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Assessing and Development of Chemical Intelligence Through e-Learning Tools

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Abstract. Modern society has entered a new era, due to the rapid development of digital technologies. The lag in the use of digital technologies poses a serious danger, causing a sharp drop in the quality of education and the dissatisfaction of public needs. AI-technology in education are designed to enhance learning capabilities of student. However, it was revealed an extremely controversial attitude towards AI-technologies in education: from enthusiastic to negative. The key reason for the lack of effectiveness of AI-technologies in chemistry teaching is to reduce technologies to a set of procedures for content delivery, control, and assessment. Such kind of technologies does not improve the students' mental abilities and does not develop of their thinking. The question arises: what algorithms should be embedded in artificial intelligence technologies so that they contribute to the mental development of the user? The article discusses the possibilities of using the hidden mechanisms of consciousness as the basis for the elaboration of human developmental algorithms. The rules for the elaboration of algorithms and the sequence of presentation of educational content are formulated. Criteria for stopping the cyclic algorithm and transition from one cyclic algorithm to another are proposed. The results of verification of rules and criteria are analyzed using the example of the GreatChemist Expert System for evaluating and developing chemical intelligence. The results of the test-retest reliability of technology for the development of chemical intelligence using the GreatChemist Expert System are discussed.

Keywords: e-Learning tools · Chemical intelligence · GreatChemist Expert System

1 Introduction

Modern society has entered a new era, due to the rapid development of digital technologies that have an unprecedented impact on people and all sectors of modern society. Education is at the center of these profound changes, which bring both extraordinary teaching and learning opportunities as well as new risks. The management, the internal architecture of education, the methods of teaching and learning are changing. Nowadays, the lag in the use of digital technologies poses a serious danger, causing a sharp drop in the quality of education and the dissatisfaction of public needs.

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The key position among digital educational technologies is occupied by artificial intelligence (AI) systems, which are understood as computer systems capable of carrying out human-like processes, such as learning, adaptation, synthesis, self-correction and using data for solving complex procedural tasks. Machine learning is a subset of artificial intelligence systems, including programs that can recognize patterns, make predictions, and apply newly discovered patterns to situations that were not previously described in their initial design. These solutions reproduce the possibilities of human reflection with the help of thousands of rules and instructions that are automatically implemented by a computer in seconds, creating the illusion that artificial intelligence systems have unlimited possibilities.

However, it should be emphasized that education is an exclusively human-centered effort, not a technology-centered solution. It is important to understand the limitations of AI [1] and recognize that AI is not yet ready to replace teachers, but has a real opportunity to augment/supplement them [2]. On the one hand, supercomputers are able to defeat the world's best players in Go [3] or chess [4]; on the other hand, the huge difficulties of supercomputers in detecting irony, sarcasm, and humor are known [5]. AI systems are successfully applied to solving periodically repeating and relatively predictable tasks, but cannot be used to solve more complex, non-standard or creative problems. The risk area for using AI in education is the hiddenness of software algorithms and methods of their use. As Frank Pasquale noted, those who control algorithms that run AI solutions have now unprecedented influence over people and every sector of a contemporary society [6]. Digital technologies have not only useful properties that make our lives easier, increase labor productivity, entertain, but also harmful properties that lead to digital dementia, lower quality of life, painful addictions, stress, insomnia, and obesity [7].

The fundamental task of intellectual technology in education should be to augment capacity of a person. All artificial intelligence systems have the potential for structural changes in the management services of educational institutions, in the field of education and training. Many AI technologies (zoom, predictive text, engine, spellchecker, etc.) designed to make life easier for people with disabilities are now a universal feature of all personal computers. AI technologies are used for educational process management, teaching and learning [8], round-the-clock student support [9], and psychotherapeutic care [10]. Digital technologies are designed to enhance the educational interaction of all students, globally expanding the possibilities of open learning, educational tools and instruments, enriching the educational environment.

A brief review revealed an extremely controversial attitude towards artificial intelligence technologies: from enthusiastic to negative. The question arises: what algorithms should be embedded in artificial intelligence technologies so that they contribute to the mental development of the user?

