Research Article

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Application of the criteria-based assessment system to the tasks of developing the functional literacy of students in teaching chemistry

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Abstract: The purpose of this paper is to modernize the educational process and the knowledge assessment system for students who study inorganic chemistry. Ways to modernize the current knowledge monitoring system were implemented by creating test tasks with a gradual increase in complexity, the so-called "three-dimensional model" of learning. As subjects for studying the practical application of this approach, 12 students were selected. The experiment took place as part of the study of the course of inorganic chemistry, which comprised 6 topics. At the same time, a holistic concept of knowledge assessment was selected, which maximally excluded any bias on the part of the assessor. Such reforms will help the state to train more specialists who will be able to compete with experts from all over the world, in particular engineers and technologists. All this testifies not only to the expediency of using a combination of these methods for teaching students of the Republic of Kazakhstan, but also to the need for further reform of outdated educational programs not only at the level of one higher educational institution, but also on a global scale.

Keywords: teaching methodology; effective learning; three-dimensional model; structuring of the educational process; criteria-based assessment; self-organization

1 Introduction

Modernity is advancing rapidly, and with it, the need to evolve educational processes. To build an effective educational system, it's crucial to learn from countries that are actively reforming their methods of presenting material and assessing students. However, it's equally important to train future specialists (chemistry professionals) at a high level using unique methods tailored to Kazakhstani higher education institutions to achieve economic success. Prastiwi and Laksono (2018) highlight stress resistance, the ability to process and analyse large amounts of information, and critical thinking as essential skills for a qualified specialist. In an era of constant information and discovery, considering all factors that affect work productivity is vital. Most companies seek specialists who can drive innovation and retain customers, and at the state level, development depends on the adaptability of state structures and continuous legislative reforms.

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Lin and Chang (2022) emphasize the importance of maximizing student engagement and fostering their desire to learn. A significant challenge lies in accurately monitoring knowledge and the success levels of a group. C. McGrath et al. (2021) found that most teachers face difficulties in the grading process due to potential biases and tasks that only partially cover student requirements or focus solely on memorization rather than practical application. S. Celik (2014) noted that low functional literacy among students is influenced by a combination of factors, including the low functional literacy of teachers. S.S. Fahmina et al. (2019), studying the chemical literacy of high school students, concluded that it is insufficient to meet general educational requirements and does not enable students to apply this knowledge effectively in various fields and daily life. The shortage of specialists can negatively impact a country's economic growth rate, making it imperative to implement reforms aimed at modernizing outdated systems and changing destructive patterns in the educational process.

The purpose of the study is to investigate and implement a three-dimensional methodological teaching system to enhance the functional literacy of students in the theory of solutions in chemistry in higher educational institutions. The three-dimensional methodological system is an organized educational model designed to improve students' functional literacy by systematically and hierarchically structuring the learning process (Sasson, 2019). The purpose of this system is to facilitate students in acquiring proficiency in educational content, ranging from basic to advanced levels. Simultaneously, it aims to alleviate the burden on teachers by simplifying the task of assessing knowledge and generating test assignments.

2 Methods

2.1 Participants

This paper presents a model for structuring the educational process, which is founded on a hierarchical method for presenting educational materials and evaluating knowledge. This experiment was conducted at the Abai Kazakh National Pedagogical University as a component of the teaching methodology for chemistry, specifically focussing on the theory of solutions. Third year students of the speciality 6B01512 Chemistry-Biology (educational program for training chemistry teachers). There were 12 students in total. Academic achievement and gender did not play a role. All participants agreed to participate. A control experiment was conducted to evaluate students' understanding of teaching the theory of solutions in chemistry classes at higher educational institutions and to identify the basis for their development of functional literacy. The duration of the experiment was 4 months. The identification of problems was achieved by active involvement in research sessions, surveys, and constructive discussions among students and faculty.

2.2 Study design

The study employed a quasi-experimental design with pre-test and post-test assessments to evaluate the effectiveness of the three-dimensional methodological teaching system. The students group was exposed to the three-dimensional methodological system. This system involved a hierarchical method for presenting educational materials and evaluating knowledge. The system was designed to improve students' functional literacy by systematically and hierarchically structuring the learning process.

