Method for Assessing the Information Content of Factors Forming the Cognitive Independence of Students

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Abstract. The article describes the problem of awakening the cognitive activity of students, arising due to revolutionary transformations in teaching technologies. It shows the need to study the factors that affect cognitive activity and assesses the information content of those factors. Based on the method of pair comparisons, a technology for ranking the factors affecting cognitive activity has been developed. A mathematical model of the formation and processing of expert assessment results and an example of calculations are given, and the feasibility of including the subsystem for evaluating factors affecting cognitive activity in the computer control system of the university is shown. The structure of an adaptive e-learning system based on the technology of taking into account the factors that form the cognitive independence of students is described. Experiments carried out in 3 universities of Ukraine have shown that the use of the developed mathematical model and information technology allows to increase significantly academic performance and to decrease the frequency of refusals from independent work of students using the e-learning environment.

1. Introduction
The current revolution in education [1-2], the e-learning technology that has received a surge (also due to the problem of COVID-19) [3-4], as well as the concept of lifelong learning [5-6] exacerbated the problems of
• the quality of e-learning environment [7-8],
• adaptive learning [9-10],
• activation of cognitive independence [11-12].
In the complex of problems of pedagogy of electronic society, the problem of such a personality quality as “cognitive independence” comes out on top [1,13].

2. Problem Statement
Various aspects of the problems of cognitive independence are considered in a huge number of scientific studies, including [13-14]. General issues [15-16], the structure of cognitive independence [17], various methods of activating cognitive independence [15-18], etc. are being studied. However, in general terms, the task of optimizing cognitive independence in the conditions of the modern stage of e-learning throughout life, unfortunately, has not been solved. There is not even a single universally accepted definition for cognitive independence. In this study, we use the definition of [19]: “Cognitive independence of students is an integrative quality of the personality, based on cognitive activity associated with the initiative and the search for various ways to solve educational and cognitive problems without the participation of a teacher (the teacher prepares a system of tasks), which ensures self-development of personality.
Identification of factors of cognitive independence is the main prerequisite (first stage) of activation of cognitive independence, as shown in [14-15].

A significant number of cognitive independence factors have been identified [19]. The problem is that the degree of manifestation of those factors varies depending on the particular educational environment and tends to change rapidly [1, 13, 14].

The question of the degree of manifestation of each factor in the general structure of cognitive independence is of interest to many researchers [14-19]. Unfortunately, there is no universal method for solving this problem. In this regard, we define the purpose of this work as follows:

“Develop a computer-based method for assessing the information content of cognitive independence factors and their ranking (in terms of pedagogical value for managing cognitive independence in the system of lifelong learning), using the structure of cognitive independence as an explicit concept.”

3. Results

3.1. Method for assessing the information content of cognitive independence factors

Informational content of the factor [20-21] - the ability of this factor to contain information about the degree of its influence on the subject of research [22-23] (in our case, on cognitive independence). Unfortunately, due to the specifics of the research object, we cannot use instrumental and imitation methods for assessing skills [19] to determine the degree of influence of any factor on the development of cognitive independence.

It has been proven [19,24-25] that expert methods based on subjective assessments of experts are the most appropriate methods for this purpose. Among the expert methods used in pedagogical research, we distinguish the following ones: the method of rank order, the method of predetermined scoring, the method of free scoring, the method of coefficient estimation of the level of assimilation, and the method of pair comparisons [19-21].

Our experiments with teachers[19], who were invited to use various technologies of expert assessment, showed that the method of pair comparisons can be considered the most convenient. In this regard, the following assessment technology has been developed:

Stage 1. Formation of the questionnaire.

To determine the degree of influence of factors on the development of cognitive independence of a student, we form a special questionnaire in which expert educators are invited to evaluate the degree of joint manifestation of the main characteristics (factors) of cognitive independence. To do this, they fill out a table to record the characteristics (factors) of cognitive independence

• a) from top to bottom in the first column of the table,
• b) from right to left in the same order.

The compiled table is scanned from left to right: each column element is compared with each row element. If, according to the expert, the element located in the left column of the table is less common than the element placed in the top row, then “1” is written in the cell at the intersection of the column and row. If the element located in the top row of the table is more common than in the left column, then “0” is put in the numerator. In the case of equal manifestation frequencies, a value of 0.5 is set in the cell. The experts do not fill out last two columns for R and P.

Stage 2. Processing questionnaires.