2 User Developmental Methodology

To solve the problem the methodology of human thinking development by means of artificial intelligence technologies (UDM) has been elaborated. UDM is a set of rules and instructions that are automatically implemented by a computer to manage human thinking development.

The purpose of the article is to describe the rules for the development of thinking using the example of chemistry education, implement them in the Expert System and verify this System.

Thinking is a key component of intelligence. If the developed algorithms will implement the rules for the development of user's thinking, then as a result of working with a computer program will be shown the growth of intelligence indicators of user.

2.1 Digital Technologies in Chemistry Teaching

The analysis of the implementation of digital technologies in the classroom showed that chemistry, like no other academic discipline, wins when using AI-technologies to explain the laws, theories, processes and objects of the micro world.

New forms of learning emerged: i-schools based on MOODLE - distance schools for adolescents with disabilities [11]; virtual schools [12]; virtual laboratories [13]; mindmapping - thinking visualization techniques [14]; electronic resources for state exams (olympiads, lessons) preparing; the new type of chemical tasks [15]. Of particular interest are brain computer interface (BCI) devices capable to measure when a student is fully focused on the content and learning tasks [16].

It should be noted that to date, the widespread adoption of digital technologies in the educational process has not led to breakthroughs in improving the quality of education. Moreover, in a number of cases, the negative dynamics of the quality of education was revealed [17]. The key reason for the lack of effectiveness of digital technologies in chemistry teaching and learning is to reduce AI technologies to a set of procedures for content delivery, control, and assessment. The rules underlying the algorithms of these computer programs does not improve the students' mental abilities and does not develop of their thinking. To improve these algorithms, it is necessary to turn to the analysis of empirical studies of psychologists, revealing the features of the development of human thinking in the learning process, for example, in chemistry classes.

2.2 Hidden Mechanisms of Consciousness as the Basis for the Elaboration of User Developmental Algorithms

At the beginning of 1789, the founder of modern chemistry A. Lavoisier wrote "When we begin the study of any science, we are in a situation, respecting that science, similar to that of children; and the course by which we have to advance is precisely the same which Nature follows in the formation of their ideas" [18]. An analysis of the processes of growth of scientific knowledge, the formation of concepts, the development of human mental abilities, as well as the emergence of ideas in the process of scientific creativity indicates the unity of the mechanisms underlying them [19, 20]. These mechanisms cause a change in the system from global and undifferentiated forms to more and more differentiated and hierarchically ordered forms (DI-principle of development). Thus, in order to implement developing learning using intelligent technologies, it is necessary to design algorithms that provide educational content in accordance with the natural laws of development.

The next important rule for the successful implementation of artificial intelligence technologies in training is the presentation of new educational content in accordance with the zone of proximal development, i.e. from the global content level through the basic level to the detailed one (Fig. 1).

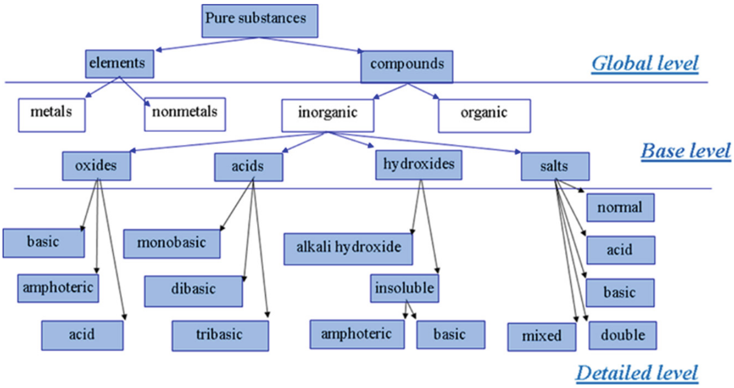

Fig. 1. Zones of proximal development in the study of inorganic compounds classes.

