

THE USE OF ELEMENTS OF NEUROPEDAGOGY IN THE CREATION OF VIRTUAL SIMULATORS FOR IN-DEPTH STUDY OF CHEMISTRY IN HIGHER EDUCATION

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Received October 2023

Accepted December 2023

Abstract

This study investigates the efficacy of incorporating neuropedagogical elements into virtual simulators for advanced chemistry education in universities. Utilizing a mixed-method approach, it uses questionnaires completed by 50 organic chemistry students. These questionnaires included both general and Likert scale questions, focusing on students' experiences with the PhET Interactive Simulation. The results highlight the positive impact of neuropedagogy on students' learning attitudes, cognitive abilities, and skill development, particularly in areas like critical thinking, analytical skills, and social competencies. A significant portion of students reported enhanced educational outcomes: 76% observed improved training effectiveness, 88% better understood the subject, and 96% found the virtual simulator-based learning more engaging. Furthermore, the study notes improvements in students' problem-solving abilities (68%), logical reasoning (92%), and comprehension of chemical processes (94%). These findings emphasize the value of integrating neuroscience principles in chemical education, potentially benefiting both tertiary and secondary education sectors. They indicate the necessity for educational adaptation in line with interdisciplinary research in cognitive and neurological sciences. This research not only serves as a valuable resource for chemistry teachers but also sets the stage for future empirical studies exploring neuroscience's role in teacher education. The study underscores the importance of further investigation into how teachers implement neuropedagogical techniques and the effectiveness of such applications, advocating for continuous development in educational methodologies.

Keywords – Neuroeducation, Neuropedagogy, Cognitive abilities, Chemistry, Simulator, Virtual.

To cite this article:

Rakhmetova, A.K., Meiirova, G., Balpanova, D.T., Baidullayeva, A.K., & Nurmakhanova, D.E. (2024). The use of elements of neuropedagogy in the creation of virtual simulators for in-depth study of chemistry in higher education. *Journal of Technology and Science Education*, 14(2), 473-483. <https://doi.org/10.3926/jotse.2532>

1. Introduction

The interest in using neurophysiological research data is quite understandable: knowledge about the functioning of the brain and the nervous system allows solving problems more effectively in many areas, including education. Such new research technologies and their use in practice pose new challenges to the education system, require constant changes and corrections. Despite efforts to improve the quality of education, more researchers representing various fields of science are looking for updated and best solutions that will help to balance the development of society and the potential for personal development in a huge flow of information (Bowers, 2016; Friedman, Grobgeld & Teichman-Weinberg, 2019; Torrijos-Muelas, González-Víllora & Bodoque-Osma, 2021). Although pedagogical science is independent, it can only develop successfully in close connection with other sciences since each of them has accumulated specific knowledge on issues important for pedagogy (Barabanova & Kazlauskienė, 2020).

In the 21st century, new trends that meet the modern spirit of techno-science have transformed into a socio-economic project called “neuroeducation”, involving the introduction of neurotechnologies and neuroscience into the education system (Baena-Extremera, Ruiz-Montero & Hortigüela-Alcalá, 2021). However, neuropedagogy has gone beyond neuroeducation. Neuropedagogy is defined as a symbiosis of science and education, the purpose of which is to stimulate the brain and create connections. By its definition, Neuropedagogy (Educational neuroscience) is an applied neuroscience that uses knowledge of cognitive neurology, differential psychophysiology, neuropsychology, data on the brain organisation of the processes of acquiring different types of educational material, etc. (Chojak, 2018; Barabanova & Kazlauskienė, 2020; Nurmakhanova, Rakhmetova, Kassymbekova, Meirova & Rakhimzhanova, 2021).