As a result of filling out the questionnaire by experts, one can calculate the degree of manifestation of the components of cognitive independence. Further, the obtained information is processed as follows: first, line-by-line summation of the contents of the cells is performed. The result of this summation is the rank R of each factor in the structure of cognitive independence. It is written to the corresponding “rank R” column of the table. The factor with the highest rank is assigned a degree equal to 1.

Then, the degree of manifestation \( P_i \) of each factor is calculated by the formula:

\[
P_i = \frac{P_{\text{max}} \cdot R_i}{R_{\text{max}}},
\]  

(1)
where $P_{\text{max}} = 1$ – the degree of manifestation of the factor that has the highest rank;

$R_i$ is the rank of the factor;

$R_{\text{max}}$ is the highest rank.

The results are entered in the column “Degree of $P$ manifestation”. This is how all data provided by each expert is processed.

Then a table is filled in where the results of the questionnaires are summarized.

The results of calculating the degrees of $P_{ni}$ from each questionnaire of the $n$-th expert for each $i$-th factor are transferred to this table, i.e., column $P_1$ is filled in for the 1st expert, column $P_2$ for the 2nd expert, ..., and column $P_n$ for the $n$-th expert.

The averaged values of the degrees of manifestation of factors in the structure of cognitive independence are calculated based on the obtained $P_i$ data:

$$P_{i,\text{av}} = \frac{\sum_{j=1}^n P_{ij}}{n},$$

(2)

where $n$ – the number of experts, $j$ – the expert’s number; $i$-factor number. These values serve as a measure of the informative value of the factor.

Further, the variance $S_i$ of expert estimates for each factor is determined, which is calculated by the formula (for a small sample, an unbiased variance estimate is used):

$$S_i = \sqrt{\frac{\sum_{j=1}^n (P_{ij} - P_{i,\text{av}})^2}{n-1}},$$

(3)

where $n$ – the number of experts, $P_{ij}$ – the degree of manifestation of the $i$-th factor in the structure of cognitive independence according to the $j$-th expert. The value of $n-1$ indicates the number of degrees of freedom.

Then, a confidence interval of values for each component of cognitive independence is determined by the formulas:

$$v_i = t_{\alpha} \times \frac{S}{\sqrt{n}}; \quad P_i^u = P_{i,\text{av}} + v_i; \quad P_i^l = P_{i,\text{av}} - v_i,$$

(4)

where $v_i$ is the confidence interval; $t_{\alpha}$ is the confidence probability; $P_i^u$ ($P_i^l$) - the upper (lower) confidence boundary of the values of information content of factors of cognitive independence.

3.2. An example of assessing the information content of cognitive independence factors

Consider an example developed as an experiment in the Center of Distance Education of the Sumy National Agrarian University, when studying the cognitive independence of students (economic specialties) who are trained at the Department of Cybernetics and Informatics (Department Head Svetlana Agadzhanova). The number of experts is 16 (teachers of the department and employees of the Distance Education Center).

The working group identified the following main factors, affecting cognitive independence (in the study of the disciplines of the computer and cybernetic cycle):

1. The need and desire to acquire knowledge and methods of activity;
2. Cognitive motive and interest;
3. Interest in the results of their independent cognitive activities;
4. Interest in a future profession;
5. Initiative;
6. Basic knowledge (owned by the individual);
7. Basic skills, computer skills and previously learned software tools;
8. Acquired knowledge of the studied disciplines of the computer cycle;
9. Acquired skills in the studied disciplines of the computer cycle, computer skills and learned software;
10. Use of scientific and methodological literature, communications, the Internet;
11. Attentiveness;
12. Strong-willed efforts;
13. Purposefulness;
14. Persistence;
15. Contact with the teacher during the performance of independent cognitive activities in order to obtain information;
16. Contact with other students during the performance of independent cognitive activities in order to obtain information;
17. The ability to set and achieve goals of cognitive activities;
18. The ability to plan their cognitive activities;
19. The ability to assess their potential in the performance of cognitive activities;
20. The ability to evaluate the results of their cognitive activities.

The calculation results, ranked by the upper confidence interval, are presented in Table 1.
In a study with a reliability level of 95% (for all components) and a number of degrees of freedom equal to 16, the confidence probability (Student’s coefficient) is \( t_{\alpha} = 2.1314 \).

Table 1 and Fig. 1 show the results of calculating the confidence intervals of the information content for each of the 20 factors of cognitive independence.