2.3 Instruments

The three-dimensional model was used to monitor and evaluate knowledge. The model consisted of three levels:

(1) Level 1 (50 points): Assessed basic knowledge and understanding of fundamental concepts.
(2) Level 2 (30 points): Involved more complex formulations and required logical thinking and practical application of theoretical knowledge.

(3) Level 3 (20 points): Contained the most complex tasks, requiring critical thinking and the ability to apply knowledge in real-world situations.

The tasks were intentionally crafted to gradually escalate in complexity, so showcasing much greater efficiency. Each student was provided with an individual workbook to complete various types of assignments. Upon completion of the course, the respective outcomes of each student were recorded on a comprehensive assessment form. Furthermore, students diligently completed their progress diaries, documenting their present outcomes for each subject. The criteria-based assessment system was implemented to evaluate student's performance based on both the educational quality they received and their levels of competence and functional literacy. The criteria encompassed knowledge and comprehension, practical implementation, analytical reasoning and investigation, and effective interpersonal communication and introspection.

The three-dimensional model not only makes it easier for students to master the material systematically from simple to complex, but also helps teachers reduce the amount of work required for the process of testing knowledge and creating test tasks (Cooper, 2020). The implementation of this method within the framework of the experiment took place in five stages, covering certain tasks assigned to it. During the first stage, pedagogical methods for the formation of functional literacy were chosen. In the second stage, the degree of readiness of students to conduct a pedagogical experiment was determined from a methodological point of view. At the third stage, the effectiveness of the pedagogical technology called "three-dimensional methodological system" was determined. The analysis of literary sources prompted the hypothesis of a relatively high efficiency of this approach. During the fourth stage, testing was carried out in accordance with the requirements of the pedagogical technology "three-dimensional methodological system". The last stage was carried out in order to analyse the results of the detecting and teaching experiment. During the lesson, after checking the correctness of the tasks of each level, the teacher hangs a "Transparent Journal" sign on the board.

3 Results

Education is a dynamically evolving process that extends beyond the simple dissemination of information. Effective education should fundamentally cultivate students' capacity to engage in critical thinking, apply acquired knowledge in unfamiliar contexts, and make well-informed judgements. This objective is accomplished by guaranteeing that students are actively involved in the process of learning, rather than merely receiving information passively. The core idea is that students should maintain their cognitive engagement in the search process, irrespective of the techniques employed to address cognitive challenges (Sagat & Nurzhanova, 2020). Consequently, educators should abstain from merely offering solutions or detailed instructions, but rather facilitate students in exploring and cultivating their own problem-solving approaches. This methodology not only improves students' comprehension but also equips them for practical obstacles, where the capacity to think autonomously and adjust is essential (Table 1).

The foundation of effective education, as outlined in Table 1, rests upon four fundamental criteria: knowledge and comprehension, practical application, analytical thinking and investigation, and communication and review. These criteria serve as the foundation for structuring curricula and instructional approaches that foster the comprehensive growth of students (Mahmud et al., 2018; Shwartz et al., 2006). In the realm of chemistry education, specifically in the domain of redox reactions, these criteria can be effectively incorporated into a pragmatic learning methodology (Table 2).

During the course, students are introduced to various topics to gain comprehensive knowledge about solution properties and inorganic compounds. Students can monitor their performance through an electronic journal and personal progress diaries (Table 3).

Initially, students encountered challenges with the new learning system due to its substantial divergence from their previous experiences. However, with time and adjustment, students came to appreciate the advantages of this paradigm. They began to actively maintain their diaries and record their results (Table 4).

Table 1: Criteria for obtaining general education.