The last decade has been characterised by the informatisation of education and the development of virtual components of learning technologies: new forms of material presentation, access to educational resources on the internet, and new forms of training organisation (webinars, video lectures, virtual laboratories, simulators) (Komilova, Kuldashaeva, Egamberdieva, Safarova & Altibaeva, 2023). A large number of virtual technologies are rapidly being introduced into various spheres of human activity. Chemistry as a science is no exception. It includes a large amount of theoretical material, which is complicated by practical and computational tasks. Voluminous topics and courses considerably reduce the motivation of students. Therefore, modern teachers face the task of constantly improving the course to increase the effectiveness of training by optimising the quantity and quality of teaching materials, as well as developing and implementing new teaching methods using elements of neuropedagogy (Carrion, García & Erazo, 2020; Li, Cao & Luo, 2021; Salame & Makki, 2021). The relevance of studying the application of elements of neuropedagogy in a high-tech information educational environment in the field of chemistry using virtual and augmented reality technologies is beyond doubt.

A key aspect of any training is its practical orientation. Research shows that the use of computer animation and simulation improves students’ conceptual understanding of chemistry. Laboratory practice is a powerful pedagogical strategy for building conceptual, procedural, and even behavioural competencies (Bakhtibaeva, Grinshkun, Berkimbaev & Turmambekov, 2016; Gabdulhaeva, Zhakupov, Darzhuman, Kabieva & Baidalinova, 2014). The implementation of interactive simulations used in education is virtual environments that allow visualising and exploring phenomena, environments where students manipulate variables using various controls and immediately receive feedback about the effect of this manipulation using animation (Salame & Samson, 2019; Gilmanshina, Minnakhmetova, Gilmanshin, Galeeva & Abyzbekova, 2020). Virtual laboratories are a means of experimental training that simulate conditions close to real ones. Admittedly, they are limited in teaching certain aspects related to the experimental practice of chemistry but at the same time they have advantages that offer greater plasticity than a real laboratory in teaching this science. Simulators are an effective tool for students to develop models of chemical processes at the molecular level (Bimaganbetova, Daniyarov, Rustambekova, Duysenova, Rysbekova & Berkimbaev, 2013). In addition, such interactive teaching methods help to develop an integrative understanding of chemical phenomena from the macro to the micro level (Carrion et al., 2020).

Although educational and cognitive sciences offer many theories and related advanced teaching methods, neuropedagogy can offer additional approaches. Learning is the result of changes occurring in the brain, so higher education should be aimed at understanding these changes and presenting new information in such a way that a student's brain perceives it more effectively (Torrijos-Muelas et al., 2021). The results of the works devoted to neuropedagogy mainly demonstrate the impact of the introduction of neuropedagogic methods in secondary schools of foreign countries (Petlák & Schachl, 2019; Friedman et al., 2019; Elouafi, Lotfi & Talbi, 2021; Marchak, Shvarts-Serebro & Blonder, 2021; Chang, Schwartz, Hinesley & Dubinsky, 2021). These studies consider neurological concepts, select the appropriate areas of neuroscientific content that are best applicable to teaching and learning, develop neuropedagogic methodologies and practices, create methodologies and practices to fill education with neuroscientific know-how, provide and analyse statistical data on the application of neurobiological concepts by research participants to classroom practice and the relationship between a teacher and a student.

The connection between education and perception (cognition) is now represented as an inseparable binomial (Coward, 2013; Fuentes, Umaña, Risso & Facal, 2021, Luria, Shalom & Levy, 2021). Since neuropedagogy is a mix of neuroscience, neurocognitive psychology, and education, this study focused on how the use of elements of neuropedagogy when creating virtual simulators affects the basic cognitive abilities, which are the highest functions of the brain (perception, analysis of information about the surrounding reality, attention, memory, speech). It was also interesting to analyse which principles of neuropedagogy, according to the interviewed students, are effective in studying chemistry using virtual simulators. In the course of studying chemistry, an organic combination of theory and practice is necessary (Niyazova, Berkimbaev, Pralieva, Berdi & Bimaganbetova, 2013). These two components help students to deepen their understanding of, for example, the structure of a substance or the mechanism of a reaction. However, in real educational practice, it turns out that teaching is divided into two parallel courses of study. Therefore, many students share the concept of mechanism-structure-phenomenon when studying and can rely only on mechanical memorisation to study the theory (Li et al., 2021).

