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Selection of ICT tools for the development of high school students' research competencies in specialized chemistry training

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Abstract. The article analyzed the place of information and communication technologies and learning tools in specialized chemistry training. The development of research competencies of high school students as one of the important results of specialized training in chemistry is considered. The analysis and systematization of ICT tools to ensure compliance with the principles of specialized chemistry training is made. The choice of ICT tools for the implementation of specialized chemistry training and development of high school students' research competencies in specialized chemistry training had substantiated. The results of research aimed at determining the feasibility of using certain ICT tools to develop of high school students' research competencies in specialized chemistry training are presented.

Keywords: research competencies, specialized chemistry training, information and communications technology, learning tools, principles of chemistry learning, electronic educational resources

1. Introduction

The main objectives of the National Strategy for the Development of Education in Ukraine for the period up to 2021 in general secondary education are to update the content, forms and methods of organizing the educational process; creation of conditions for strengthening of professional orientation, maintenance of specialized training, individual educational trajectory of development of high school students according to their personal needs, interests and abilities; increasing the efficiency of the educational process based on the implementation of the achievements of psychological and pedagogical science, pedagogical innovations, information and communication technologies (ICT) [74].

The "Concept of specialized education in high school" emphasizes the need to use innovative learning technologies, organization of research, project activities, specialized educational

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practice of students, etc. [51, p. 6]. The set tasks reflect the current trends in the development of secondary education, ICT and teaching aids, determining the feasibility and necessity of modernization of science and mathematics education.

The main tasks of specialized training include assistance in the development of creative independence, formation of a system of ideas, values, research skills and abilities – components of research competencies that will provide graduates with the opportunity to successfully self-realize [51, p. 4].

The main purpose of specialized chemistry training is the development of students' competencies necessary for the creative realization of personality, and the acquisition of skills of independent scientific-practical and research activities. Among them, a special place is occupied by research competencies – a complex personal construct, which can be characterized through knowledge and skills, necessary for carrying out the research activity, positive attitude to it and awareness of its importance regardless of whether it is carried out individually or jointly [63]. The research competencies formation is manifested in the acquisition of knowledge, skills and methods of activity for the effective implementation of educational and research activities and the ability to independently acquire new knowledge [50, p. 7], acting as a goal of specialized chemistry training.

According to Velychko and Fitsailo [88], when organizing specialized chemistry training, due attention should be paid to supporting and developing students' independence in learning, their participation in activities such as project and research, which should help students of specialized classes achieve of creative use of knowledge. The learning process in the specialized (profiled) school focuses mainly on the active use of research techniques, which involves problem statement, organization of research, design and defending of results, self-evaluation. In the specialized chemistry training the self-development and self-education of students acquires great importance. This is facilitated by an increase in the part of students' independent work, including computer and other sources of information.

Realization of the purpose and objectives of specialized chemistry training is impossible without taking into account tendencies of informatization of a society as a whole, and system of education in particular. Creating conditions for access to information, including educational information, by creating a nationwide network of information support for science and education is one of the tasks facing the informatization of society in Ukraine [66]. Satisfaction of human rights to equal access to information services and its needs, taking into account individual characteristics, abilities, aptitudes in specialized training can occur through distance learning, which occurs mainly through the mediated interaction of distant participants in the learning process in a specialized environment that functions on the basis of modern psychological and pedagogical and information and communication technologies [51, 52].

Thus, there are contradictions between the need to use ICT tools as one of the important means of forming students' research competencies in specialized teaching of chemistry, and insufficient development of methods of using ICT tools to form research competencies of students in specialized chemistry training.

The interpretation of the research competence concept is given by Burchak [11], Garay-Argandona et al. [28], Genkal [29], Kryva [40], Mindeeva [50], Rakov, Gorokh and Osenkov [75], Salmento, Murtonen and Kiley [79], Tumasheva et al. [87]. The problems of research competencies formation of students in the conditions of specialized training were considered by Alibekian [2], De Schrijver [22], Verbytskyi [89]. The problem of using ICT as a means of teaching chemistry has been widely covered by Aksela [1], Derkach [23], Husaruk [34], Lewis [43], Sanger et al. [80], Waight and Gillmeister [91].

The problems of systematic use of ICT as a means of forming students' research competencies in specialized chemistry training remains insufficiently researched, which determined the *research goal*: theoretical substantiation of the choice of ICT tools for chemistry specialized training, aimed at the development of students' research competencies.

2. Theoretical background

State standard of basic and complete general secondary education of Ukraine [18] defines *competence* as the integrated ability of a student acquired in the learning process, consisting of knowledge, skills, experience, values and attitudes that can be holistically implemented in practice.

Accordingly, *research competence* can be defined as a complex personal formation, which can be characterized by the knowledge and skills necessary to perform research activities, a positive attitude towards it and awareness of its importance, regardless of whether it is performed personally or jointly. The formation and development of research competence is inseparablylinked with the development of general (academic) competencies, can be considered as their component and is a necessary condition for professional development and personal self-improvement [58, 62, 63]. The highest level of research competence development is achieved in the process of independent creative research activity [58].

The most suitable for the research competencies development of high school students is the profile level of chemistry education (specialized chemistry training), which ensures the implementation of both external form of differentiation of chemistry education (through the creation of appropriate classes, groups, etc.), and partially internal (through the creation of dynamic groups to study elective courses, including distance learning forms of organization).

One of the most effective means of individualization and differentiation of chemistry teaching, which contribute to independent and creative work of students and promote the development of research competencies, are ICT tools, the use of which is closely connected with the main direction of society development in the late 20th – early 21st century – informatization as a set of interrelated organizational, legal, political, socio-economic, scientific, technical, production processes, aimed at creating conditions for meeting the information needs of citizens and society through the creation, development and use of information systems, networks, resources and information technology, which are built on the basis of modern computing and communication technology [66].

According to the "Model law on informatization", it is an organizational socio-economic and scientific-technical process, which is based on the widespread application of information systems and technologies in order to radically improve working conditions and quality of life, significantly increase the efficiency of all types of activities of individuals and legal entities [55].

Informatization contributes to the formation and development of the information society, which consists of many different aspects of political, social, economic and humanitarian nature, which is characterized by high dynamics of development, and in which information, knowledge and intellectual potential are paramount importance. The main characteristic features of the information society include [77]:

- the increasing the role of information and knowledge in all spheres of society;
- growth in the volume of information and communication products and services in gross domestic product;
- the creation of a global information space to ensure effective information interaction of people, their access to global information resources and meet their needs for information products and services.

Rudenko [77] defines the purpose of the information society as the comprehensive and organic development of man, the creation of conditions for his spiritual and mental enrichment, the build-up of national human capital as the basis for the development of political, social, economic, humanitarian, cultural and other spheres of social life, primarily in the interests of improving the well-being of citizens, economic efficiency and strengthening statehood.

Since 1998, Ukraine has been running a National Informatization Program, whose main goal is to create the necessary conditions for providing citizens and society with timely, reliable and complete information through the widespread use of information technology and information security of the state, and among its main tasks should be the creation of a nationwide network of information support for science and education, the formation and support of the market of information products and services, the integration of Ukraine into the world of information space [66].

Of all the fields of chemical science, analytical chemistry is one of the most technologically advanced, involving the use of numerous electronic devices. When creating instruments for chemical analysis, a large number of discoveries in the field of not only chemistry, but also physics and engineering were often tested. The emergence and development of chemistry informatics tools was no exception.

Trends in improving the structure and functionality of devices, first of all for chemical analysis, were associated with their automation, hybridization and miniaturization, which was directly due to the use of computers in their design and manufacture. The first digital computers that were used for chemical analysis appeared in the late 1950s. In the 1970s, with the advent of personal computers, most analytical instruments for physical and physicochemical methods of quantitative chemical analysis were already equipped with microprocessors. In addition, computers were used to perform complex mathematical calculations and process large arrays of numerical data. It was at this time that the first versions of software for this appeared – such programs as Mathcad, Maple, MATLAB. In the 1980s, programs for quantum-chemical calculations such as HyperChem, MOPAC, Gaussian, GAMESS, etc. were created. But calculations of this level of complexity are not found in school practice, so there is no special need to use such software products.

At the end of the 20th century, it became common practice to connect the device to a personal computer both to record, process and visualize the experimental data, and to control the device and program its operation. The creation of laboratory complexes for schools, consisting of special computer measuring units and sensors, has begun. An example of such application of computer technology in chemistry teaching is a set of chemical equipment from L-micro company, which includes sensors for measuring pH, optical density, temperature, conductivity, pressure, etc. The sensors are connected to a personal computer using a special computer measuring unit. Such equipment allows to perform a large number of laboratory works, including quantitative chemical analysis, recording the results online.

The learning of the basics of analytical chemistry in school is inextricably linked with the development of analytical chemistry as a science. Computer technology can be considered both as a means of scientific knowledge within analytical chemistry as a field of science, and as a teaching tool within the study of the basics of analytical chemistry in specialized classes of the school. In the 1980s and 1990s, the term "Computer Based Analytical Chemistry" (COBAC) appeared. It emphasizes the emergence of methods, techniques, certain areas of analytical chemistry, which could not have arisen without computers [68]. Examples are computer modeling of chemical-analytical processes and methods of analysis, development of expert systems designed, in particular, to decipher the structure of organic compounds, the emergence of pattern recognition systems, including multisensory systems [94, pp. 227–235].

Education is also undergoing significant changes due to informatization, as well as any other areas of human activity in modern society. As noted by Pidkasistyi [73, p. 187], informatization of education is a set of measures to restructure pedagogical processes based on the introduction of information products, tools and technologies in training and education. Bykov [13] interprets this concept as an ordered set of interconnected organizational and legal, socio-economic, educational and methodological, scientific and technical, production and management processes aimed at meeting the information, computing and telecommunications needs associated with the possibilities of methods and means of information and communication technologies of participants in the educational process, as well as those who manage and provide this process.

Informatization of education, acting as a determining information and communication basis for the education development, harmonious development of personality and socio-economic systems of society, is an integral part of informatization of society, which provides, in particular, the formation of cognitive, personnel and scientific-technical foundation and socio-economic phenomena. Informatization of education significantly affects the content, organizational forms and methods of teaching, as it is associated with the introduction of ICT methods and tools in the education system, creating a computer-based information and communication environment based on them, enabling subjects of educational process to use tools and services of this environment, to access its resources in solving various problems [13].

According to Bykov [13, p. 144], the main purpose of informatization of education at the present stage of development of society and education is to prepare students for active and productive life in the information society, to improve the quality, accessibility and efficiency of education, to create educational conditions for the general population to implement life-long learning based on the wide introduction of ICT methods and tools and computer-based technologies to support human activities.

The modern stage of informatization of the Ukrainian education system involves the implementation of the principles of open education, subordinated to modern educational paradigms of human-centeredness and equal access to quality education, which leads to significant changes in the implementation of the educational process, in particular, the improvement of educational goals, methods of organization of the educational process, teaching content and pedagogical technologies, composition and structure of computer-based learning environment. All these changes form the content of ICT-based education, which provides a broad, comprehensive and effective use of ICTs for implementing the functions of the education system, which reflects global trends in the development of educational systems [16].