	Criteria	Description
A	Knowledge and understanding	Knowledge and updating of specific facts, information and characteristics that correspond to the purpose of the educational program within individual groups and subjects. The ability to demonstrate understanding by analysing, reproducing, predicting the information received.
B	Application	Application and use of previously acquired information and knowledge in new or unfamiliar situations and contexts. Ways to demonstrate the application of knowledge relevant to curriculum objectives in each grade and at each subject level: Practical work, diagramming, image map proficiency, problem solving, projects, coming up with new results.
C	Critical thinking and research	Formation of an opinion through analysis, synthesis, evaluation of information obtained from educational sources. Show the ability to collect and analyse information and results that correspond to the purpose of the educational program within individual classes and subjects. Explore, evaluate and draw independent conclusions from the proposed assumptions by gathering the right information and using the data. Demonstrate the ability to reflect on a conclusion consistent with the purpose of the educational program within each session and subject.
D	Communication and reflection	Oral and written presentation of information, facts and thoughts, opinions, corresponding to the purpose of the educational program within the framework of each lesson and subject. The ability to listen to information presented by other people and react accordingly, accept someone else's point of view, come to a common point of view, explaining one's own point of view. Making a decision by reflecting on thoughts, opinions and events that have been said, or acting as a result of reflection.

Source: Yandriani et al. (2021).

Table 2: Examples of questions on the topic "Redox Reactions"

Task level	Examples of questions	Answers to questions
1	1. What is a chemical reaction?	The phenomenon in which the nature of the original substance changes and new compounds are formed.
	$^{0}Fe+^{+2}CuSO_4 \rightarrow {}^{+2}FeSO_4+Cu^{0}$	The degree of oxidation of iron and copper has changed. The
	2. What changes occurred during the reaction?	neutral iron atom gave up 2 electrons and became an ion with a charge of "+2", and the Cu^{+2} ion accepted 2ē and became a neutral atom.
	3. How to calculate the chemical equivalent and equivalent mass of a substance?	For determining the equivalent of an element, it is necessary to divide the mole (quantity) of that element by its valence. $f_E = \frac{1}{B}(\text{mol})$, E is the chemical equivalent, 1 is the amount of the substance obtained (mol), B is the valence of the element.
	4. How to calculate the equivalent mass of an element?	The equivalent mass (E) of an element is calculated by the following formula: $E = \frac{A_r}{B}\left(\frac{g}{mol}\right)$ A_r is the molar mass of atoms of an element, g/mol. B is the valence of an element in a compound.
2	1. Why is the oxidation state of any element in the free state equal to zero?	Any element exhibits zero oxidation in the free state, for example: H_2, Fe, F_2, Na, O_2, N_2, A_r. Because there is no process of giving or receiving electrons.
	2. Why do redox reactions occur?	The redox reaction consists of two half-reactions: $^{0}H_2 + {}^{0}F_2 \rightarrow 2^{+1}HF^{-1}$ Oxidation: $H_2^0 - 2e^- \rightarrow 2H^+$, Reduction: $F_2^0 + 2e^- \rightarrow 2F^-$
	3. What is the main idea of the topic?	During the redox reaction, the reducing atom (or particle) donates electrons, and the oxidizing atom (or particle) acquires them. The oxidation state of an atom of any element is

Table 2: (continued)