**Table 1.** The ranking results of the factors that form the cognitive independence of students
(Sumy National Agrarian University, Ukraine)

| ParameterNo. | \( P_{i,90} \) | \( S_i \) | \( n_i \) | \( P_i^* \) | \( P_i^{**} \) | \( P_i^{*} \text{ rank} \) |
|--------------|-----------------|---------|--------|----------|-----------|-----------------|
| 16           | 0.6929          | 0.3413  | 0.1892 | 0.8821   | 0.5036     | 1               |
| 8            | 0.7312          | 0.1435  | 0.0796 | 0.8108   | 0.6516     | 2               |
| 20           | 0.6626          | 0.2429  | 0.1347 | 0.7973   | 0.5279     | 3               |
| 15           | 0.6276          | 0.2927  | 0.1623 | 0.79     | 0.4653     | 4               |
| 9            | 0.7135          | 0.1136  | 0.063  | 0.7765   | 0.6505     | 5               |
| 6            | 0.663           | 0.1126  | 0.0625 | 0.7255   | 0.6006     | 6               |
| 7            | 0.6251          | 0.1293  | 0.0717 | 0.6968   | 0.5534     | 7               |
| 19           | 0.514           | 0.3156  | 0.175  | 0.689    | 0.339      | 8               |
| 12           | 0.5855          | 0.148   | 0.082  | 0.6675   | 0.5034     | 9               |
| 10           | 0.6273          | 0.0661  | 0.0367 | 0.664    | 0.5906     | 10              |
| 14           | 0.4967          | 0.1912  | 0.106  | 0.6027   | 0.3906     | 11              |
| 11           | 0.5594          | 0.0658  | 0.0365 | 0.5958   | 0.5229     | 12              |
| 18           | 0.4512          | 0.2475  | 0.1372 | 0.5885   | 0.314      | 13              |
| 13           | 0.5063          | 0.1373  | 0.0761 | 0.5824   | 0.4302     | 14              |
| 4            | 0.5455          | 0.0418  | 0.0232 | 0.5686   | 0.5223     | 15              |
| 1            | 0.5142          | 0.0623  | 0.0345 | 0.5488   | 0.4797     | 16              |
| 3            | 0.4576          | 0.1272  | 0.0706 | 0.5281   | 0.387      | 17              |
| 2            | 0.4965          | 0.0257  | 0.0143 | 0.5107   | 0.4822     | 18              |
| 5            | 0.4407          | 0.0691  | 0.0383 | 0.479    | 0.4024     | 19              |
| 17           | 0.3684          | 0.1662  | 0.0922 | 0.4605   | 0.2762     | 20              |
3.3. Improving educational technologies using the results of assessment of the information content of cognitive independence factors. An example.

Using the results of assessment of factors allows each university to find those “pain points” that need special attention when improving educational technologies [10, 24-28]. Based on the result of the experiment described above, a special technology (Fig. 2) was developed (information environment for e-learning) with special advanced features [19, 26, 29,30], including:

- Communication between students in the process of independent work (factor 16, rating 1);
- Self-control of the learning process (factor 20, rating 3);
- Prompt communication with the teacher (factor 15, rating 4).

**Figure 1.** Confidence intervals of the degree of manifestation of personal qualities in the structure of cognitive independence ($P_{up}, P_{lo}$ - upper and lower confidence limits)

**Figure 2.** System of adaptive e-learning based on intelligent agent-manager
The use of a new educational information environment in the groups of faculties of management, food technology, agricultural mechanization, veterinary and agronomy of the Sumy National Agrarian University (data obtained as a result of the experiment [29, 30]) allowed them
- to increase significantly academic performance from 72.3 to 81.4 (by 100 point scale);
- to decrease the frequency of refusals from independent work of students using the e-learning environment from 24.8% to 7.3%.

The use of the system of adaptive e-learning based on an intelligent agent-manager made it possible to reduce the percentage of refusals from the use of e-learning (the quality of training, according to teachers’ estimates, has increased, but the statistics have not been properly processed):
- Sumy State University (disciplines "Data Mining", "Decision Theory", "Ergonomics", "Methodology of Scientific Research"; teachers - professor E.A. Lavrov and associate Professor E.G. Kuznetsov) from 30.1 to 8, 3;
- Kiev National University named after T.G. Shevchenko (discipline "Discrete mathematics"; teacher - assistant O.E. Siryk) from 17.9 to 5, 1.