The transition from one level of educational content to another is advisable only if the mental operations of this level are performed precisely at high speed (automaticity is achieved). Computer implementation of this rule is possible with the help of algorithms of cyclical representation of tasks. The stops of cyclical algorithm and the higher-level cyclic algorithm transition occurs when the user reaches the empirical criteria for the formation of the skill:

1. Accuracy and empirically determined reaction time.
2. Reducing EEG power spectrum indicators.

2.3 System of Core Chemical Concepts as a Base of Chemical Intelligence

What is chemical intelligence? Chemical intelligence can be described through a combination of the following characteristics:

- a high level of sensory-perceptual sensitivity to the structural and substantive characteristics of chemical reality ("Sense of matter and chemical process");
- a set of thinking operations and concepts which are relevant to chemistry ("Chemical thinking") [21];
- the ability to proceed from the externally observed characteristics of a substance and its changes to consideration of its internal structure, and to encode this information using chemical signs and symbols ("Chemical language");
- a subtle distinctive sensitivity to chemical interaction characteristics (such as weight, hardness, density, temperature, consistency, etc.) ("Chemical hands");
- selectivity and strength of memory for chemical information ("Chemical memory");
- a set of personality traits such as responsibility, accuracy, and good self-control;
- sanguine and mixed highly active types of temperament.

Chemical thinking and a system of chemical concepts are characteristics that distinguish a gifted chemist from giftedness in other fields of activity. Thinking is an analytical-dissected form of cognition, qualitatively different from holistic-integrated representation of reality at the level of perception. In thought, the ratio of the characteristics of isolated objects acts as a separate independent elements, which is not available at the level of perception.

The content of thoughts is infinitely diverse, but the structure of thought, whatever order it may be, includes three essential elements:

- separation of objects;
- comparing them with each other;
- determining the direction of these comparisons (spatial or temporal adjacency, similarity, affiliation, causality, etc.).

Chemical thinking is ability to

- discover chemical objects and their characteristics;
- compare chemical objects and their characteristics with each other in various directions;
- determine the range of directions of this comparison depending on the conditions of the tasks [21].

Core chemistry concepts include such concepts as substance; homogeneous/heterogeneous systems; chemical phenomenon; simple and complex substance; oxides, acids, bases, salts; redox process; reversible/irreversible chemical reactions, hydrolysis, chemical equilibrium. It should be emphasized, in order to the AI-technologies contribute to the development of the user when working with chemical content, it is necessary that the transition from one cyclic algorithm to another be implemented in accordance with the DI-principle of development. The design cyclic algorithms is a simple task for programmers. Elaboration of chemical content is quite easy for chemists. However, the identifying sequences of nature-like transitions from one concept to another is one of the most difficult psychological problems.

3 GreatChemist Expert System

The GreatChemist Expert System was designed based on the User Development Methodology (UDM). UDM is a set of rules and criteria for the development of human thinking, which should be taken into account when creating artificial intelligence technologies for educational purposes. These rules, criteria are described in Sects. 2.2 and 2.3.

GreatChemist Expert System received Official registration certificate for computer programs No 2006614415, Russian Federation (E.V. Volkova and A. Raskovalov are copyright holders).

Functionality of GreatChemist Software is computer testing; collection, storage and processing of data; presentation of the results in different forms such (graphic profile of chemical intelligence, textual interpretation of the data, the results table for a single person and for a group of participants), collection and automatic data processing.

The Expert System offers the user 14 contents aimed at the formation of the core concepts of chemistry:

- *Substance and body.*
- *Chemical and physical phenomena.*
- *Homogeneous and heterogeneous systems.*
- *Simple and complex compounds.*
- *Oxides, acids, bases, salts.*
- *Chemical solitaire.*
- *ORP & not ORP.*
- *Oxidizing agent & reducing agent.*
- *Spatial structure.*
- *Isomeres & not isomers.*
- *A reversible & non-reversible chemical process.*
- *Direction of the chemical process.*
- *Hydrolysis.*
- *Calculation Tasks.*

In one cycle, the GreatChemist Expert Systems offers 42 tasks consequently, in which it is necessary to divide accurately and quickly stimuli into 2, 3 or more groups in accordance with the instructions. The base of the stimuli is much wider than the number of presentations (The principle of redundancy of the base of tasks). Therefore, at the next presentation, new stimuli occur always. The time spent and the number of errors are recorded. The cycle repeats until the required accuracy and speed of solution will achieve.