Signs of informatization of education include, in particular, the emergence and development of components of learning technology [90, p. 13]:

- new forms of information presentation (e.g., , multimedia, including text, graphics, animation, sound, and video);
- access to electronic educational resources through the Internet;
- new forms of training organization (webinars, video lectures, virtual laboratories), etc.

Instructional technology is an integrative model of the educational process with clearly defined goals, diagnosis of current and final results, the division of the educational process into individual components, which provides clear and consistent implementation of certain educational activities in terms of operational feedback. Since the main goal of any technological process is to obtain a product of a given sample, the development of learning technology requires the definition of the learning objectives, the projected result and the path from objectives to result – organized in a certain way teacher-student interaction [9].

The introduction of computers in the practice of learning has allowed a different interpretation of the concept of instructional technology. Thus, the Carnegie Commission on Higher Education in 1972 defined instructional technology as follows: "the enrichment and improvement of the conditions in which human beings learn and teach achieved through the creative and systematic organization of resources, physical arrangements, media, and methods" [85, p. 89]. A report by the Carnegie Commission on Higher Education states that the work of educators and methodologists in developing learning materials using new information technologies has sparked new interest in learning theory and its application to course planning, curriculum development and equipment of educational institutions: "such novel media as computers and television a place in the ranks alongside the slide projector, the textbook, and the teacher as useful participants [of the educational process]. This integration of new media, long-familiar technology, planning of instructional space, learning theory, and the professor into a total effort is sometimes called the "systems approach" or the "learning environment approach" to instruction" [85, p. 10]. In this case, "instructional media must also be stored, maintained, and eventually replaced when they wear out or become obsolete" [85, p. 13].

In fact, any instructional technology is an information technology, because the basis of the technological learning process is data (reflected in the human mind as information) and their transformation. Following Zhaldak [92, p. 8], information and communication technologies in education is various means of informatization of education – a set of methods, tools and techniques used to collect, organize, store, process, transmit and transfer various messages and data for educational purposes.

ICTs provide virtually unlimited opportunities for individualization and differentiation of the learning process, building one's own educational trajectory. The use of ICTs in the learning process can be represented in a three-level structure. At the first level, ICTs of instruction are used as a supplement to traditional teaching tools to solve narrow subject tasks of the learning process, performing educational, control, training and, less frequently, game functions. At the second level, ICT-based learning is used to address both subject-specific and cross-curricular objectives of the learning process in the system of traditional tools, providing game, simulation, research, design and project activities. At the third level, ICTs are used to solve didactic tasks in an integrated learning process to develop students' systemic thinking. At this level, ICT is used as a key component of the system of learning tools [33].

As Bykov [13, p. 149] notes, the effectiveness of the informatization of education depends largely on the activities of the national industry of computer-based learning tools (ICT-based learning tools), including educational software. This industry should provide an increase in the efficiency of training and education, spread the access of citizens to ICTs, Internet and information resources for education, organize cooperation with state and local authorities in education and science, promote the democratization of education and the integration of Ukrainian education into the world educational space.

Zhuk [93] defines teaching aids as any means, devices, equipment and facilities used to transmit information in the learning process. Since teaching aids are an integral part of the learning environment and part of many teaching aids, there are many synonyms of this term, like "learning tools", "educational facilities", "instructional media", "audiovisual aids", "sight materials", "educational materials", "instructional materials", "educational technology" etc., used depending on the context of the pedagogical situation. On the one hand, teaching aids, influencing the subjects of training, create the conditions for the possibility of achieving specific, pre-determined learning objectives, and on the other – they are always inherent in the diversity of forms of implementation and methods of their use, which follows from the paradigm of education that has developed in society.

Thus, teaching aids can be understood as natural and / or artificial objects that form the learning environment and participate in learning activities, while performing educational, upbringing and developmental functions [93].

The following relationships can be distinguished between teaching aids and components of the learning process:

- for teachers, teaching aids are a tool to optimize the learning process and manage learning activities;
- for students, teaching aids are means of cognition and means of enriching the learning environment;
- in relation to the content of education, teaching aids are ways of presenting the content of education and means of monitoring academic achievements;
- in relation to the methods of the educational process and forms of teaching and learning organization, learning tools are the means of supporting learning communication.

In the learning process, any learning tools performs one or more functions, among which we can highlight, in particular, the following:

- *epistemological* (as a source of information about the objects or processes under study);
- *praxeological* (as a tool for practical activities of students);
- *axiological* (to increase students' interest in the subject and stimulate their independent educational and cognitive activities);
- *communicative* (as a tool of educational communication).

On the teacher's side, teaching aids can also perform the functions of *monitoring, controlling and managing students' learning activities*.

Consider how general didactic and partial methodological principles of chemistry teaching are implemented in the process of using teaching aids.

3. ICT for implementation of the principles of specialized chemistry training

3.1. Principle of unity of educational, developmental and upbringing functions of teaching

The general didactic *principle of unity of educational, developmental and upbringing functions of teaching* in specialized chemistry training is realized first of all in the development of students' research competencies as a basis for choosing a future profession, formation of value orientations, development of ecological components of worldview. To implement this principle, all teaching aids are used.

3.2. Principle of scientificity of the content and teaching methods

The principle of *scientificity of the content and teaching methods* in specialized chemistry training is implemented in three leading groups of teaching aids:

1) tools in which the scientificity of the content is provided – primarily textbooks, scientific and popular science publications on chemistry in traditional and electronic forms;
2) tools in which the scientificity of the teaching methods is provided – textbooks on the theory and methods of teaching chemistry, manuals for teachers, guidelines for conducting classes in traditional and electronic forms;
3) tools of computer modeling of chemical processes developed on the basis of corresponding scientific theory

The implementation of the principle of scientificity in the specialized chemistry training involves the use of research methods and methods of problem-based learning, acting as a necessary basis for the development of students' research competencies. In this regard, all means of supporting students' learning and research activities can be referred to the means of implementation of the principle of scientificity.

An important role in ensuring the scientific content and methods of specialized chemistry training belongs to the *scientific Internet resources*. The chemistry teacher should be familiar with the modern state of chemical science, the latest scientific discoveries and events in this field of science, and apply the obtained information with appropriate methodical adaptation in the teaching process. The efficiency of using scientific resources of the Internet is increased through the use of search engines (general purpose and specialized – ChemSpider, PubChem, Chemical Structure Lookup Service). Chemical information resources are widely available on the Internet, and therefore the effectiveness of search using genera -purpose search engines depends only on the user's qualifications in building queries [78].

The use of *computer models* allows to reveal the essential connections of the studied object, to reveal its regularities more deeply, which, as a result, leads to a better mastering of the material. The student can investigate the phenomenon by changing the parameters, compare the results, analyze them, and draw conclusions. For example, in the laboratory work "Gravimetric Analysis of Chloride" in the virtual laboratory ChemLab, the student can instead of the 5 g of the substance containing chloride ions listed in the instructions, take 3 g, or 6 g, or 10 g of it. But in each case, student will receive the corresponding mass of sediment argentum chloride, which, when performing calculations, will come to the same results and conclusions, and therefore better understand and memorize the corresponding pattern [59].

3.3. Principle of systematicity and consistency

Implementation of the *principle of systematicity and consistency* in the specialized chemistry training is possible in those teaching aids that provide step-by-step presentation of educational material, primarily – multimedia tools (electronic textbooks, presentations, etc.).

When designing a lesson with the use of multimedia, it is necessary to clearly plan a sequence of steps both with and without the use of ICT, to provide different ways of communicating with students, and to organize constant feedback with them. Husaruk [34] points out that the proper use of multimedia in chemistry lessons saves about 30% of teaching time as compared to the work on an ordinary blackboard.

Multimedia presentation provides an opportunity to present educational material as a system of reference signals filled with structured information in algorithmic order [86]. The main advantages of presentation material include, but are not limited to:

- information capacity – the ability to accommodate a large amount of graphic, textual, audio data;
- mobility – the availability and simplicity of the necessary technical equipment allows you to use presentations in various conditions;
- interactivity – the ability to directly influence the course of the presentation.

The main advantages of using methodically correctly created multimedia presentations in the educational process include [10, p. 4]:

- increased expressiveness, visibility and spectacularity of the material;
- clear structuring of the material in accordance with the goal of the lesson;
- concise and concentrated presentation of selected and prepared material;
- creation of optimal conditions for the perception of the material, in particular through the design of individual slides and presentations as a whole.

Multimedia presentations can play different roles in the learning process, among which the following can be highlighted [10, pp. 13–14]:

- organizational – creates conditions for active work of the audience through the creation of problem situations, the need for comparison, organization of self-examination and self-control;

- illustrative – provides visualization of those data that are difficult or impossible to hear or reproduce directly in the classroom;
- reference – used to provide data that further discloses the content of individual elements of the topic, detailing it;
- structuring – provides clarity of perception of the material, its logical sequence and emphasis on the main provisions, conclusions, etc.

As a rule, it is more convenient for a person to perceive information presented in small, complete fragments. This way of presenting information is typical for multimedia presentations and is provided, on the one hand, by a small slide, which requires formulating data concisely, abstractly, in the form of marked text, and, on the other hand, by animation, which allows to display data step by step, in small fragments [10, p. 32].

According to Bobrovskaia [7], the use of multimedia presentation in an interactive mode provides an opportunity to manage learning using different teaching methods (problem-based, heuristic, research-based). The capabilities of multimedia presentations as a teaching tool are reflected in the principles of their construction:

- conciseness – placing only essential information objects in a concise form while maintaining maximum information content;
- structure – the design of the structure of the information object in a clear form that reflects its nature and easy to remember;
- autonomy – relatively separate information objects are placed on individual slides;
- generalizations – graphic information objects should not contain elements denoting unimportant details;
- unification – design of all information objects in a single style.

Ostroverkhova [67] identifies the following ways to implement the principle of systematicity and consistency:

- logical consistency in the formation of knowledge, skills and abilities of students (each element of educational material is logically connected with others, the next is based on the previous, is the basis for learning new, provides consistency of thinking, cognitive strength and potential);
- observance of logical connections between forms and methods of teaching, control of educational and cognitive activity of students and its effectiveness;
- development of skills for rational planning of educational activity (construction of logically coherent answer plans, performance of laboratory works);
- systematization and generalization of the ways of activity;
- coordination of students' activities in accordance with the requirements and actions of teachers of various subjects;
- identification and implementation of interdisciplinary and intradisciplinary links in the learning process;
- implementation of requirements for the acquisition of systematic knowledge of students about the object of study;

- implementation of systematic and consistent control of students' learning achievements.

Thus, the implementation of the principle of systematicity and consistency of learning requires the use of tools for planning learning activities and systematic and consistent control of students' learning achievements.

