (T6 test) and in the fixed pace after a certain period of "training" (training psychomotor skills and "automation" of activities) became relatively stable, but even after the adaptation to the activity there were days of improvement and deterioration of the result. However, the reliability of the tasks was quickly rising to a virtually maximum and remained at a level that was relatively stable [20].

### 3.3 Experiment research

Previous results were obtained in research directly at the school where subject learned, and on the sixth lesson, i.e. at time of the day local minimum in circadian rhythm, besides without break after lessons.

The goal of the experiment under discussion was to check the general features of adolescents' cognitive stability-instability under influence of learning workload and heliophysic factors over a month. The differences were as follows:

- Day time (16:30 – 17:00)
- Day of the week (Monday, Wensday and Friday, the same day time)
- Place of the experiment (The Kiev Palace for Children and Youth)
- Electropuncture diagnostics.

6 subjects participated in the experiment 2 or 3 times per week, 2 of them performed tests not less than 9 times (4 weeks). It has been revealed that dynamics of the average test performance time in cognitive tests T6 and T9 (accordingly M6 and M9) had an oscillatory character over the month, but with individual specifics (Fig.1).

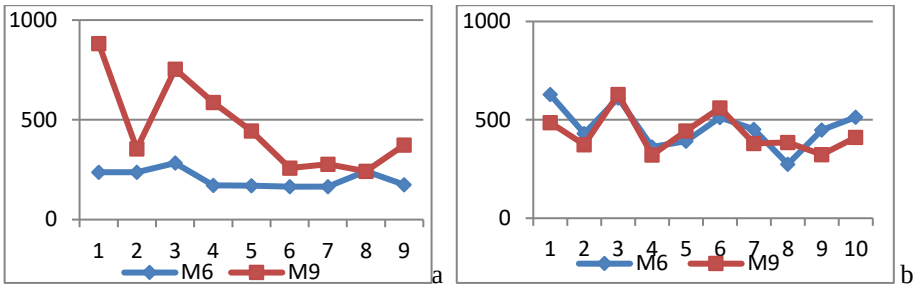


**Fig. 1.** Average test performance time on days of experiment; a - subject #1, b - subject #2

Tests performance reliability was not stable in those days as well, but had another character of change. Because the time performance (M) and reliability (η) could depend on subject individual strategy, we used aggregative index of capacity which linked these indicators into one value:

$$W = \frac{\eta}{M} * 1000 \quad (1)$$

According to data obtained, it is possible to note an organization of individual activity in time (Fig. 2). Attention is drawn to the sharp drop in the performance of the second subject on the 6th day of testing. According to data stored, that day was a day of extremely increasing of the solar wind speed. Since the relationship between solar wind and human performance was revealed in our previous studies in the modeling of operator activity [7], we analyzed experimental data to clarify, what factors the success of cognitive tests can depend on.

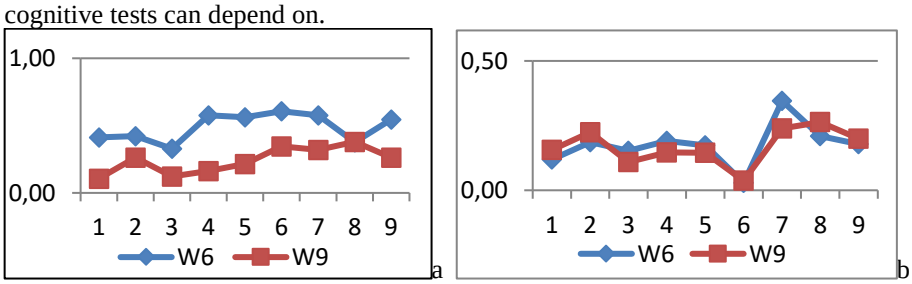


**Fig. 2.** Test performance capacity on days of experiment; a - subject #1, b - subject #2

Analysis of the effects of energy balance (by Nakatany), autonomic regulation (on the parameters of the heart rate and blood pressure), the features of the nervous system (in particular, functional mobility of the nervous processes) and external factors (solar wind speed SW and density n of its proton component at the time of testing) found their high correlation with tests performance speed, and especially 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 of the test rate M (the index corresponds to the test number) 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 ($p < 0.01$).

An important result is not only a high correlation between the indicators of cognitive activity and other factors, but particular the most informative factors. It has been revealed that the composition of the factors varies (the individuality of people affects) for different tests and testers, but the indices of the nervous system features, energy balance/imbalance and indices of the solar wind were substantially influenced.

These results confirmed extended possibilities of using the developed methodology and technology for STEM education of the high school students.

## 4 Conclusions and outlooks

Thus, the experimental results of student projects, obtained directly using the proposed ICT-DR by the authors of the projects, have allowed broadening knowledge about the studied phenomena and making a real contribution to the development of science. The experience obtained in the research allowed for one of the co-authors to prepare the scientific project presented at the INTEL ISEF Eco contest. Namely, the project annualized and discussed results described above. That research was planned to be continued as regards experiments series with the same and new subjects, and involvement of new researchers and preparation of new projects in the fields as psychology, as astrophysics, physiology, human behavior and mathematics.

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