For example, in order to develop the ability of user to distinguish inorganic compounds, Expert System presents the formulas of chemical compounds on the screen at a random order. The user is to divide these stimuli into groups according to the instruction: into two groups (global level), into four groups (basic level), into fourteen groups (detailed level) (Fig. 1). GreatChemist Expert System estimates the choice reaction time (T, sec), quantity of errors (n) and quantity of levels formed.

It allows us to define a zone of proximal development and thus to organize the education process which leads to the increasing in chemical intelligence of every student.

In order to identify the essential criteria of the concepts, the user has to establish the identity or differences, cause-effect relationships, compare, analyze, synthesize, and evaluate the probability. Only by correctly identifying the signs of the concept, student will be able to give the correct answer for unknown stimuli.

As we can note, the GreatChemist Expert System implements the rules and criteria for the development of students' thinking (UDM, see Sect. 1) in the study of chemistry.

However, there is question whether the introduction of these rules and criteria into intelligent systems will contribute to the intellectual development of users? The answer to this question will be considered in Sect. 3.

4 Verification of GreatChemist Expert System

Empirical verification of the GreatChemist Expert System was carried out on samples of students in grades 9–11 (458 people) and Faculty of Chemistry students (575 people).

4.1 Test-Retest Reliability

Significant test-retest correlations testify to the reliability of the expert system (Tables 1, 2 and 3).

Table 1. Test-retest reliability (students aged 15 to 16)

Students aged 15 to 16		Students			
		10th grade		11th grade	
		Test	Development	Test	Development
Retest	Spearman's rho	0,845	0,261	0,898	0,554
	Sig. (2-tailed)	0,000	0,007	0,000	0,000
	N	101	105	55	56

Table 2. Test-retest reliability (students aged 17 to 18)

Students aged 17 to 18		Students			
		First year students		Second year students	
		Test	Development	Test	Development
Retest	Spearman's rho	0,694	0,382	0,712	0,417
	Sig. (2-tailed)	0,000	0,002	0,000	0,000
	N	66	66	288	288

Table 3. Test-retest reliability (students aged 19 to 20)

Students aged 19 to 20		Students			
		Third year students		Fourth year students	
		Test	Development	Test	Development
Retest	Spearman's rho	0,767	0,370	0,774	0,352
	Sig. (2-tailed)	0,000	0,010	0,000	0,012
	N	48	48	50	50

When performing the test, the user solves 1108 tasks for classification, establishment of identity or difference, analogy. Training and development of user was confirmed by significant correlations between retest time and indicators of development.

4.2 EEG Power Spectrum Indicators Before and After Using GreatChemist

GreatChemist Expert System was synchronized with recording EEG power spectrum indicators (Fig. 2.). Comparison of EEG power spectrum indicators before and after training using an expert system revealed a significant reduction in inter-level differences. This fact evidences that complex tasks began to be carried out with the same ease as simple ones.

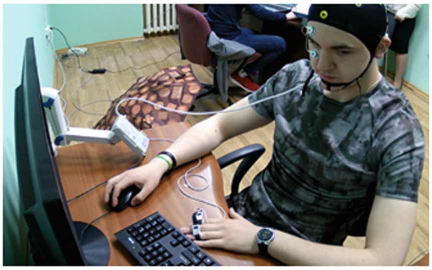

Fig. 2. GreatChemist Expert System synchronized with recording EEG power spectrum indicators.

The unexpected result was that when users have achieved the accuracy of the answer, all they, completing tasks, spent the same time regardless of individual psychological differences (Fig. 3).