Control over the level of students' academic achievements – obtaining and processing data on the success of learning and mastering educational material. Monitoring of students' learning achievements is an integral part of the educational process. Its purpose is to identify the completeness, depth and quality of mastering the material of a particular topic, section or training course. It is a difficult task to control the mastering of the material in detail by each student of the class, so the test of knowledge and skills of students should be carried out using both computer-based and traditional forms of control, since each of them has its own advantages and disadvantages, which, when used together, can be eliminated.

The use of computers as a means of control provides an opportunity to organize preliminary, current or final control clearly, objectively and efficiently, and appropriate computer programs – to plan individual work to address gaps in knowledge, skills and abilities of students [45], monitor feedback, diagnose errors and evaluate learning outcomes.

Many scientific researches and developments are devoted to the problem of standardized test control of knowledge and legitimacy of the received results. Some aspects of this problem were covered in the works of Avanesov [3], Furnham [27]. This problem has become especially relevant with the introduction into the practice of assessing the knowledge of graduates of external independent assessment, which is carried out using pedagogical testing technologies or other pedagogical technologies to control the level of academic achievements [5].

At present, technologies and algorithms for compiling tests and test tasks of various types have been developed [3]. At independent development of tasks it is necessary to be guided by the following requirements of didactic value (compliance with standards of chemistry curriculum), validity (control and evaluation of that studied by high school students), trustworthiness (reproduction of results at repeated testing at this stage of training), representativeness (completeness of the material presentation), reliability (ease and simplicity of use, the presence of clear instructions for conducting and evaluating test results), standardization of the form (giving a certain form to tests and test tasks) and facetedness (multivariate presentation of information in tasks).

Test tasks developed in compliance with all requirements and rules, according to Pak and Toletova [70, p. 47], have a number of advantages:

a) the objectivity of data on the quality of students' learning achievements, associated with the absence of subjective factor in assessment;
b) diagnostic value associated with the possibility of statistical processing of large amounts of data, the separation of patterns;
c) saving time spent on creating tasks and checking a large number of students' works;
d) technologicity of the educational process associated with the automation of many operations of preparation and conducting knowledge control;
e) semantic advantage, which consists in the brevity and accuracy of problem formulation.

Integrated use of learning planning tools and tools for systematic and consistent monitoring of student achievement is possible in *learning management system* (LMS), such as Moodle. The characteristic features of Moodle include:

- presentation of training courses in the form of individual modules, which are interconnected not only logically but also functionally;
- thematic and calendar planning of the educational process;
- support for various forms of organization and teaching methods in the appropriate LMS tools;
- monitoring of students' learning and cognitive activity of students and control of its effectiveness;
- planning of students' learning activities, in particular, while performing virtual laboratory work;
- generalization and summarizing of acquired knowledge, skills and abilities;
- coordination of students' activities in accordance with the requirements and actions of teachers and among themselves with the help of LMS communication tools;
- storage and submission of samples of educational and research activities.

3.4. Principle of strength of knowledge acquisition

Implementation of the *principle of strength of knowledge acquisition* requires the integrated use of all tools of activation learning and research activities of students, leading of which are visual aids, means of practicing skills and abilities (simulators), tools for monitoring and self-control of educational achievements and virtual laboratories. The latter are a means by which the highest level of activity of educational and research activity can be realized – independent educational and research activity, which is performed in extracurricular time and considered in the context of self-education, self-improvement, self-affirmation [47].

Robinson [76] classifies *virtual laboratories* according to the source of information they contain. Laboratories of the first type operate only with a limited set of facts entered by programmers during development. In such programs, it is impossible to change the conditions of the experiment and get results that will differ from each other. The course of the virtual experiment and its results are usually presented by means of computer animation and the user has very limited influence on the course of the virtual experiment, which is limited to following instructions and prompts programmed by the developer, manual control of tempo of educational information or necessity of its repetition.

Virtual laboratories of the second type operate on facts that are the result of a mathematical model of a certain process and are based on theoretical ideas about it. Working with such programs allows to expand the range of possible user actions, including those that were not foreseen by programmers when creating a virtual laboratory [76]. Repeated experiments in such virtual laboratories can yield many different results depending on changes in the conditions of the experiment, but they will all be related by mathematical regularity. The possibility of wrong sequence of performance or inaccuracy in performance of separate actions by the user in the virtual laboratory is also admitted, but in this case results of experiment will be incorrect, which was observed at carrying out of natural experiment [59].

A essential advantage of virtual laboratories of the second type, such as Model Science ChemLab [54], Crocodile Chemistry [20], Virtual Lab [19], is the possibility of active student's intervention in the course of work: when performing a laboratory work student can repeat it many times, each time changing one or more parameters at own discretion. In most cases (if the student's actions do not contradict the logic of the experiment and are possible to perform in a real laboratory) the student will get the right results that will only emphasize the patterns, the discovery of which was the purpose of work [59].

In specialized chemistry education, work with virtual objects should be accompanied by work with relevant real objects or detailed commentary both in the computer program itself and by the teacher. Thus, when implementing the principle of strength of knowledge acquisition, it is advisable to use virtual laboratories at the stage of knowledge consolidation and in preparation for real laboratory work (as a simulator), as well as a means of ensuring visibility [34].

3.5. Principle of accessibility

The implementation of the *principle of accessibility* in the specialized chemistry training is to take into account the individual characteristics of students, which requires solving the problem of adaptation – learning individualization while maintaining the quality of the learning process in a given area of its values. This indicator of quality, according to Dovgiallo [24, pp. 68–69], there is a function of the knowledge quality assessment achieved by the student in the period between pre- and post-test, and learning time.

The automatic adaptation of the learning system to changing external conditions and maintaining the ability to effectively achieve didactic goals when the characteristics of the learner change is called adaptability. Adaptive systems are characterized, in particular, the program's focus on achieving a certain goal, obtaining information about external conditions in the process and using it to change their own behavior [46].

An adaptive curriculum is an instructional program in which the sequence of presentation and the nature of the teaching material depend on the learning history (data on the time of tasks and mistakes made) and individual characteristics of the student, including psychological characteristics. The implementation of an adaptive curriculum is impossible without solving the tasks of diagnostics (knowledge level, psychological peculiarities of the student, etc.) and optimization (in particular, the choice of the subsequent instructional impact) [41].

The task of learning process adaptation is solved with the help of adaptive automated learning systems and expert learning systems that generate such regulatory influences (ways of presenting the material, examples, cues), whose perception by the student leads to stabilization or improvement of current evaluations of his/her success in mastering the content of the instructional content. Using such systems, the teacher accumulates and processes the data necessary to determine the effective regulatory influence, after which the presentation of the educational material is adapted to the individual characteristics of the student [24, p. 69].

The theoretical basis for building adaptive automated learning systems is programmed learning, which Ball [6, p. 420] defines as a type of learning carried out in accordance with the curriculum, which controls both the amount of knowledge, skills and abilities to be mastered by students and how to organize them educational activities. This is achieved by dividing the training material into separate portions and intensive exchange of information between the student and the training software, which is carried out mainly in the form of "question – answer".

Programmed learning uses linear training software with a fixed sequence of portions of educational material and branched training software in which the sequence of portions of educational material depends on the student's answers to the task. It should be noted that programmed learning can be implemented not only with the help of software, but also with the help of programmed manuals in the traditional form – specially designed and compiled books [6]. Examples of such manuals are "Lehrprogramm Chemie" [65], "Basic Concepts in Organic Chemistry: A programmed learning approach" [83] and others.

Ball [6, pp. 422–423] notes that the use of programmed learning in many cases did not live up to expectations of a sharp increase in the effectiveness of education, but the use of computers to implement programmed learning will make it possible to avoid many of its inherent limitations and shortcomings.

Expert systems are widely used in natural sciences and engineering as an intellectual equivalent of an appropriate expert to solve a problem in cases when a human expert is not available. An expert system must contain a knowledge base – a set of rules and information from a certain area of knowledge, a data interpreter – a mechanism for obtaining necessary information from the knowledge base and formulating a logical conclusion, and an interface – software necessary for a dialogue with the user [82].

Expert systems are part of many chemical software: for example, ChemBio3D Ultra includes an expert system for the prediction of synthesis products CAMEO (Computer Assisted Mechanistic Evaluation of Organic Reactions) [71]. Some virtual laboratories and chemical calculators have properties of expert systems: for example, a virtual laboratory can act as an expert system, automatically selecting the necessary masses and volumes of reagents under incompletely defined reaction conditions. The main condition for implementing the principle of accessibility with expert systems is the function of explaining the way in which the answer has been obtained. Such a function can be implemented in expert learning systems that implement the functions of learning management, diagnosis of student errors and problem solving in a particular subject area, based on expert knowledge and showing expert-level results.

Expert educational system is an adaptive automated educational system used to achieve a certain learning objective, expressed through a certain set of student's characteristics – his/her competence. Based on the current state of development of student competence and teaching methods, a task is generated – a certain set of information requiring the student's response. The student's answer is compared with the reference solution and the characteristics of the student's model are adjusted based on the comparison. Based on the new characteristics, a new task is formulated – this sequence of actions is repeated until the learning objective is achieved.

The leading place in the structure of expert tutoring systems is occupied by knowledge bases: educational knowledge base in a particular subject area, knowledge base on possible student mistakes, knowledge base on the learning process, and the student model, which is formed by the initial testing of the student and contains information about the state of knowledge of the student and his/her process of learning. The purpose of learning is expressed in terms of the student model. In this regard, the training expert system can be represented as three expert systems that interact with each other: problem solving system, diagnosing student's errors and planning the learning management process [72].

Game software provide the student with a computer-based environment, a set of certain opportunities and tools for their implementation. The use of means provided by game software to implement the opportunities associated with the study of the game world and activities in this world, leads to the development of the student, the formation of his/her cognitive skills, self-discovery of patterns, relationships of objects of reality are of general importance. The use of computers as a learning tool allows in the training game to implement individualization of learning, to promote the implementation of didactic potential inherent in the game, to organize an environment for free search for solutions to the educational task set by the teacher [35, p. 553].

Chemistry educational games are represented by both local and online tools designed for use on personal computers, mobile devices, etc. Most of these tools are focused on actualization, applying and testing knowledge: quests, puzzles, charades, etc. But there are also games, in which scenario provides the opportunity to acquire new knowledge: in the form of tips, access to built-in directories, encyclopedias and more. The target audience of computer educational games in chemistry is also diverse – there are relevant software, the content of which is aimed at children of both primary school age and university students.

3.6. Principle of consciousness and activity of students

Implementation of the *principle of consciousness and activity of students* involves the use of tools aimed at enhancing educational activities, its organization and planning, increasing the personal significance of learning outcomes.

The use of ICT at the stage of students' acquisition of new knowledge provides an opportunity to use additional stimuli to focus attention even during frontal work with the class, to make material that in traditional forms of learning quickly tires students, emotionally rich and attractive [45].

In order for ICT tools to become a means of intensifying educational activities, it is necessary to form in students a stable cognitive motivation to solve educational and research problems, in particular, by means of computer modeling. The latter use both the multimedia capabilities of the computer and computational ones, which allows to monitor a certain process, influencing its progress by giving commands from input devices to change values of process parameters.