According to the first principle of neuropedagogy, the brain is a “parallel processor”, and it can perform several functions simultaneously. If educational and cognitive activity is diverse both in form and in meaning, if a variety of teaching methods and techniques are used, which, in addition, are implemented at an optimal level of complexity, then an environment is created to meet the needs of the brain in learning and cognition (Sagitova, Gilmanshina, Gilmanshin, Galeeva, Abyzbekova & Saduakaskyzy, 2020). Using EEG, researchers have demonstrated that a differential approach to learning stimulates the somatosensory and motor systems and involves more cortical regions in connection with repetitive learning (Doukakis, 2019).

The aim of this study was to demonstrate the beneficial effects of incorporating neuropedagogical elements into the development of virtual simulators for an in-depth study of chemistry in higher education settings. Additionally, it sought to highlight the effectiveness of utilizing the “new” insights provided by neuropedagogy to enhance both teaching and learning processes. The research question of this study is: How effective is the integration of neuropedagogical elements in the creation of virtual simulators for enhancing the study of chemistry in higher education, and what impact does this integration have on the teaching and learning process?

2. Methodology

The research was a quantitative, correlational study conducted at Abai Kazakh National Pedagogical University, Almaty, Kazakhstan, from 01.09.2021 to 01.12.2021. The focus was on examining the effectiveness of neuropedagogical methods in teaching organic chemistry through virtual simulators. The sample consisted of 50 students enrolled in the organic chemistry course. The sample was selected based on convenience sampling, ensuring voluntary participation and adherence to ethical standards regarding anonymity and informed consent. Participant demographics such as nationality, age, gender, or duration of study were not factored into the analysis to avoid biases. The study employed a mixed-methods approach, combining quantitative data from structured online questionnaires with qualitative feedback.

The questionnaires, divided into two blocks with a total of 20 questions, assessed students' attitudes towards using modern computer technologies and the effectiveness of neuropedagogical principles in virtual learning environments. A Likert scale was utilized for responses, allowing nuanced understanding of opinions (Jamieson, 2013; Fuentes et al., 2021).

PhET Interactive Simulation (2021) was the primary tool for creating virtual environments for learning chemical concepts and processes. These simulators are designed to support various educational objectives and can be integrated into different pedagogical approaches (Salame & Makki, 2021). Statistical analysis was conducted using the frequency percentage. The analysis focused on identifying correlations between the use of neuropedagogical methods and changes in students' cognitive abilities and learning effectiveness. The validity of the study was ensured through the use of established data collection tools (Likert scale and PhET simulations) and a well-defined research framework. Reliability was addressed by standardizing the questionnaire administration and ensuring consistent conditions for all participants. Ethical standards were rigorously maintained throughout the study. Participants were informed about the data collection purpose, methods, and their rights. All data was collected and processed with strict adherence to confidentiality and anonymity, especially important due to the online nature of the study amidst the Covid-19 pandemic restrictions.

3. Results

3.1. Efficiency of Using PhET Simulators

The results of processing respondents' answers to general questions are shown in Figure 1. The questions concerned students' perception of the introduction of virtual reality into chemical education and evaluation of the effectiveness of using virtual simulators in teaching practice.

As the obtained data showed, almost all students (96%) are confident that training with virtual simulators is more interesting and informative. About 76% of respondents noted an increase in the effectiveness of training using virtual simulators. Therewith, only 44% are sure that their academic performance increases as a result of the use of interactive teaching methods.