4. Conclusions

Cognitive independence is an integrative quality of a person, based on cognitive activity associated with the initiative and the search for various ways to solve educational and cognitive tasks, ensuring self-development of a person.

The technology of questioning and processing the opinions of experts (teachers), based on the method of pair comparisons, is a convenient means of identifying the degree of influence of various factors. Due to the rapid change in teaching technologies and the psychological characteristics of students, an assessment of the degree of influence of factors on cognitive independence should be carried out regularly.

Embedding a subsystem for assessing the influence of factors in the learning management system is a convenient means for assessing.

Assessing the importance of factors affecting cognitive independence is a necessary step in improving the educational process, including the electronic educational environment.

The experiments carried out confirmed the constructiveness of the method and the possibility of significant improvements in the quality of the educational process, based on a systematic study of factors affecting cognitive independence.

The use of the developed mathematical model and information technology allows to increase significantly academic performance and to decrease the frequency of refusals from independent work of students using the e-learning environment.

The capabilities of modern educational environments should constantly expand on the basis of research on factors affecting the cognitive independence of students (including taking into account the requirements of adaptability, communication between students in the learning process, self-control of the learning process, quick communication with the teacher, etc.).

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References

[1] Blaschke L M 2015 Heutagogy and lifelong learning: A review of heutagogical practice and self-determined learning. The International Review of Research in Open and Distance Learning 13(1) pp 56-71
[2] Cochrane T, Narayan V, and Oldfield J 2013 iPadagogy: Appropriating the iPad within pedagogical contexts *International Journal of Mobile Learning and Organisation* **7**(1) pp 48-65

[3] Joshua D 2016 E-Learning platform system for the department of library and information science (ModibboAdama University of Technology, Yola) *A Developmental plan. Information Impact* **7**(1) pp 51-69

[4] Pereira O and Rodrigues J 2013 Survey and analysis of current mobile learning applications and technologies *CM Computing Surveys (CSUR)* **46**(2) pp 27-35

[5] AlQahtani A A Y and Higgins S E 2013 Effects of traditional, blended and e-learning on students' achievement in higher education *J. Computer Assisted Learning* **29**(3) pp 220-234

[6] Voloshinov S, Kruglyk, Osadchyi V, Osadcha K and Symonenko S 2020 Realities and prospects of distance learning at higher education institutions of Ukraine *Ukrainian Journal of Educational Studies and Information Technology* **8**(1) pp 1-16 doi: https://doi.org/10.32919/uesit.2020.01.01

[7] Verkhova G V and Akimov S V 2017 Electronic educational complex for training specialists in the field of technical systems management *IEEE II International Conference on Control in Technical Systems (CTS)* St. Petersburg 2017 pp 26-29

[8] Tyshchenko E J and Strjuk A M 2018 The relevance of the development of the model of adaptive learning *Computer Science & Software Engineering: Proceedings of the 1st Student Workshop on Computer Science & Software Engineering* pp 109-115

[9] Kotova E E and PisarevA S 2017 Adaptive prediction of student learning outcomes in online mode 2017 *IEEE II International Conference on Control in Technical Systems (CTS)* St. Petersburg, 2017 pp. 138-141 doi: 10.1109/CTSYS.2017.8109509

[10] Atto K and Kotova E E 2020 Communicative Strategies Simulation in Intelligent Learning Environment *IEEE Communication Strategies in Digital Society Seminar (ComSDS), St. Petersburg, Russia*, 2020 pp. 37-39 doi: 10.1109/ComSDS49898.2020.9101338

[11] Burov O Y 2017 ICT for performance assessment of emergent technologies operators *Proceedings of the 13th International Conference on ICT in Education, Research and Industrial Applications. Integration, Harmonization and Knowledge Transfer, Kyiv, Ukraine, May 15-18*, CEUR-WS 2017 **1844** p 127

[12] Pinchuk O, Burov O and Lytvynova S 2019 Learning as a Systemic Activity *Advances Intelligent Systems and Computing* **963** pp 335-342 doi: 10.1007/978-3-030-20135-7_33

[13] Yen J and Liao W 2018 Effects of Cognitive Styles on Learning Performance and Gaming Behavior in a Programming Board Game *7th International Congress on Advanced Applied Informatics (IIAI-AAI)/(Yonago, Japan)* pp 334-337 doi: 10.1109/IIAI-AAI.2018.00071