Consciousness of learning in the process of independent learning and research activities can be increased by using an intelligent interface – obtaining various references, explanations, recommendations, etc. [32] in the process of independent search and processing of educational information using intelligent search engines. Further increase in the level of students' consciousness in learning is associated with the transition to ICT tools to support independent work.

Such an approach, when students can show their initiative in the performance of work, has a positive effect on academic achievement and students' interest. But along with initiative, students can also engage their own imagination and try to perform such actions which were not provided by the scenario of the given work (for example, heat the solution to boiling, or cool it to freezing) just out of curiosity: it is safe to do so in computer simulation environment – so, in the virtual laboratory ChemLab one can use equipment, the use of which was not provided by the scenario of the work. The results of such unplanned actions can be transferred by students to the relevant objects and processes of the real world, and therefore virtual laboratories have always been strictly required to tightly comply with virtual objects and processes to real objects and processes. Virtual chemical laboratories are expedient to use in cases when it is impossible to conduct real chemical experiments due to lack of necessary reagents and equipment, duration of work, possible danger for students' health during work, etc., or in cases where working with a model of an object or phenomenon will allow to understand their essence and regularities of flow better. Testing the use of virtual chemical laboratories in the learning process showed an increase in cognitive interest of students in the real experiment, the development of their research and experimental skills, in particular the ability to observe, to highlight the main thing, to focus attention on significant changes, to choose the best algorithms for the experiment, to comply with safety rules [57].

Educational games in chemistry are also a means of enhancing students' learning activities. This is also achieved by increasing interest in educational game activities through the introduction of elements of competition (with other students, with intelligent software, with a previous level achieved). Of particular note are online learning games, which require the distribution of work between several participants to achieve the desired result.

An example of an *environment that enables specialized chemistry training*, both in game form and traditionally, is Open Wonderland – a virtual environment designed to support collaborative business or educational activities of users represented by avatars, in real time with remote access. The Open Wonderland environment allows to host graphics and video files, animations, web browsers, voice telephony tools, Java applets, various types of documents and other objects that the user can actively use to interact in a virtual environment. Lancashire [42] points out that a variety of chemistry software tools can be integrated into the Open Wonderland: virtual labs, simulation tools such as Jmol and JSpecView.

Such a virtual environment not only provides the possibility of distance learning, but also organizes and activates the users in different modalities. The use of virtual learning environments provides an opportunity to simulate quasi-professional activities of both individual students and student groups, contributing to the conscious choice of future profession. Given the opinion of Maksymenko [48, p. 30] that the learning process in the profile school should promote conscious choice of life path – the main mental neoplasm in adolescence, and its value is subjectively evaluated by student only in the context of planning his/her own future, respectively, the success of the educational task high school students, primarily as a confirmation of the effectiveness of their own actions, the correctness of individual-specific learning strategy, and activity strategy in general. The learning outcomes are considered by the student through the prism of their own future, their importance for the implementation of personal inclinations, plans, ambitions.

To effectively choose the future educational and professional trajectory, the student must receive sufficient information about possible options for their implementation in an accessible and emotionally attractive form. The most important means of obtaining such information are the media, in particular, popular science and career guidance resources on the Internet. Of particular importance is the possibility of using these tools to promote a certain field of science or field of professional activity for a large audience. Implementation of informational, educational and cultural-educational functions of television and the Internet allow students not only to obtain information about future professional activities, but also to make informed choices, corresponding to their own interests and inclinations, and increase personal motivation to learn and achieve goals.

An example of a multifaceted chemical Internet resource is the website of the popular science journal "Chemistry and Chemists" (http://chemistry-chemists.com). The site is a set of several interrelated, but separate content sections:

- actually popular science chemical journal, which exists only in electronic format and is freely distributed;
- a forum for exchanging experiences, discussions and debates on various topics in chemistry and other natural sciences;
- an archive of photographs from chemical laboratories, chemists' workplaces, chemical companies, etc.;
- a video archive of chemical experiments and its own YouTube channel, which are powerful tools for visualization of learning and promotion of experimental and research activities;
- a library of science books in electronic format and a collection of hyperlinks to library and chemistry resources;
- collections of scientific and chemical folklore: legends, songs, stories, and anecdotes.

The educational function is performed by the journal, the forum, and the electronic library; the function of popularizing science is implemented by almost all sections of the website; the career guidance function is primarily performed by the forum and the photo materials from chemical laboratories.

The program for specialized chemistry training of students of secondary schools [36] states that in specialized chemistry training self-education and self-improvement of students are of great importance. This should be facilitated by increasing the part of students' independent work, including work with computers and other sources of educational information.

The effectiveness of independent work, like any other activity, increases due to careful planning and clear organization. Modern ICT tools allow students to plan their own activities as well as those of their groups. Such tools include, first of all, time planning tools (electronic calendars, organizers, planners, etc.) that support the functions of creating records and reminders of planned events, and can be used both personally and in a certain group. Google Calendar and Microsoft Outlook Calendar are among the best known such tools.

A significant number of ICT learning tools, such as Moodle, are equipped with such tools as a calendar, notification window of upcoming important events, etc. Official websites of educational institutions, personal websites of teachers and faculty usually use these tools.

3.7. Principle of visualization

The implementation of the *principle of visualization* (clarity) implies the use of various visual aids in the learning process, conditioned by the laws of physiology of higher nervous activity and psychological laws of perception and aperception. The classification of ICT visual aids according by the data transmission channels allows dividing them into visual (moving and stationary models, diagrams, symbols, etc.), audial (synthesized or reproduced sound) and audiovisual (multimedia) [14, p. 397].

According to Fridman [26, pp. 21–22], clarity is not a property or quality of real objects or phenomena, but a property of mental images of these objects. It is an indicator of simplicity and comprehensibility of a mental image, which person creates as a result of the processes of perception, thinking, memorization and imagination, which depends on the characteristics of person, interests, inclinations, level of cognitive development and motivation. The formation of a visual image occurs only as a result of active work aimed at its creation. An important role in such work is played by *modeling*.

Moroz [56] defines model as the "objective, symbolic or mental (imaginary) system that reproduces, imitates or reflects some defining characteristics, ie the principles of internal organization or functioning, certain properties or attributes of the cognition object (original), straight, direct study of which for some reason is impossible, ineffective or impractical, and can replace this object in the process under study, in order to obtain knowledge about it". Models reproduce only the most significant features of a phenomenon or process, and the reproduction of these features must be adequate, ie the model must be isomorphic to the object under study.

The relation between the original and the model is not natural, but epistemological, due to the process of cognition, and is established by the researcher [56].

The creation, selection and application of models has one or more goals [26, pp. 25–26]:

- replacement of the object in a real or imagined process with a model, based on the considerations of convenience for carrying out activities in certain conditions (substitute model);
- creation of an idea of a real or imaginary object using a model (model-representation);
- model interpretation of the object (model-interpretation);
- research or study of an object by studying a model (research model).

When studying chemical concepts of macro- and microcosm, which cannot be observed directly, the use of models as means of visualization, implementation of the above goals of creation and application of models acquires special importance.

Modeling of static objects such as molecules, crystal lattices, single apparatuses or technological schemes of chemical production has been used in chemistry teaching practice for a long time and is provided mainly by material or character-symbolic models. Development of ICT tools created conditions for modeling dynamic objects – chemical processes and phenomena – through their visualization in real or model time.

According to Boltianskii and Savin [8, pp. 306–309], isomorphism and simplicity of perception are the main features of visualization. To create a means of visualization it is necessary to identify the main properties of the phenomenon under study (create its model), and adequately reflect these properties (make the model isomorphic to the phenomenon). Regarding the learning process, Fridman [26, pp. 76–77] points out that the requirement of isomorphism is "too strong, in most cases unrealizable and unnecessary, because having some similarity or analogy is quite sufficient".

According to Fridman [26, pp. 77–78], the content of learning at school should include mastering the modeling method, one of the general and most important methods of scientific cognition. Modeling is an important learning tool and action through which one can achieve a variety of learning goals and objectives that require the materialization of abstract concepts, highlighting the essential and generalization of educational material, reflection on their own learning activities, memorization of the structure and establishment of connections and relationships of the learning material. It is also advisable to acquaint students with the model nature of the phenomena and actions they study.

Many models can be created to illustrate the same phenomenon or object, using different approaches. But no type of model is completely universal. For example, to implement the principle of visualization in chemistry teaching, a large number of varieties of models of organic molecules have been created over the last century and a half: ball-and-stick model, Dreiding stereomodels, Barton models, Fieser models, Stuart-Briegleb models and more. Each of the models reflected certain characteristics of the modeling object: while the Dreiding models allowed to measure interatomic distances and calculate conformational energy, Stuart-Briegleb models provided an opportunity to visually estimate the spatial stress. Therefore, different types of models can be considered as complementary, and the most adequate models are selected according to the content of the educational task [21, pp. 7–12].

Computer models created by computer modeling tools also cannot be considered universal, but the absence of limitations inherent in most material models (fixed shape and size, destructiveness), make computer models a more flexible tool for implementing the principle of visualization. For example, a number of specialized computer programs, such as ChemBio3D, ChemDraw, ChemSite, RasMol, BIOVIA Draw, Symyx Draw, JChemPaint, ChemSketch, MarvinSketch, ChemPaster, etc. allow to create, view, store and explore two- and three-dimensional models molecules of any complexity in the optimal color and geometric display, to view the created models at any angle. Creation of models in such software enables to get necessary additional and reference information about the object or its separate components during viewing.

Similar advantages have computer models of macroobjects, such as complex laboratory facilities, industrial units, etc.

By method of visualization one can distinguish virtual chemistry laboratories which use two-dimensional, three-dimensional graphics and animation. By method of obtaining information from students, virtual chemistry laboratories are divided into those placed on electronic media and those placed on the websites of manufacturers or educational institutions on the Internet [57].

Fridman [26, p. 50] identifies as a teaching aid two types of modeling of educational material for better memorization by students:

- logical organization of instructional material and its presentation in a visual form;
- presentation of instructional material with the help of mnemonic means in the expection of the emergence of figurative associations.

Both types of modeling are implemented using specialized ICT tools for building diagrams, chemical editors, etc. or general-purpose ICT tools (text and graphic editors).

Visual aids are an important component of the system of teaching aids – the equipment of educational institutions, the use of which provides a direct impact on learning activities. According to Bykov [14, p. 401], didactic objects that affect the relevant human receptors have a direct influence on the learning activity, and technical learning tools ensure the existence, storage, processing, transmitting and the possibility of using appropriate didactic objects in the educational process.