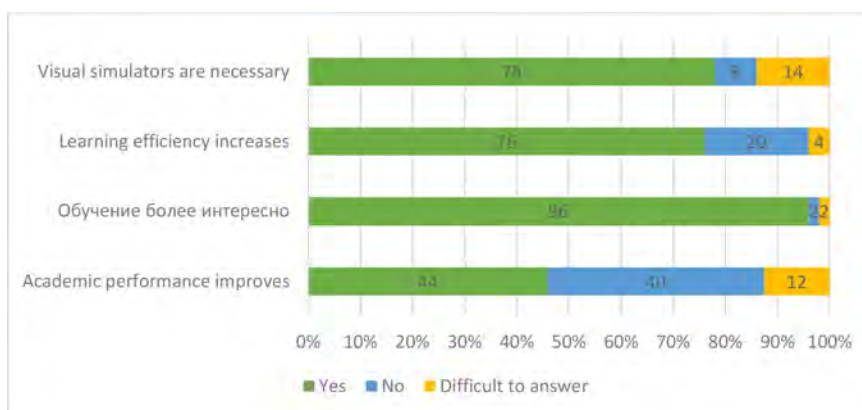


Figure 1. Assessment of the impact of using PhET simulators on learning characteristics

3.2. Cognitive Ability Research

Considering the fact that one of the latest and most innovative approaches to education is paying considerable attention to the brain functions in the student's learning process, studies of students' cognitive abilities have been conducted. The results of the study of changes in the neuropedagogy mechanisms of consciousness and behaviour are presented in Figure 2. Students were asked to answer the question "Does studying a chemistry course on virtual simulators have an impact on improving cognitive abilities?" The answers concerned such basic types of thought processes as memory; perception; development of concepts; problem-solving; imagination and logic.