Task level	Examples of questions	Answers to questions
		determined by the number of electrons that it conditionally gave or acquired. Its numerical value and sign depend on the electronegativity of the element. Metal atoms with low electronegativity always show a positive oxidation state, while non-metals have both positive and negative oxidation states.
	4. Complete these changes: $N_2^0 \rightarrow 2N^{+2}$; very high temperature (3000 °C) $N_2^0 \rightarrow 2N^{-3}$; with hydrogen (500 °C)	1) Reducing agent: $N_2^0 + O_2^0 \rightarrow 2N^{+2}O$ (In lightning) 2) Oxidizing agent: $N_2^0 + H_2^0 \rightarrow 2N^{-3}H_3^{+1}$ (500 °C, catalyst, pressure)
3	1. Does the concentration of nitric acid that reacts with a metal affect the reaction products (describe using the example of the reaction with zinc)?	Zn+4HNO3(conc.) = $Zn(NO_3)2+2NO_2+2H_2O$ $3Zn+8HNO_{3(40\ \%)} = 3Zn(NO_3)_2+\underline{2NO}+4H_2O$ $4Zn+10HNO_{3(20\ \%)} = 4Zn(NO_3)_2+\underline{N_2O}+5H_2O$ $5Zn+12HNO_{3(6\ \%)} = 5Zn(NO_3)_2+\underline{N_2}+6H_2O$ $4Zn+10HNO_{3(0.5\ \%)} = 4Zn(NO_3)_2+\underline{NH_4NO_3}+3H_2O$
	2. What substances can be classified as strong and very strong oxidizing agents?	Potassium chromate and dichromate (K_2CrO_4, $K_2Cr_2O_7$) are r$_7$educed from (Cr+6) to Cr+3 in an acidic environment. $K_2Cr_2O_7+3H_2S+4H_2SO_4=\underline{Cr_2(SO_4)_3}+\underline{3S}+\underline{K_2SO_4}+\underline{7H_2O}$ Concentrated sulphuric acid (H_2SO_4) $Hg+2H_2SO_4=\underline{HgSO_4}+SO_2+2H_2O$ Concentrated nitric acid (HNO_3) $P+5HNO_3=H_3PO_4+\underline{5NO_2}+H_2O$
	$^{+5}HNO_3 \rightarrow {}^{+4}NO_2 \rightarrow {}^{+3}HNO_2 \rightarrow {}^{+2}NO \rightarrow {}^{+1}N_2O \rightarrow {}^{0}N_2 \rightarrow {}^{-3}NH_3$ 3. Indicate how the redox and acid activity changes in the series.	Redox activity increases, while acid, on the contrary, decreases.
	4. Evaluate the oxidizing properties of aqua regia.	Aqua regia is obtained by mixing a mixture of one volume of nitric acid and three volumes of hydrochloric acid: $HNO_3+3HCl \leftrightarrow NOCl+Cl_2+2H_2O$ The resulting chlorinated nitrosyl decomposes into atomic chlorine and nitrogen monoxide: NOCl=NO+Cl Aqua regia has a strong oxidizing effect due to the atomic chlorine formed in the solution. Gold and platinum dissolve in aqua regia.

Source, K.S. Taber (2013).

Table 3: The subject "methods of teaching chemistry". Specialty 6B01512 chemistry-biology, group KhBK-3/1. Evaluation sheet (the results of one of the students from the group journal).

Topic No.	level 1 (50 points max)					level 2 (30 points max)				level 3 (20 points max)			Audit evaluation	Accumulated at home	Total	Journal grade
	1	2	3	4	5	1	2	3	4	1	2	3				
1	+	+	+	+	+	+	+	v	v	v	–	–	**50**	**20**	**70**	
2	+	+	+	+	+	+	+	+	+	v	v	–	**60**	**15**	**75**	**2.0(C)**
3	+	+	+	+	+	+	+	+	–	v	–	v	**80**	**15**	**86**	**3.0(B+)**
4	+	+	+	+	+	+	+	+	v	+	v	v	**72.5**	**22.5**	**70**	
5	+	+	+	+	+	v	v	v	–	–	–	–	**50**	**19**	**70**	
6	+	+	+	+	+	+	+	v	v	v	v	–	**75**	**15**	**85**	**3.0(B+)**

The bold values under the column "Journal grade" represent the final grades for the student in the "Methods of Teaching Chemistry" course. These grades are displayed as follows: 2.0(C): represents a "C" grade with a score of 2.0 on a 4-point grading scale. 3.0(B+): Represents a "B+" grade with a score of 3.0 on a 4-point grading scale.

Table 4: Page of the student's electronic diary.