[14] Nicola S and Pinto CandMendonça J 2018 The role of education on the acquisition of 21st century soft skills by Engineering students 2018 *3rd International Conference of the Portuguese Society for Engineering Education (CISPEE)(Aveiro)* pp 1-4 doi: 10.1109/CISPEE.2018.8593495

[15] Shmigirilova I B 2015 Cognitive competence compared to cognitive independence and cognitive activity *ObrazovanietNauka* 01 March 2015 **17** p134 -146

[16] Yakymchuk N and Kazachenok V 2018 Developing Cognitive Independence of Future Informatics Teachers by Multimedia Tools *European Journal of Contemporary Education* **17**(3) pp 581-597

[17] Eliseev V 2016 The development of cognitive independence of students of the University through networking cooperation 2016 *International Conference “Education Environment for the Information Age” (EEIA-2016)* Section: Technological and Methodology for Education Environment. Technological and Methodology for Education Environment p02014

[18] Novikova I 2014 Cognitive independence as a basis for lifelong learning *International Journal Of Applied And Fundamental Research* **2** URL: www.science-sd.com/457-24742
[19] Logvinenko V G 2005 Methods of forming of cognitive independence of students of technical specialties in the process of study of informatively-communicative technologies Dissertation (Kharkiv Ukrainian engineering-pedagogical academy)  

[20] IEEE Standard Computer Dictionary: A Compilation of IEEE Standard Computer Glossaries 1991 IEEE Std610217 doi: 10.1109/IEEESTD.1991.106963  

[21] Qu Z, Zhang H, Liu D, Li F and Liu G 2019 An Investigation on the Factors Influencing Preservice Information Technology Teacher's TPACK Level in China 2019 International Joint Conference on Information, Media and Engineering (IJCIME), Osaka, Japan pp. 47-50 doi: 10.1109/IJCIME49369.2019.00019  

[22] Kamaruddin M, Razali R and Deraman A 2011 Critical success factors of executive information systems development for education management - A preliminary investigation Proceedings of the 2011 International Conference on Electrical Engineering and Informatics, Bandung pp 1-6 doi: 10.1109/ICEEI.2011.6021714  

[23] Zhang Y, Wang Y 2019 Empirical Study on the Influencing Factors of ICT-TPCK Vocational Teachers in Higher Education Eighth International Conference on Educational Innovation through Technology (EITT), Biloxi, MS, USA pp 137-141 doi:10.1109/EITT.2019.00034  

[24] Alsrehan H S 2019 Factors Influencing Education and E-learning Technology in UAE Universities as a Predictor of Community Satisfaction International Arab Conference on Information Technology (ACIT), Al Ain, United Arab Emirates pp 150-158 doi: 10.1109/ACIT47987.2019.8991014  

[25] Hamidullah S and Samiullah P 2015 Intelligent tutoring system: Approaches, researches and e-learning solution IEEE 8th International Workshop on Computational Intelligence and Applications (IWCIA) ( Hiroshima) pp 53-58 doi: 10.1109/IWCIA.2015.7449462  

[26] Lavrov E, Barchenko N, Lavrova O and Savina N 2019 Models of the Dialogue “Human - Computer” for Ergonomic Support of E-Learning” 3rd International Conference on Advanced Information and Communications Technologies (AICT)(Liviv: Ukraine) pp 187-190 doi: 10.1109/AICT47987.2019.8847763  

[27] Verkhova G V and Akimov S V 2018 The Role of the Unified Educational Cyber Environment in Improving the Quality of Training of Engineer Personnel XVII Russian Scientific and Practical Conference on Planning and Teaching Engineering Staff for the Industrial and Economic Complex of the Region (PTES), St. Petersburg, 2018, pp 70-74 doi:10.1109/PTES.2018.8604190  

[28] Kotova E. E. 2018 Supporting the Process of Training Specialists in an Integrated Educational Environment 2018 Third International Conference on Human Factors in Complex Technical Systems and Environments (ERGO)s and Environments (ERGO), St. Petersburg pp 140-145 doi: 10.1109/ERGO.2018.8443821  

[29] Lavrov E and Lavrova O 2019 Intelligent adaptation method for human-machine interaction in modular E-learning systems Proceedings of the 15th International Conference on ICT in Education, Research and Industrial Applications. Integration, Harmonization and Knowledge Transfer(Workshops, Kherson, Ukraine, June 12-15)2 pp 1000-1010  

[30] Barchenko N 2019 Ergonomic methods for human-machine interaction in modular learning systems Dissertations (Kharkiv National University of Urban Economy)