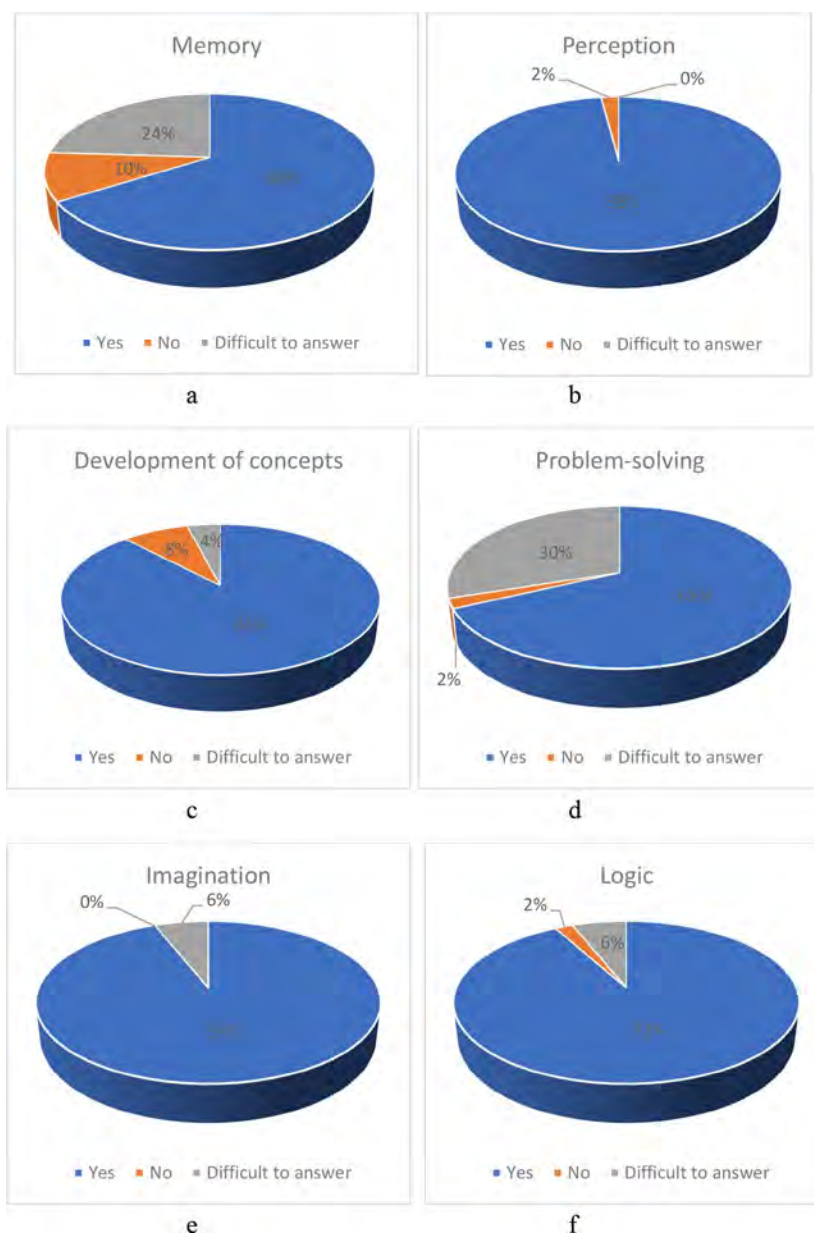


Figure 2. Respondents' answers to the question about the impact of virtual simulators on cognitive abilities

According to the data presented in Figure 2, training on virtual simulators has a positive effect on all the main types of thought processes. Almost all students who took part in the study noted an improvement in perception, imagination, and logic. The number of respondents who gave a positive answer varies from 92% to 98%. Obviously, PhET Interactive Simulation allows visualising, for example, the structure of an atom at the level of elementary particles: proton, electron, and neutron. When conducting such an interactive virtual practical work, the student turns from a passive observer into an active experimenter, acquiring the ability to apply knowledge in practical virtual tasks, the ability to analyse, generalise, systematise information, and formulate conclusions from experimental studies. According to the respondents, 66% of them had improved memory, while 24% did not notice such changes. This is explained by the short period that passed from the simulator classes to the survey, and the students did not fully realise such changes.

3.3. The Effectiveness of Using the Elements of Neuropedagogy

The respondents taking part in the study were asked to evaluate the effectiveness of using elements of neuropedagogy when creating virtual simulators for advanced study of chemistry in higher education

institutions, based on the general basic principles of neuropedagogy (Chojak, 2018). Since the interviewed students are not qualified specialists in the field of neuropedagogy, they were provided with examples of the application of such principles in real educational practice. The questions were evaluated on a five-point Likert scale: completely agree (5 points), agree (4 points), find it difficult to answer (3 points), disagree (2 points), and completely disagree (1 point). The results of the evaluation distribution, expressed in the percentage of students who answered the questions, are presented in the Table 1.

The principle of neuropedagogy	Example of application in the learning process	Number of respondents (%) who answered the questions				
		Completely agree	Agree	Difficult to answer	Disagree	Completely disagree
The brain as a “parallel processor”	Variability of teaching methods and forms	70	28	0	2	0
Learning and cognition as natural mechanisms of brain development	Learning at the optimal level of complexity	60	34	0	4	2
Reliance on previous experience and the search for meaning as innate qualities of the brain	Interdisciplinary connections in training	94	6	0	0	0
The brain searches for meaning through the establishment of patterns	Solving problems to find patterns	68	26	0	4	2
The role of emotions in learning and teaching	The use of the aesthetic factor and elements of entertainment, modelling of future professional activity	98	2	0	0	0
Analysis and synthesis in the functioning of the brain	Interaction of the whole and the particular, analysis and synthesis, induction and deduction, direct and inverse methods of problem solving	72	10	6	8	4
Involvement of consciousness and subconsciousness	Development of self-control and self-awareness, relying on previous experience	90	6	4	0	0
Visual-spatial memory and the system of “cramming”	Visual learning, a combination of different forms of information presentation	96	2	2	0	0
The principle of creative freedom	Development of creative thinking	92	4	0	2	2
The principle of uniqueness	Methods of individualisation of training	76	8	6	4	6

Table 1. Evaluation of the effectiveness of using neuropedagogic elements in the creation of virtual simulators

98% of students agree (70% of them completely agree) with the fact that the variability of methods of training (in this case, the use of virtual simulators) is necessary. Only one student (2%) expressed disagreement. Creating an optimal level of complexity for learning and cognition is considered necessary by 94% of respondents (60% fully agree and 34% agree). 100% of respondents agreed on the need for interdisciplinary connections in teaching and the use of aesthetic factors and elements of entertainment.