Among the visualization tools Bykov [14, pp. 403–414] singles out such ICT tools by the subject of didactic influence as subject-image (figurative, iconic and figurative-sign didactic objects realized in audio, visual and audiovisual form) and subject-information resources (teaching aids, which is a specially encoded, structured and ordered set of information objects described in the language of a particular computer or their class, and/or corresponds to the protocol of computer tools and technologies of computer networks). Together, they refer to *electronic educational resources*, EER (E-Learning Resource, ELR) – a type of teaching aids used for informational and procedural support of didactic tasks (or their fragments), aimed at implementing the educational function of the education system, existing in electronic form, placed and submitted to educational systems on electronic data storage devices are a set of electronic information objects (documents, documented information and instructions, information materials, procedural models, etc.) [17, p. 2]. Their use allows for flexible and adaptive formation of static and dynamic didactic objects, interactive interaction of educational process participants, visual presentation of information objects (in audio, visual and audiovisual forms), control of external standard and special devices included in laboratory kits and complexes [14, pp. 414–415].

Electronic didactic demonstration materials are electronic educational resources, used to demonstrate (visual representation, visualization, visual-sound representation) of individual phenomena, objects, processes being studied, in order to deepen their understanding by enabling them to observe the student [17, p. 4]. Examples of such materials in the specialized chemistry training can be models of chemical utensils and models of devices in virtual laboratories or chemical editors (ChemSketch), models of operating chemical plants (electronic visual libraries).

For creating, storing, editing and reproducing didactic objects of visual ELRs such as portraits of chemists, images of chemical equipment and processes, pictures, diagrams, animations, diagrams, drawings, text, formulas etc, are used programs of office packages, libraries of electronic presentations on chemistry, image and photo processing programs, editors of chemical formulas (ChemSketch, ChemDraw, Marvin Beans, BIOVIA Draw), software and educational complexes of chemistry ("Chemistry, Grade 9", "Organic Chemistry, Grades 10-11"), electronic periodic systems (PL Table, "Periodic Table 2022: Chemistry"), etc.

To create, store, edit, and reproduce didactic objects of audio-visual ELRs, such as animations, video recordings, movies, programs for audio and video processing and reproduction, tools for creating multimedia presentations, libraries of electronic visual aids, and software and methodological complexes of educational purposes in chemistry, etc. are used.

Table 1 shows the main types of ELRs used to implement the principle of visualization in the specialized chemistry training. Additional types of ELR to ensure visualization are electronic educational data, electronic educational and methodological materials, electronic program and methodological materials, electronic additional scientific and educational materials [17, pp. 8–9].

At the present stage of ICT development, the leading ones are *networked ELRs* – a coded description of an ordered set of electronic objects that exist and are stored in computer networks, as well as electronic address, which is used together with a computer to solve a certain didactic task or its fragment [14, p. 415].

Examples of networked ELRs for specialized chemistry training are virtual laboratories (ChemCollective Virtual Labs, LiveChem, electronic edition "Chemistry. Grades 8-11. Virtual laboratory"), electronic textbooks and reference books, chemical websites etc.

The following visualization tools are used in specialized chemistry education: computers,

Table 1
ELRs for implementing the principle of visualization in the specialized chemistry training.

ELR type	Implementation of the principle of visualization
educational electronic editions handbook electronic editions demonstration electronic editions electronic educational and methodical complexes	visual and audiovisual electronic didactic demonstration materials, simulation visual models
computer-based training laboratories	remotely controlled physical objects, simulation visual models
simulating electronic editions	simulation visual models

projectors, multimedia boards, cameras (photo, video, web, document, etc.), etc.

3.8. Principle of linking learning to practice

The implementation of the *principle of linking learning to practice* in the specialized chemistry training involves the use of chemistry methods to solve problems with practical and industrial content, laboratory work and other educational research.

The use of ICT tools expands opportunities for students' practical activities in class and in extracurricular activities, giving students the opportunity to use in practice the acquired theoretical knowledge, even in cases where the phenomenon or process being studied is not directly available.

Many types of ELRs purposes are used to support the practical activities of students in the specialized chemistry training , the most important of which are listed in table 2.

Demonstration electronic publications include materials of electronic journals of the relevant subject area, popular science information sources in electronic form, educational and popular science films of industrial content and appropriate presentation materials.

The functions of electronic workshops and simulators are performed by the following electronic publications: "Chemistry. Grades 8-11. Virtual laboratory", "Virtual chemical laboratory. Grade 11", "Chemistry. Virtual laboratory. Simulators", program-methodical complex "Interactive creative tasks. Chemistry. Grades 8-9", Open Wonderland virtual environment, IR Tutor, some game and test programs, etc.

The functions of computer-based learning laboratories and simulation modeling editions are performed by the following software products: ChemLab [54], Crocodile Chemistry [20], Virtual Lab [19], chemical section of PhET Interactive Simulations, VirtuLab and Wolfram Demonstrations Project.

The functions of modeling editions are performed by the following software resources: Cortona3D, LabVIEW, HyperChem, etc.

As programs necessary for solving problems of a certain class, automation of calculations, processing the results of the experiment, etc., i.e. the subject package of applied programs can be considered: chemical calculators (CHEMIX School, ChemMaths and online chemistry calculator (https://allcalc.ru/taxonomy/term/1)), electronic laboratory journals (https://www.

Table 2
ELRs for implementing the principle of linking learning to practice in the specialized chemistry training.

ELR type	Implementation of the principle of linking learning to practice in the specialized chemistry training
electronic workshop simulator software	practical tasks and exercises for consolidation of competencies, practical skills and application of theoretical knowledge, self-training
computer-based learning laboratory	research with remotely controlled objects, mathematical, informational and simulation visual models
simulation modeling editions	computer modeling tools to change (control) individual structural and functional characteristics of the model
modeling editions	tools for building and researching models
subject packages of application programs	programs for solving problems of a certain class, automation of calculations and other similar operations
demonstration electronic editions	visual representation of ways of applying methods and means of chemistry to meet the mankind needs

dotmatics.com/products/studies-notebook/) and specialized computer modeling tools.

The most complete functions of all types of ELR implementation of the principle of linking learning to practice in specialized chemistry training are implemented by virtual chemical laboratories, which provide the following opportunities:

- safe research;
- repeated performance of experiments, which might be labor-consuming or time-consuming in a real lab;
- familiarization of students with the technique of performing experiments, chemical utensils and equipment.

Semerikov et al. [81], Teplytskyi [84] has shown that computer modeling in the environment of spreadsheets is an effective means of developing the creative abilities of students, which allows a large number of different calculations using a powerful set of built-in functions and user-created formulas, obtaining data samples that meet certain criteria, visually presenting calculation results with graphs and charts, performing statistical analysis of data and examining the influence of different factors on them. The main advantage of spreadsheets over specialized modeling tools is the ease of use of data processing tools and the step-by-step (in rows and cells of the table) presentation of each stage of data processing. In addition, the use of spreadsheets usually does not require the user to have special training in programming.

3.9. Principle of individualization

The *principle of individualization* acts both as a general didactic and as a principle of specialized training and provides direction to take into account individual characteristics and creating conditions for the development of each student, which is the basis for the implementation of personality-centered learning in specialized school.

One of the disadvantages of using a computer in the learning process, according to some researchers, is the disruption of direct communication between students and the teacher. But often the teacher's productive communication in the classroom is only with individual students, while others may be distracted by other activities. Using a computer allows the teacher to transfer some teaching functions to it, which frees the teacher from some reproductive forms of organization of training and provides more attention to the individual approach to each student [4, p. 16].

Komissarova et al. [38] define individualization of learning as such an organization of the educational process in which methods, techniques, the pace of learning are selected based on the level of development of learning abilities, preparedness and other individual differences of students.

Individualized learning is based on the student's model and provides learning influences based on this model. Individualized learning provides an opportunity to most effectively organize the learning process through the optimal distribution of learning time, organization of educational material in accordance with the characteristics of the student and the choice of adequate teaching methods and features of student learning management [38].

The availability of modern computing devices allows each student to work with them individually or in small groups at a comfortable pace and with the ability to choose the level of complexity of the material.

Individualized learning can be organized in three modes:

- the choice of learning influences is entirely computer-driven;
- the way of controlling the learning process is chosen by the students;
- mixed management of the educational process.

Adequate selection of learning influences in the implementation of individualized computer-assisted learning is based on a dynamic model of the student's personality and activity, taking into account intellectual, emotional-personal and motivational-demand characteristics.

Komissarova et al. [38] identify four main groups of characteristics of the psychological portrait of students, which can have a significant impact on the learning process and require adaptation of the educational system:

- personal factors (intelligence, extraversion / introversion, anxiety, creativity);
- cognitive styles (field independence, suggestibility, critical thinking, imagery, rigidity, operational / conceptual learning);
- learning strategies (heuristics / systematicity, serialism / holism);
- subjective structure of knowledge (inference rules, schemes, semantic network).

One of the essential features of individualized computer-based learning is the constant feedback between the computer and the user. Students have a certain freedom of action, which creates the preconditions for the formation of personal cognitive style. Being able to work with a computer individually also reduces the psychological burden of fearing the wrong answer, which will be assessed by the teacher and other students: a certain confidentiality of intermediate results makes the learning process more comfortable.

The learning process can be considered individualized if:

1) each student has his own automated workplace (stationary or mobile), equipped with an interactive terminal (usually with network access);
2) educational programs provide an opportunity to implement complex algorithms for multicriteria assessment of knowledge, skills and abilities, diagnosis of the state and behavior of the student and have a developed tools for decision-making on learning management;
3) communication tools provide an opportunity to provide a dialogue with the student in a particular subject area in natural language.

Individualized learning can be organized based on the use of automated and expert learning systems [38]. A representative of automated learning systems is the Moodle system – a software package for creating and managing e-learning courses.

The Moodle system has a wide range of tools for organizing and supporting learning, including advanced tools for learning communication between course participants. Voronkin [90, p. 120] notes that Moodle provides an opportunity to implement active and group teaching methods, provided by available pedagogical tools with a variety of methodological equipment: reference, information, communication, control, management, collection, processing and storage of data on the course. Such a wide set of tools provides the opportunity to flexibly plan and control the learning process, distribute, collect and test tasks, coordinate students' activities by choosing individual learning strategies for each student.

The theoretical basis for the creation and application of e-learning courses in Moodle are the pedagogical principles of social constructivism [25]:

1. *Organization of learning through research.* According to this idea, it is possible to qualitatively improve and quantitatively speed up the process of cognition, if you organize it as an interaction of students with specially designed objects and modeling environments.
2. *Designing learning and research communities.* Building communities is important for collaborative learning research. For this purpose, in addition to learning objects of different complexity and other material for research and experimentation, it is necessary to create communities of learning process participants by constructing such rules of its internal social interactions, which will provide new dimensions to the learning process and thereby enrich it. The study material should be designed in such a way that a special distribution of roles and research activities of the students is possible in relation to it. The distribution should reveal the essential characteristics of the reality to be taught and create opportunities for joint meaningful discussions to deepen the understanding of the object or process under study.
3. *Personality orientation.* The modern approach to understanding the learning content defines it as an activity aimed at improving the system of personal constructs of students, so the learning content is personality-oriented and is formed by a teacher together with students in their personal movement along individual learning curves.
4. *Saturation of the educational space with knowledge carriers* – the availability of a variety of literature (not only textbooks), possibility of work with experts (not necessarily with

professional teachers), with telecommunications networks (Internet, local electronic resources), organization of visual and practical activities (work with laboratory equipment, with artifacts of culture, real productive activities), etc. The rich educational environment allows each student to acquire the experience of activity necessary for the development of personal construct system and to build his/her own educational trajectory.