Points Student Full name	Level 1 (50 points)					Level 2 (30 points)				Level 3 (20 points)		Classroom score	Homework score	Total	Grade
	1	2	3	4	5	1	2	3	4	1	2				
Topic 1	+	+	+	+	v	–	–	–	–	–	–	40	10	50	"3"
Topic 2	+	+	+	+	v	–	–	–	–	–	–	40	10	50	"3"
Topic 3	+	+	+	+	v	v	–	–	–	–	–	40	20	60	"3+"
Topic 4	+	+	+	+	+	v	v	–	–	–	–	50	20	70	"3+"
Topic 5	+	+	+	+	+	+	+	v	v	–	–	70	20	90	"4"
Topic 6	+	+	+	+	+	+	+	+	v	v	–	80	95	85	"4+"
Individual work no. 1	+	+	+		+	+	+	+	+	+	–	80.5	–	85	"4+"
Practical work no. 1	+	+	+	+	+	+	+	+	+	–	–	80	–	91	"4"

The implementation of this dynamic and interactive educational approach has demonstrated significant promise in enhancing students' learning experiences. By emphasizing the acquisition, comprehension, practical application, analytical thinking, inquiry, communication, and evaluation of knowledge, educators can foster a holistic development of students' cognitive abilities.

The performance evaluation system allows students to actively monitor their progress and adapt their learning strategies accordingly. Despite the initial challenges of transitioning to this new system, the long-term benefits in terms of analytical thinking, problem-solving, and self-directed learning are substantial. This approach not only readies students for academic success but also provides them with the necessary abilities to effectively handle real-life obstacles in their future professions and personal domains.

4 Discussion

The importance of educational and practical application of the structuredness of the studied material in everyday life is one of the main aspects responsible for motivating students to learn. Giving priority to the above principles subsequently greatly simplifies the preparation of a functionally competent student (Yandriani et al., 2021). Cooper (2020) has demonstrated the ways to successfully integrate a three-dimensional learning model for mastering the basics of chemistry. Also, studies by Stowe et al. (2021) were based on the formation of an idea of the correct monitoring of knowledge within the framework of chemistry education. Their scientific group noted the one-sidedness of mastering the material, when students had difficulties in applying the theoretical foundations in practice.

Juurlink et al. (2022) showed that the hierarchical structuring of the methodological system, including all of its proposed components, forms a high level of functional literacy of students and serves as a good foundation for developing a modern educational platform. This technology is called "three-dimensional methodical system learning technology". "Three-dimensionality" indicates a multi-level structure, where the presence of each component is necessary, as noted by Taber (2013), namely: goals, content, method, form and means of education. The traditional "knowledge" of education is only the first rung on the "ladder of development" for students. According to the research of Sasson (2019), such a hierarchy not only creates the components of a methodological learning system but also allows one to perceive motivation, activity, knowledge, learning quality, and learning process, as well as one's cognitive activities. The following points can be called features of the technology: systematic assimilation by students of educational material from simple to complex; so that the result can be measured, the organization of the learning process in the form of a competition; obtaining a qualitative

comprehensive assessment of knowledge; creation of favourable conditions for the use of developing and teaching methods (Santos de Aquino & Carneiro-Leao, 2019).

For secondary school students in preliminary studies, the change in the assessment system and daily monitoring of knowledge helped not only increase their interest in studying disciplines but also motivated teachers to get involved in the learning process (Sagat & Nurzhanova, 2020; Sjostrom et al., 2020). A similar approach is also important for older students, although the measure of its influence will be somewhat different, since with age, awareness of obtaining new information and the distribution of time allocated for learning occurs more rationally. Taking into account the above, one of the mechanisms for its successful implementation is the need to technologize the educational process, as Cutrim and Araujo (2021) noted in their paper.

Lin and Chang (2022) noted that when using a three-dimensional learning system, students are more willing to interact with peers. Surveys also showed that the level of students' interest in the subject increased significantly. This scientific group did not establish how much the method helped to increase the overall level of academic performance of the participants in the experiment. Correct objective assessment can help not only to identify the disadvantages and advantages of the tools that are used during the educational process but also to visualize the dynamics of the impact of reforms on established traditional canons. The content of modern education is determined by the priority of the principles of "accessibility", and "scientific character" and taking into account the age characteristics of students (Freire et al., 2019). These principles are necessary, but scientific character should be avoided, complicating access and content in the form of ready-made information, because such educational content does not allow students to learn online (Bernholt et al., 2018). With such content, it is impossible to create a new education standard based on the concept of transition from "information knowledge" to "competencies", the development of students' functional literacy and the introduction of a criteria-based assessment system. Therefore, the principles that determine the content of education should be reformulated by the experience of modern world practice. The important points include (Clinton, 2022; Indah et al., 2020):