This percentage of responses is predictable. The highest percentage of negative responses (8% disagree and 4% completely disagree) was given to the question about analysis and synthesis in the functioning of the brain; 6% of respondents found it difficult to answer this question. The absence of negative answers to the question about the development of self-control and self-awareness confirms students' awareness of the simultaneous involvement of the processes of consciousness and subconsciousness in the human brain and the effectiveness of using this principle of neuropedagogy in the learning process. Methods of individualisation of training are supported by 84% of respondents, 10% disagreed, and 6% found it difficult to answer this question. There is a generally positive trend in all the answers regarding the effectiveness of using elements of neuropedagogy when creating virtual simulators. In other words, the absolute majority of respondents (on average 94.2%, 81.6% of them completely agree) agree that it is much more effective to build the educational process in accordance with the natural mechanisms of functioning of the brain discovered by science and purposefully develop the mental abilities of students.

4. Discussion

The percentage of students who believe their academic performance has improved due to interactive teaching methods (44%) is slightly lower than the data presented in the literature (Salame & Samson, 2019; Taibu, Mataka & Shekoyan, 2021). Perhaps this indicator is associated with the still insignificant share of the use of virtual simulators in the practice of chemical education, as well as with a relatively small ($N = 50$) selection of respondents. Nevertheless, in general, the results of this survey correlate well with the data presented in the literature, where the use of virtual simulators in training leads to an overall positive experience (Salame & Makki, 2021) and are confirmed by electroencephalographic examinations (Doukakis, 2019). Literature data indicate that the use of virtual reality elements favours the development of basic concepts in chemistry teaching (Salame & Samson, 2019), as well as that the use of interactive technologies is advisable at the stage of searching for a solution to the lesson as a reinforcement of the conventional learning process (Abyzbekova, Zholdasbayeva, Tapalova, Yespenbetova, Balykbayeva & Arynova, 2023). The results of the survey are consistent with the above statements. 88% of the surveyed students confirmed an improvement in understanding compared to conventional teaching, consisting of lectures and practice, 68% said that classes on virtual simulators helped them in solving their tasks.

The huge role of emotions in learning is confirmed by numerous studies (Chang et al., 2021). A high percentage of agreement is also observed in questions about the clarity of learning and the development of creative thinking. 96% and 92% of students, respectively, completely agree with the need to use these principles of neuropedagogy. The data obtained are also consistent with literature data (Hattie & Yates, 2013; Marchak et al., 2021). Neuropsychological studies show (Bowers, 2016; Kurashige, Kaneko, Yamashita, Osu, Otaka, Hanakawa et al., 2020) that the development of analysis and synthesis of two important interacting concepts requires corresponding reinforcement through adequate teaching techniques and methods. In other words, the educational material should be delivered in the form of constant interaction of the whole and the particular, analysis and synthesis, induction and deduction, direct and indirect methods of problem solving, concretisation and generalisation, etc. (Baidalinova, Gabdulhaeva, Zhakupov, Darzhuman & Kabieva, 2014). Perhaps such a distribution of answers in the presented study is conditioned upon insufficient explanation of this principle of neuropedagogy when developing a question and misunderstanding of the essence of the question by respondents.

The results of this study (Table 1) indicate that more than 90% of respondents agree with the above statements, and 98% of respondents note that their perception of the material has improved (Figure 2). The human brain always functions in the mode of communication between past experience and a new situation. A student understands and comprehends something new for themselves when the brain finds support in already existing knowledge and ideas, which are extremely important to constantly update in the learning process (Friedman et al., 2019). In addition, learning is effective when the potential of the brain develops by overcoming intellectual difficulties through the establishment of patterns. That is why

interdisciplinary connections in learning are so important. The research results record 100% agreement of respondents on this issue (Table 1).