5. *Cooperation* – the teacher is not so much a "knowledge holder" as an equal partner in educational communication. An important component of the principle of cooperation is that each participant of the educational process (including the teacher) has a personal status, which is unequal and dynamically changing in different components of the educational process. It is customary to distinguish four levels of this status: visitor (guest), client, permanent member of the group for classes, expert (status is not assigned, but naturally determined by the educational community itself, so that the same person may have different statuses in different situations). Another component of the principle of cooperation is the monitoring of personal educational achievements, and it is not about the assessment of the student by the teacher, but about the mutual evaluation of achievements by the educational community.

The system, which implements the above principles, is open and aimed at forming a system of competencies.

Golenova and Zhukova [30] emphasize that the use of Moodle to manage the learning process provides:

- multivariate presentation of educational information;
- interactivity of learning;
- creation of a constantly active reference system;
- repeated repetition of training material;
- automation of control of learning outcomes;
- creating and maintaining of students' portfolios;
- regular monitoring of the activity and content of students' work;
- extensive opportunities for communication;
- analysis of learners' needs.

The advantages of Moodle are free distribution, multilingual interface, cross-platform, openness, the ability of users to participate in the development of new and improvement of previously created tools and applications of the system. Due to the listed features, Moodle contains not only general-purpose tools, but also tools specific to each academic discipline, and this set is constantly replenished by new developments of users [37].

In order to effectively support chemistry learning activities in Moodle, support for specific components such as chemical language and chemical experiments is required. Chemical language is a set of chemical nomenclature, terminology and symbols, the rules of their composition, transformation, interpretation and operation. If such components of chemical language as chemical nomenclature and terminology can be easily reproduced by standard means of presentation of text information, chemical symbolism usually requires the use of special software to reproduce its components such as chemical formulas (especially electronic, structural and display ones), symbols for writing chemical equations, etc.

Since one of the most important functions of chemical language is the function of reality reflection, the chemical language ha found its continuation in modeling the structure of matter and its structural elements – it became possible to carry out transition from structural and display formula of substance to volumetric model of molecule or crystal lattice (3D visualization of formula).

It is impossible to avoid using chemical symbols not only when creating a text or multimedia support for chemistry training material, but also when creating tests to check the level of knowledge of chemistry.

To ensure the effectiveness of using chemical language in creating chemistry courses Moodle provides a number of tools, of which it is possible to highlight the following [64]:

- Chemistry editor (https://moodle.org/plugins/atto_chemistry) – an add-on to the Atto editor, which is a convenient tool for creating records of virtually all common types of chemical equations: molecular, ionic, thermochemical, nuclear reaction equations and reversible chemical processes; contains a built-in periodic table of chemical elements, as well as a set of functions to create specific components of chemical texts: ion charges, proton and nucleon numbers, arrows, etc., but does not provide the ability to create and edit electronic, structural and display chemical formulas;
- EasyChem Chemical Structure and Equation Editor (https://moodle.org/plugins/atto_easychem) – an add-on to the Atto editor that provides the ability to create chemical formulas in HTML format; it contains a set of ready-made templates of chemical formulas and structures, which is sufficient to meet most needs of the user, who creates text using chemical symbols, but does not have the function of creating three-dimensional structures of molecules;
- Chemical Structures and Reactions Editor (https://moodle.org/plugins/view/atto_structure) is an add-on to the Atto editor that uses the Chemaxon's Marvin JS software package (https://chemaxon.com/products/marvin-js) and provides the ability to create electronic and structural formulas of substances (including their three-dimensional reflections), mainly organic molecules, as well as schemes and equations of reactions involving them;
- ChemRender filter (https://moodle.org/plugins/filter_chemrender) – a filter for embedding interactive 3D molecular structures that allows to upload ready-made files of 3D models of molecules or crystal structures and integrate them into the appropriate page of the training module;
- Java Molecular Editor (https://moodle.org/plugins/qtype_jme) – a question type that requires the student to draw a molecule in response to a question using a special editor;
- EasyOChem (https://moodle.org/plugins/browse.php?list=set&id=59) – software for interactive learning and teaching chemistry, which includes some plug-ins include specially designed types of test tasks that involve working with chemical formulas:
  - Newman Projections (EasyONewman) – test tasks for recognizing and interpreting Newman projections for organic molecules, which supports different settings to create and view the conformations of molecules in different perspectives;
  - Electron Pushing / Curved Arrow (EasyOMech) – a task to test students' knowledge of the mechanisms of chemical reactions, which is the need for interactive choice of the direction of transition of electron pairs, radicals, ions, etc.;

– Drag and Drop Organic Chemistry Nomenclature (EasyODDName) – a question type designed to improve the understanding of IUPAC rules on the compilation of organic compound names;
– 2D/3D Structure Display Short Answer (EasyOStructure) – a short answer question type that involves the interpretation and analysis of the structural formula of an organic molecule, provided in a special window in planar or three-dimensional display;
– Select Atoms or Molecules (EasyOSelect) – allows one to create questions using structural formulas of molecules or reaction schemes, the answer to which is the choice of individual atoms, chemical bonds and other structural elements of molecules according to the wording of the question;
– Fischer Projections (EasyOFischer) – the student must create a Fischer formula for an optically active organic compound, given in this type of question, by dragging atoms or groups of atoms into a specially prepared template;
– Lewis Structures (EasyOLewis) – allows one to create tasks that requires the student to correctly place electron pairs and unpaired electrons in the formula according to the task;
– Name to Structure or Reaction (EasyOName) – with Chemaxon's Marvin Applets one need to draw the structure of the molecule of the substance or a given reaction scheme;
– Spectra Filter (Chemdoodle) – a filter for Moodle that converts links to JCAMP-DX files into interactive images of the spectra of substances.

In the Moodle system we also introduced tools to support the most important component of chemistry learning and research activities – an experiment, in particular, a model chemistry experiment. Such tools include a plugin (filter) VlabEmbed, which we developed in 2015 and which allows to embed the freely distributed ChemCollective Virtual Lab into the pages of Moodle course. Virtual Lab has the ability to model experiments in many areas of chemistry: analytical, physical, biochemistry, etc. The filter includes a localized version of Virtual Lab in Ukrainian (both the interface and the repository of laboratory works are localized) [61].

3.10. Principles of differentiation and social balance

Complementary to the principle of individualization is another principle of specialized training – the *principle of differentiation*, which is to provide conditions for voluntary choice of students' profile, based on their cognitive interests, abilities, achieved learning outcomes and professional intentions. In a broad sense, the differentiation of learning is understood as a form of taking into account the individual characteristics of students in the learning process based on their division into characteristic typological groups on various indicators (level of learning opportunities, performance, pace of learning, cognitive interest, etc.).

The implementation of the principle of differentiation in the conditions of variability and diversity of chemical education raises the problem of providing specialized training for students of small groups and those students who have chosen a profile that is not available in the school. To solve this problem the *principle of social balance* provides coordination of three positions:

possibilities of educational services, demands of the labor market and social expectations of school graduates.

Ensuring the educational needs of students through the implementation of the last two principles is proposed through *distance learning* – individualized process of acquiring knowledge, skills, abilities and ways of cognitive activity, which occurs mainly through the mediated interaction of remote participants in a specialized environment, that operates on the basis of modern psychological and pedagogical and information and communication technologies.

The purpose of distance learning is to provide educational services through the use of modern ICT in education at certain educational qualification level in accordance with state educational standards, and the objectives are to provide citizens with the constitutional right to education and professional development regardless of gender, race, nationality, social and property status, type and nature of occupation, worldviews, religion, health, place of residence according to their abilities [52].

Bykov [12], emphasizing the versatility and scope of distance learning, highlights among others the following characteristics:

- distance learning is a form of education that creates conditions for students to freely choose the composition of academic disciplines, teaching staff in each of the disciplines and a particular educational institution;
- distance learning is adaptive to the basic level of knowledge and specific learning objectives of students;
- distance learning is focused on strengthening the active role of learners in their own education (setting educational goals, choosing dominant directions, forms and rates of learning), which makes it possible to solve specific problems related to the development of creative component of education and difficult to achieve according to traditional learning technologies;
- distance learning technologies together with traditional ones (textbooks, other teaching aids) create a distributed learning environment accessible to a wide audience of users.

A modern type of distance learning is e-distance learning (electronic distance learning, e-learning), which Bykov [12] defines as "a type of distance learning in which participants in the educational process carry out mostly individualized educational interaction both asynchronously and synchronously using electronic transport systems for the delivery of teaching aids and other information objects".

Melnychenko [49] notes that the distance form of learning changes the roles and content of activities of both teachers and students. In particular, the process of distance learning orients students to mostly independent, creative search, promotes the formation of skills to independently acquire knowledge and apply them in solving practical problems using ICT tools. Teachers must have a high level of proficiency in modern pedagogical and information and communication technologies, methods of creating and supporting a distance learning environment, be creatively active and motivated to constantly improve their skills.

In general education institutions, the implementation of distance learning requires the availability of appropriate staffing and system support, which is not always available, especially in understaffed schools. According to Bykov [15], it is effective to transfer the authority to provide distance learning to external data processing centers (ICT outsourcing). This enables schools to avoid regular updating and upgrading of their own ICT infrastructure, reduce the number of their own ICT services and the requirements for the professional competence of their staff, and, as a result, considerably reduce the overall cost of providing distance learning.

In this context, it is advisable to widely use ICT outsourcing in the process of education informatization based on cloud technologies, in the course of which the education system acquires new qualitative properties integrated through the creation of modern organizational and technological conditions for the activities of all participants in the educational process and improving the quality of educational services [15].

In order to organize distance learning, general education institutions may create classes (groups) with a distance form of training [53]. This creates conditions for the implementation of specialized training in distance learning, in particular, in rural areas, in the absence of students to form a class, etc. [39], as well as in single-profile schools to ensure the choice of another profile by individual students (or, at the student's request, the opportunity to simultaneously receive education in two profiles).

3.11. Principles of variability and flexibility

The essence of the *principle of variability*, complementary to the principles of differentiation and social balance, in the multilevel curricula, educational programs, educational content, the use of various technologies, providing students with the opportunity to choose freely studied subjects (courses), changes in activities, using an integrative approach in the study of subjects. The further development of this principle is the *principle of flexibility*, which essence in providing opportunities and conditions for changing the learning profile, content and forms of organization of specialized training, including distance learning, a wide choice of curriculum content and opportunities for its correction.

The implementation of these principles requires the use of ICT tools that provide adaptive multilevel learning, support for various pedagogical technologies (including game-based, project-based, etc.) and a variety of ways to deliver and present learning materials.