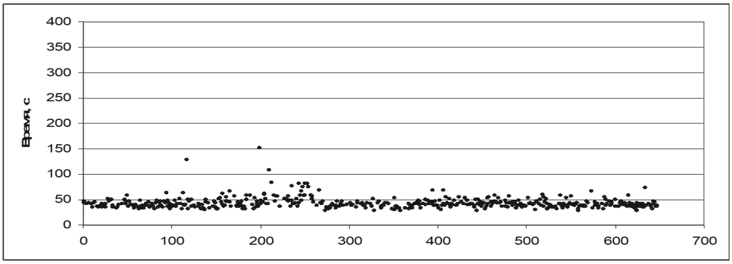

Fig. 3. The reaction time of distinguishing oxides, acids, bases, and salts when users have achieved the accuracy of the response.

4.3 Comparative Experiment

The results of the comparative experiment, presented in Table 4, testify that only in the case of using of the transitions from one cyclic algorithm to another in accordance with the DI-principle of development, the indicators of chemical intelligence increase (experimental group). In this case, the solution of chemical problems leads to an increase in chemical intelligence.

However, if the required accuracy and speed of solving chemical problems on the detailed level are not achieved, then the chemical intelligence indicators are reduced (control group). In the latter case, the more a student studies, the less chemical information he is able to keep in long-term memory and the less interest he has in studying chemistry.

This is a very important fact. Firstly, it explains why the implementation of modern artificial intelligence technologies in education does not lead to the mental development of users. Secondly, it points to a way of improving the technology of artificial intelligence in education to enhance the mental development of students.

Table 4. Dynamics of chemical intelligence, speed and accuracy of solving chemical problems in experimental and control groups.

Indicators		Experimental Group		Control Group	
		14 years	15 years	14 years	15 years
Speed and accuracy of solving chemical problems					
Global level	T1, c	64	31*	84	50*
	N1	2.7	0.5	3.4	2.16
Basic level	T2	149	47*	108	79*
	N2	2.33	0.83	3.76	2.66
Detailed level	T3	320.77	147.33**	371.73	342.75
	N3	19.33	4**	21	**15.16***
Chemical intelligence					
Chemical intuition	points	5.04	10.9***	**5.86**	**4.25**
Long-term memory	%	54.3	95.8**	61.3	62.5
Interest in chemistry	points	1.18	5.66**	**4.16**	**2.38**

p < 0,05; p** < 0,01; p*** < 0,001*

5 Conclusion

The 21st century is the century of paradoxes. The main paradox of the new millennium is that evolution is aimed at enhancing person's intelligent capabilities, but social processes associated with the thoughtless implementation of artificial intelligence technologies leads to people digital dementia. One of the reasons for this phenomenon lies in the excessive differentiation of sciences and weak interdisciplinary connections. Unfortunately, the analysis of publications on the implementation of artificial intelligence technologies in education did not reveal a single study devoted to solving the above problem. In this respect, the study presented is unique.

Turning to the analysis of the hidden from programmers mechanisms of consciousness allows us to design algorithms of AI-technologies that provide educational content in accordance with the natural laws of human development. The main principle of development any systems (DI-principle) consists in moving from the global and undifferentiated states to more and more differentiated and hierarchically ordered forms.

The presentation of new educational content should be realized in accordance with the zone of proximal development, i.e. from the global content level through the basic level to the detailed one.

Computer implementation of this rule is possible with the help of algorithms of cyclical representation of tasks. The stop of cyclical algorithm and transfer to another level should be realized through the empirical criteria for the formation of the skill:

1. Accuracy and reaction time.
2. Reducing EEG power spectrum indicators.
3. Plateau on learning curve.

Educational content should be presented in such a way that the user will need to compare, analyze, synthesize, evaluate the probability, and reveal cause-effect relationships among many stimuli to complete the task, and then to use in a new situation.

The verification results of these principles and rules on the example of GreatChemist Expert Systems confirm the productivity of these ideas. The results obtained are of practical importance for the development of AI-technologies in education.

Perspective for future work consists in the elaboration of virtual helmets possessing built-in EEG electrodes, which will able, not only provide information to the teacher about the student's attention and fatigue, but also manage the development of user thinking.

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