From the standpoint of the development of objective knowledge, memory and the transformation of representations carried out in the process of further cognitive interaction of the representation (model) and the cognisable reality (object) are of great importance (Gonzalez & Martins, 2017). The results of the study (Figure 2) prove that as a result of the use of elements of neuropedagogy, students improve the development of a system of meanings of introduced concepts, i.e., the development of experience and algorithms for the development of conceptual knowledge. 88% of respondents note such an improvement. The brain operates with at least two memory systems: a visual-spatial one, more natural for the functioning of the brain, and a system of “cramming”. The knowledge that enters the brain through the “cramming” system is short-lived and unproductive and is located in memory randomly. Therefore, such information is difficult to find if necessary (Friedman et al., 2019). Virtual simulators that activate visual-spatial memory radically change the way content is transmitted and understood due to a unique combination of visual and sensory information, which leads to an effective learning experience. This is confirmed by the results of this research (Table 1).

Another necessary component of the successful educational and professionally-oriented activities of students at the university is the development of creative potential (Murzalinova & Kukuzova, 2021). Approaches to the development of students' creative potential involve the creation of a favourable environment in the learning process. Brain development is stimulated only in conditions of creative freedom and is blocked in an environment of pressure, coercion, or threat. There is no creative thinking without the principle of creative freedom. Imagination, intuition, unconscious mental activity, and a person's need for self-actualisation, disclosure and expansion of their creative capabilities, are the factors that are present when learning with a virtual simulator (Bapanova, Orekhova, Kadirsizova, Kasbayeva & Sholpankulova, 2023). During the survey, 96% of students (Table 1) agreed with this statement. The further development of these capabilities may eventually lead to the emergence of original ideas and projects, a new approach to solving problems and tasks, and the ability to organise existing ideas into new combinations. Thus, considering the main components of the mental sphere of the student's personality, namely, cognitive styles of students, emotions, features of attention distribution, memory devices, etc. allows forming an effective “visual” representation of knowledge and optimising the learning process.

5. Conclusions

According to the results of the study, it was proved that the use of elements of neuropedagogy in the creation of virtual simulators for in-depth study of chemistry at the university has a positive impact on the learning process. The educational process becomes more effective due to the application of neuropedagogical principles in modern information and communication technologies. This approach enhances students' informative and communicative competencies, activates their cognitive activity, and fosters independence in mastering knowledge. Additionally, it strengthens their motivation for learning by developing skills to work with interactive technologies. 76% of the students participating in the survey noted an increase in the effectiveness of training.

It was established that the use of virtual simulation in chemical education can positively affect both the cognitive abilities of students and the level of motivation. It is shown that the main types of the thought process, such as memory, perception, logic, imagination, the development of concepts, and the ability to solve problems are effectively stimulated by interactive teaching methods. The test results have shown an improved understanding of the subject (88% of students note this) and an increased interest in studying chemistry (96% called learning with a virtual simulator more interesting). Notably, providing students with a rich, fascinating learning experience using elements of neuropedagogy helps to develop deeper knowledge and skills, especially such as problem solving, creativity, emotional intelligence, critical thinking, which are in demand in the modern world. Among the students who participated in the study, 68% observed that the skills acquired through the course helped them in problem-solving. Furthermore, 92%

reported that they could build logical connections more effectively. Additionally, 94% noted that studying with virtual simulators enhanced their ability to imagine and thus better perceive and understand chemical processes at various levels, from substances and elements to molecules, atoms, and the dynamics of chemical reactions.

The results presented in this study can be useful not only for chemistry teachers in higher educational institutions but also for chemistry teachers in secondary schools. The data presented in the study confirm the need to solve the problem of educational adaptation to the results of interdisciplinary research in the field of cognitive science, neuroscience, and other neuroscience. In addition, these materials can stimulate future empirical research on the evaluation of neuroscience in teacher education. The need for further research in this area is beyond doubt. In the conducted study, which is only the first stage, the assessment of the symbiosis of neuropedagogy and virtual simulation is limited to the feedback of a relatively small number of students. The next stage of research is to identify how teachers use elements of neuropedagogy in the learning process, to study the explanations of these applications, to determine feedback, which plays an important role in the development and implementation of the educational process.

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

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Journal of Technology and Science Education, 2024 (www.jotse.org)



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