3.12. Principle of continuity

The *principle of continuity* implies the relationship between pre-profile training (secondary school), specialized training (high school) and vocational training. In the ICT-based chemistry teaching, this principle can be implemented in two ways:

1) "bottom-up", when the same ICT tool is used at both the previous and next level of training (e.g., mastering general-purpose spreadsheets in pre-profile computer science training, in profile chemistry training are used as a tool for processing experimental results, and in professional chemical training also as a modeling tool);
2) "top-down", when the ICT tool used to provide a higher level of training is methodically adapted for use at a lower level (e.g., computer modeling tools used in vocational training to investigate molecular structure and dynamics can be used in specialized chemistry training to visualize and animate them as a means of visualization.

3.13. Principle of diagnostic and prognostic feasibility

The *principle of diagnostic and prognostic feasibility* is to identify the abilities of students for a sound orientation to the profile of study and further professional self-determination. In the "Concept of profile education in high school", career guidance diagnosis is one of the leading forms of psychological support of specialized training aimed to identify interests, aptitudes, abilities and professionally important personality traits in the context of students' professional self-determination. Career guidance diagnostic techniques help to assess the level of readiness for educational and professional prospects. Interviews in career guidance offices are among the main forms of pre-profile training of students [51].

Most often, psychological career guidance diagnosis consists of testing, interviewing, or surveying. Based on the interpretation of the results of these activities, a conclusion is made about the student's aptitude to a particular area of human activity, certain professions and so on. As the procedure of testing and interpretation of results can be easily automated, a large number of such diagnostic career guidance activities are carried out using ICT (partially or fully), including network (the latter provide the opportunity to organize mass testing).

Among the resources aimed at the professional diagnosis of students and entrants, it should be noted:

- "Proforientator-UA" (https://proforientator.com.ua/ua/) is designed for students, graduates and entrants aged 13-18 years, which consists of: computer testing (in the computer class, duration about one hour), obtaining the results of the test in print and individual counseling (personally qualified psychologist in the presence of parents, lasting about one hour), which can be organized online;
- "Career guidance platform of State Employment Service" (http://profi.dcz.gov.ua/tests/) is designed to provide career guidance services remotely: the registered user has the opportunity to receive free career guidance services in an online format without visiting the employment center and to make his own career guidance in case of need: choosing (changing) a profession; choice of future direction for vocational training; determination of the aptitude for entrepreneurial activities evaluation of own abilities and skills (soft skills); self-development.
- "Proforientator.info" (http://proforientator.info/?page_id=100) propose a 3 groups of tests:

  1) tests to determine in which profession you would *want* to work: differential diagnostic questionnaire; professional diagnostic questionnaire; J. Holland's test for determining professional personality types; method of studying motives for choosing a profession; method of determining the motives for choosing the field of labor activity; methodology "Map of interests"; methodology for determining the type of profession (according to E. A. Klimov);
  2) tests to determine a *capacity* for certain professions: H. Eysenck's method of studying temperament; method of studying characterological traits of an individual; methodology for determining professionally important personality traits;
  3) tests to determine which professions you have *abilities* for: method of determining a person's general creative abilities; method of studying special human abilities; method of studying the individual's volitional organization.

3.14. Principle of effectiveness

According to Pak [69, p. 59], the principles of learning also includes the *principle of effectiveness*, which implies the transition of knowledge into beliefs and actions in the process of productive interaction of learning participants. This principle reflects the competence approach to teaching chemistry. Based on the essence of the principle, it is advisable to use ICT tools to support collaborative learning and research activities for its implementation in specialized chemistry training:

1) *tools for synchronous* (text, audio, video chat, etc.) *and asynchronous* (e-mail, forums, voice-mail, SMS, etc.) *educational communication*;
2) *LMS tools for educational communication* (in asynchronous and synchronous modes), conducting educational web conferences (webinars, virtual classes, etc.);
3) *tools to support for collaborative learning and research activities*, which provide the opportunity to create documents, provide access to them, edit, track the history of changes, save and synchronize them.

At the current stage of ICT development it is advisable to use tools to support collaborative learning and research activities using one of the cloud access models. Models are most often used in specialized chemistry education:

- SaaS (Software as a Service), in which the program runs on a remote server, and the results of its work are provided to the user through general-purpose client software (usually a web browser) or specialized software;
- DaaS (Desktop as a Service), in which the client software provides the user with access to the source interface of a program (or several programs) running on the server.

Their use enables a certain group of users to work together and edit documents using browser-based, mobile, and other clients in both synchronous and asynchronous modes. Multifunctional representatives of such tools include Google Drive, OneDrive, which provide the ability to create, edit and save text documents, spreadsheets, presentations, survey forms and more. Among cloud-based ICT tools designed to support only one type of activity in the educational process are tools for creating diagrams, charts, mind maps (MindMeister, LucidChart), tools for creating presentations (Prezi, Canva), tools for creating posters (Piktochart, Stencil), tools for working with images (Pixlr, piZap), etc.

Document-sharing tools include wiki and their analogues – websites or databases developed by the user community by enabling users to add and edit content [44], as well as systems that support simple and accessible way to create hypertext and encourage individual and collective creation [25, p. 29]. The use of wiki in the educational process provides an opportunity to organize individual or group work of teachers and students, organize a comprehensive study of individual theoretical issues and create an encyclopedic knowledge base in a particular field of science, the opportunity to discuss content formatting and design, tracking the activity of participants who jointly create content, involving students in working with ICT, etc. [31].

Among the Ukrainian-language wiki, there are several educational projects – in addition to Wikipedia, these are Wikiversity, Wikibooks, Wikiquote, Wikisource, etc.

A representative of collaborative software tools is GitHub, which we used to develop the VlabEmbed filter (https://github.com/ssemerikov/moodle-filter_vlabembed) for the Moodle LMS [61].

4. Method

Thus, to ensure the implementation of the principles of specialized chemistry training, ICT tools are used, which can be divided into two groups:

1) general purpose ICT tools:
   - *virtual learning environments* (Open Wonderland, OpenSim etc.) – Internet resources to provide collaborative learning activities of users represented by avatars, in real time with remote access;
   - *graphic editors* (Paint, Paint.NET, GIMP, 3ds Max, Blender, Photoshop, CorelDRAW, etc.) – software for creating and editing images, photo effects and artistic compositions;
   - *expert systems* (CLIPS, eXpertise2Go, etc.) – software for obtaining an expert opinion or assessment in a particular field of knowledge, based on certain source data;
   - *electronic laboratory journals* (Electronic Lab Notebook, etc.) – software for entering, formatting and saving data obtained as a result of the experiment;
   - *spreadsheets* (Microsoft Excel, Collabora Online Calc, Google Sheets, Gnumeric, etc.) – software for organizing, storing and processing data in tabular form;
   - *audio and video processing and playback tools* (VirtualDub, iMovie, Blender, Audacity, OBS Studio, Movie Maker, MPlayer, etc.) – software that allows you to edit, convert and play audio and video files in various formats;
   - *tools for viewing e-books* (CoolReader, DjVu Viewer, FBReader, eBoox, etc.) – software for viewing printed publications in electronic formats;
   - *tools for building relationships diagrams* (Coggle, Xmind, Freemind, etc.) – software for creating and saving relationships diagrams;
   - *authoring tools* (Adobe Captivate, Lectora, Articulate Storyline 360, SAP Litmos LMS, Cognitive Tutor Authoring Tools, etc.) – tools for developing the content of e-learning courses: e-textbooks, e-lab workshops, tests, reference books, auxiliary learning materials based on Internet technologies;
   - *tools for synchronous and asynchronous educational communication* (e-mail, forums, voicemail, SMS, etc.; text, audio, video chats, etc.) – software for exchanging text, audio and video messages between users;
   - *tools for career guidance diagnostics* ("Proforientator-UA", "Career guidance platform of State Employment Service", "Proforientator.info", etc.) – software for determining personal inclinations and preferences of students regarding branches of knowledge and future areas of activity by testing;
   - *tools for control and self-control of educational achievements* (MyTest, MultiTester, UniTest System, Hot Potatoes, etc.) – software that contain a system of tasks and automate procedures for control, processing and analysis of its results;

- *tools for planning educational activities*: electronic calendars, organizers, planners (Google Calendar, Zoho Calendar, LeaderTask, Outlook, etc.) – software for planning and organizing personal and collaborative activities, efficient allocation of working time and coordination of deadlines for individual stages of research;
- *tools for conducting educational web conferences*: webinars, virtual classes, etc. (WizIQ, BigBlueButton, Microsoft Teams, Google Meet, etc.) – tools for distance learning by providing remote communication between participants of the educational process in real time;
- *multimedia presentation creation tools* (Apache OpenOffice Impress, PowerPoint, Prezi, Photopia, etc.) – software to create, edit and save multimedia presentations in the form of a sequence of slides;
- *general-purpose search engines* (Google, Bing, Petal Search, META, Mojeek, Gigablast, Sogou, etc.) – tools for finding information in the World Wide Web;
- *learning management systems* (Moodle, Dokeos, Blackboard Learn, etc.) – software for the development and dissemination via the Internet of structured learning materials (courses) with the possibility, in particular, to support distance learning;
- *database management systems* (MySQL, Microsoft Access, LibreOffice Base etc.) – software that provides the ability to create, update and administer databases, to process queries to them, as well as collect and analyze user data;
- *text editors* (Microsoft Word, LibreOffice Writer, LyX, etc.) – tools for creating, editing, formatting and printing texts;
- *cloud-based tools for support collaborative learning and research activities* (Google Drive, Dropbox, OneDrive, etc.) – Internet document repositories and Web-based tools for their collective viewing and editing.