(1) The principle of compliance by students with the need to learn as a result of their own active cognitive activities. Without it, it is impossible to organize an interactive learning process.
(2) Compliance with the requirements of the taxonomy of developmental education and goals. Such content allows developing education and objectively assessing the quality of education according to certain criteria.
(3) The principle of taking into account the didactic possibilities of information and communication technologies. Without this principle, it is impossible to implement the idea of e-learning. At present, most textbook authors are not aware of the didactic capabilities of a computer. In this case, the creation and use of an electronic textbook in the educational process is tantamount to adding a new add-on to the old base.

The importance of the criteria-based assessment for each of the subjects will differ depending on the goals set:

For educators:

- Formulate criteria leading to qualitative results;
- Obtain information that allows differentiating actions and plan for the future;
- Improve the quality of education;
- Plan the amount of learning for each person, taking into account the individual characteristics of a student;
- Use different evaluation methods;
- Make suggestions to make the curriculum accessible.

For students:

- Use various teaching methods that increase cognitive abilities and the level of thinking;
- Understand the evaluation criteria leading to success;
- Get feedback while evaluating oneself and others;
- Develop the ability to think critically, speak freely, demonstrate knowledge.

For parents:
- Get acquainted with the evidence of the quality of education of a child;
- Monitor academic progress;
- It provides an opportunity to receive recommendations to support learning.

The development of technology has contributed to the introduction of such an innovation as artificial intelligence into the educational process. As noted by D. Marchak et al. (2021), the advantages of this method include the possibility of using it during remote learning, as well as the involvement of teachers in the creative process, the ability to diversify the way the material is presented. Such implementations require educational reforms and cannot be applied locally. Also, the lack of basic knowledge about artificial intelligence, the principles of its work and ways of application among teachers will not contribute to the popularity of this method. Modernization of educational approaches should occur gradually and find approval among all participants in the educational process. Then such a technique will show high efficiency and will contribute to the growth of the quality of education and the level of training of future specialists (Nurliani et al., 2021).

This study and discussion show that the three-dimensional methodological teaching system improves chemistry students' functional literacy. Students' chemical understanding and application have improved with the structured approach, which hierarchically presents educational materials and evaluates knowledge. The three-dimensional model with three complexity levels helped students learn from basic to advanced levels. The systematic approach simplified teacher assessment and gave students a clear path to understanding and applying chemical knowledge. Individual workbooks and progress diaries helped students track their progress and adjust their learning strategies.

Traditional teaching methods emphasise memorisation rather than application, but the three-dimensional system addresses this. Modern education emphasises systematic assimilation, qualitative assessment, and positive learning conditions. The discussion also emphasises the need for functional literacy and critical thinking education reforms. The three-dimensional methodological system improves students' academic performance and prepares them for future challenges by deepening their understanding of chemical concepts and their applications. The study and discussion show that the three-dimensional methodological teaching system improves students' functional literacy in chemistry. This method improves academic performance and prepares students for success by teaching critical thinking, problem-solving, and self-directed learning.

5 Conclusions

In summary, the adoption of the three-dimensional methodological teaching system has shown considerable promise in improving the practical knowledge of chemistry students in higher education institutions. The implementation of this method, which hierarchically arranges educational materials and assesses knowledge using three levels of complexity, has not only streamlined the evaluation process for instructors but also offered students a well-defined roadmap to comprehending and utilising chemical principles. The implementation of individual workbooks and progress diaries has been effective in motivating students to actively track their progress and adjust their learning approaches accordingly. Despite early difficulties, the enduring advantages of this approach encompass enhanced analytical reasoning, problem-solving abilities, and self-directed learning, equipping students for both scholastic achievement and practical obstacles in their future careers. This discussion underscores the need to include functional literacy and critical thinking in educational reforms, underscoring the necessity of adopting a thorough and methodical strategy to update obsolete systems and enhance the standard of education.

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