2) ICT tools for specialized chemistry training:
   - *adaptive automated chemistry learning systems* ("Lehrprogramm Chemie" [65], "Basic Concepts in Organic Chemistry: A programmed learning approach" [83], etc.) – programmed chemistry learning tools that automatically adjust to the individual characteristics of the learner;
   - *virtual chemical laboratories* (Model Science ChemLab, Crocodile Chemistry, Virtual Lab, LiveChem, "Chemistry. Grades 8-11. Virtual laboratory", chemical section of PhET Interactive Simulations, VirtuLab, Wolfram Demonstrations Project, CHEMIST, etc.) – tools for visual simulation of the flow chemical experiments that allow the user to manipulate virtual chemical equipment [60];
   - *electronic periodic systems* (PL Table, Ptable, The periodic table of the elements by WebElements, Periodic Table, etc.) – electronic versions of the periodic table of elements with multimedia presentation of information about them in different modes ;
   - *computer modeling tools for chemical processes* (HyperChem, MOPAC, etc.) – software for quantum chemical modeling, molecular mechanics and dynamics, calculation of structure, spectra, etc.;
   - *chemistry educational games* (chemical section of PhET Interactive Simulations, "Balancing Chemical Equations", "Chemical elements", Chembridge, Chemroul, etc.) – computer games that use knowledge of chemistry as a story basis;

- *popular science and career guidance chemical Internet resources* (online versions of chemical journals, "Chemistry and Chemists", specialized YouTube channels, websites of scientific and educational institutions, chemical sites (ACS Education, XuMuK.ru, chemie.de, CHEM4KIDS.COM Chemistry Stack Exchange, Chemical Book, etc.) – online versions of chemical journals, specialized YouTube channels, sites of scientific and educational institutions, chemical sites, etc., which promote chemistry and professions related to it;
- *program-methodical complexes for chemistry education* ("Chemistry, Grades 8-9", "Chemistry, Grade 9", "Organic Chemistry, Grades 10-11", "Periodic Table 2022: Chemistry", etc.) – complex of educational software to support chemistry teaching;
- *simulators and electronic workshops* ("Chemistry. Grades 8-11. Virtual laboratory", "Virtual chemical laboratory. Grade 11", "Chemistry. Virtual laboratory. Simulators", "Interactive creative tasks. Chemistry. Grades 8-9", IR Tutor, etc.) – software designed to develop skills and abilities, application of theoretical knowledge, self-training;
- *chemical calculators* (ChemicalAid, Chemical Equations online!, CHEMIX School, ChemMaths, Chemical Engineering AppSuite HD, etc.) – software designed to automate calculations when solving problems with chemical content;
- *chemical search engines* (ChemSrc, ChemSpider, PubChem, Chemical Structure Lookup Service, etc.) – databases containing information about the properties of substances and tools to optimize the search for this information;
- *chemical editors* (ChemBio3D, ChemDraw, ChemSite, RasMol, BIOVIA Draw, Symyx Draw, JChemPaint, ChemSketch, MarvinSketch, ChemPaster, MolPrime+, etc.) – software tools for creating, editing and processing graphic objects with chemical content (formulas, structures, devices, etc.).

In order to determine the ICT tools for specialized training chemistry which should be used in the process of the development of high school students' research competencies, an expert evaluation was organized using an electronic questionnaire of specialists: chemistry researchers, and teachers of chemistry, science, and computer science. The questionnaire was posted at https://goo.gl/SIscwG, the processing of the results of which made it possible to select the ICT tools, the use of which in the development of students' research competencies in the specialized chemistry training is pedagogically balanced.

5. Results

42 respondents took part in the survey, of which 22% were teachers of schools, lyceums, gymnasiums, and 78% were university teachers and researchers of educational research institutes. The largest group consisted of university teachers with the title of associate professor – 43,9% of the total number of respondents. Chemistry is taught by 31.7% of respondents, 22% teach other natural sciences, and 29.3% teach other courses (mostly mathematics and computer science). In terms of pedagogical or scientific-pedagogical work experience, the group with 11 to 20 years of work experience accounted for the greatest number of participants – 39%. Years of experience less than 5 years were 7.3% of the respondents, from 5 to 10 years – 31.7%, from 21 to 30 years – 14.6%, from 40 to 50 years – 7.3%.

Respondents were asked to evaluate the feasibility of using each of the 31 ICT tools for the development of students' research competencies in specialized chemistry training according to the following scale: "It is difficult to determine the answer", "It is inexpedient to use the tool", "It is rather advisable to use the tool than inexpedient" and "It is advisable to use the tool". The evaluation results are given in table 3.

All expert assessments were divided into two categories – "confident" when one of the options was chosen, which clearly indicated the assessment of the feasibility of using ICT, and "unconfident" when the expert could not determine the feasibility of using this ICT to develop students' research competencies in specialized chemistry training, choosing "It is difficult to determine the answer". The experts' confidence rating in assessing the feasibility of using ICT tools to develop students' research competencies in specialized chemistry training x_{con} is the ratio of the total number of "confident" answers n_{con} to the total number of answers n_{tot}:

$$x_{con} = \frac{n_{con}}{n_{tot}}.$$

Assessment of the feasibility of using ICT tools for the development of students' research competencies in specialized chemistry training x_{fsb} was calculated as the ratio of the difference between the number of "feasible" n_{adv} and "not feasible" n_{inx} evaluations to the number of "confident" expert evaluations n_{con}:

$$x_{fsb} = \frac{n_{adv} - n_{inx}}{n_{con}}.$$

The boundary value of the feasibility of using a particular ICT tool ($\overline{x_{fsb}}$=0.65) was defined as the arithmetic mean of the estimates of feasibility n_{adv} of all tools n_{alm}=31:

$$\overline{x_{fsb}} = \frac{1}{n_{alm}} \sum_{i=1}^{n_{alm}} x_{fsb\ i}.$$

Thus, according to the experts' opinion, 17 ICT tools were the most feasible to develop students' research competencies in specialized chemistry training (in table 3 their feasibility and confidence assessments are highlighted in bold):

- spreadsheets (x_{fsb}=0.80);
- tools of control and self-control of educational achievements (x_{fsb}=0.76);
- multimedia presentation creation tools (x_{fsb}=0.76);
- general-purpose search engines (x_{fsb}=0.85);
- learning management systems (x_{fsb}=0.72);
- text editors (x_{fsb}=0.76);
- cloud-based tools to support collaborative learning and research activities (x_{fsb}=0.72);
- adaptive automated chemistry learning systems (x_{fsb}=0.76);
- virtual chemical laboratories (x_{fsb}=0.92);
- electronic periodic systems (x_{fsb}=0.71);
- computer modeling tools for chemical processes (x_{fsb}=0.75);
- chemistry educational games (x_{fsb}=0.74);

Table 3
The results of expert evaluation of the using feasibility of ICT tools for the development of students' research competencies in specialized chemistry training.

ICT tool	Answer: It is difficult to determine the answer	Answer: It is inexpedient to use the tool	Answer: It is rather advisable to use the tool than inexpedient	Answer: It is advisable to use the tool	Evaluation: Feasibility	Evaluation: Confidence
virtual learning environments	6	2	15	18	0.46	0.85
graphic editors	1	5	13	22	0.43	0.98
expert systems	15	3	13	10	0.27	0.63
electronic laboratory journals	3	1	12	25	0.63	0.93
spreadsheets	0	1	6	34	**0.80**	**1.00**
audio and video processing and playback tools	2	1	16	22	0.54	0.95
tools for viewing e-books	1	0	17	23	0.58	0.98
tools for building relationship diagrams	1	2	12	26	0.60	0.98
authoring tools	2	3	13	23	0.51	0.95
tools for synchronous and asynchronous educational communication	2	1	12	26	0.64	0.95
tools for career guidance diagnostics	10	3	9	19	0.52	0.76
tools for control and self-control of educational achievements	0	1	8	32	**0.76**	**1.00**
tools for planning educational activities: electronic calendars, organizers, planners	0	3	14	24	0.51	1.00
tools for conducting educational web conferences: webinars, virtual classes, etc.	3	1	17	20	0.50	0.93
multimedia presentation creation tools	0	1	8	32	**0.76**	**1.00**
general-purpose search engines	0	0	6	35	**0.85**	**1.00**
learning management systems	2	1	9	29	**0.72**	**0.95**
database management systems	7	4	18	12	0.24	0.83
text editors	0	0	10	31	**0.76**	**1.00**
cloud-based tools for support collaborative learning and research activities	2	1	9	29	**0.72**	**0.95**
adaptive automated chemistry learning systems	7	1	6	27	**0.76**	**0.83**
virtual chemical laboratories	3	0	3	35	**0.92**	**0.93**
electronic periodic systems	3	0	11	27	**0.71**	**0.93**
computer modeling tools for chemical processes	1	0	10	30	**0.75**	**0.98**
chemistry educational games	2	0	10	29	**0.74**	**0.95**
popular science and career guidance chemical Internet resources	1	0	9	31	**0.78**	**0.98**
program-methodical complexes for chemistry education	1	0	9	31	**0.78**	**0.98**
simulators and electronic workshops	1	0	6	34	**0.85**	**0.98**
chemical calculators	1	1	12	27	0.65	0.98
chemical search engines	2	0	10	29	**0.74**	**0.95**
chemical editors	3	0	7	31	**0.82**	**0.93**
Mean	*2.65*	*1.16*	*10.65*	*26.55*	***0.65***	***0.94***

- popular science and career guidance chemical Internet resources (x_{fsb}=0.78);
- program-methodical complexes for chemistry education (x_{fsb}=0,78);
- simulators and electronic workshops (x_{fsb}=0.85);

- chemical search engines (x_{fsb}=0.74);
- chemical editors (x_{fsb}=0.82).

Thus, out of 20 general-purpose ICT tools, 7 were considered the most expedient, and out of 11 specilezed ICT tools for chemistry profile teaching – 10.

6. Discussion and conclusion

The arithmetic mean of the confidence of experts in assessing the feasibility of using ICT tools for the development of students' research competencies in specialized chemistry training is 0.94, which indicates high awareness of experts with the proposed ICT tools and high confidence in assessing the feasibility of using these tools to develop students' research competencies.

At the same time, we can identify several ICT tools for which the confidence score was significantly lower than the arithmetic mean:

- virtual learning environments;
- expert systems;
- tools for career guidance diagnostics;
- database management systems;
- adaptive automated chemistry learning systems.

Such low confidence ratings mean that a significant number of experts cannot determine the feasibility of using a particular ICT tool for the development of students' research competencies, which in most cases is caused by by lack of awareness of the tool's capabilities, methods of its use in specialized chemistry training, low availability of the tool due to high cost or lack of localization in Ukrainian, etc.

The tools that received a low confidence rating are used sporadically in the practice of teaching chemistry or are not in the professional interests of chemistry teachers, and the methodology of using such ICT tools in specialized chemistry training is undeveloped.

However, despite the low confidence rating, a tool such as "adaptive automated chemistry learning systems" was identified by experts as one of the most appropriate for the formation of research competencies of students in specialized teaching of chemistry.

At the same time, despite the low confidence rating, such a tool as adaptive automated chemistry learning systems was identified by the experts as one of the most appropriate for the development of high school students' research competencies in specialized chemistry training.

Approximately half of the proposed ICT tools were assessed by experts as appropriate for the development of students' research competencies in specialized chemistry training, and the largest number of them are tools that are ICT tools for specialized chemistry training. This state of affairs on the one hand means the need for continuous development and improvement of ICT teaching aids in chemistry, expanding their range and methodological justification for their use, and on the other hand – the lack of adaptability of general purpose ICT teaching aids to develop research competencies in chemistry teaching.

Among the ICT tools with the highest feasibility ratings are: virtual chemical laboratories; general purpose search engines; simulators and electronic workshops.

According to the survey results, the least feasible for the development of students' research competencies in specialized chemistry training is the use of expert systems and database management systems.

The results of the research allow to substantiate the choice of the most appropriate ICT tools for the development of students' research competencies in the specialized chemistry training. Taking into account the results of previous research aimed at creating a system of students' research competencies in specialized chemistry training [58, 62], the next stage of the research is to determine the role of ICT tools in shaping the particular components of the system of students' research competencies in specialized chemistry training. The next research question will be to determine the most appropriate ICT tools for the development of each specific research competence. The solution of this problem will make it possible to create a model for the development of high school students' research competencies in computer-based specialized chemistry training.

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