Developing Research Competencies in High School Students Through Specialized Chemistry Education: A Computer-Based Approach

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Abstract: The article discusses the trends in the development of the education system with a focus on specialized education in chemistry. The goal of specialized education is to deepen theoretical knowledge, improve practical skills, and foster independent and continuous self-education in students. The school chemistry course prioritizes the unity of theory and practice, a research approach to teaching, and differentiation. Research competencies are described as new personality formations that develop gradually in the process of educational and research activities. Specialized chemistry education is the optimal form for the formation and development of students' research competencies. The key concept of the study is research competencies of high school students in specialized chemistry teaching, which are defined as a systemic professionally oriented property of the student's personality. A system of research competencies of high school students in specialized chemistry education is designed, consisting of three groups: general scientific research competencies, scientific research competencies, and special chemical research competencies. The article also discusses the stages of educational and research activities, lesson and extracurricular forms of organizing educational and research activities, and the importance of forming research competencies in students.

1 INTRODUCTION

The main tasks 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; create conditions for strengthening the professional orientation of students, providing specialized training, individual educational trajectory of students in accordance with their personal needs, interests and abilities; increase the effectiveness of the educational process through the introduction of the achievements of psychological and pedagogical science, pedagogical (President of Ukraine, 2013).

The Concept for the development of science and mathematics education (STEM education), aimed at consistent and systematic solution of issues related to ensuring sustainable innovative development of science and mathematics education and improving its quality, identifies among the ways to solve this problem, in particular, the creation of information and methodological complexes for science and mathematics subjects (electronic manuals, virtual laboratories, electronic databases, educational portals, etc.), as well as ensuring conditions for their use (Cabinet of Ministers of Ukraine, 2020).

According to the Law of Ukraine "On Education" (Verkhovna Rada of Ukraine, 2017) specialized secondary education corresponds to the third level of the National Qualifications Framework, which requires students to develop the ability to work effectively in a team, critical thinking, independent educational and professional activities, responsibility for its progress and results, oral and written communication skills, etc. Studies of in the field of theory and methodology of ICT in education have proven the effectiveness of using ICT tools to develop these abilities. According to the (Verkhovna Rada of Ukraine, 2017), specialized education in science involves the acquisition

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of competencies by students in research and development, design, invention and rationalization activities that can be supported by ICT.

The main tasks of specialized education include assistance in the development of creative independence, the formation of a system of ideas, value orientations, research skills – components of research competencies that will provide a school graduate with the opportunity to successfully realize himself/herself. The issues of forming students' research competencies in the context of specialized education were considered by Alibekian (Alibekian, 2013), Verbytskyi (Verbytskyi, 2012), Zhuk (Zhuk, 2021), Kiv et al. (Kiv et al., 2019).

The main goal of competence-based learning of chemistry students is to develop the competencies necessary for the creative realization of the individual and the acquisition of skills of independent scientific and practical research and development activities, and the leading forms of organizing such activities are laboratory work and projects aimed at forming students' research competencies. The theoretical and methodological foundations of specialized teaching of chemistry were developed in (Jegstad et al., 2022; Sawatruksa and Rodpun, 2019; Segerblom, 1931; Velychko and Fitsailo, 2010). ICTs as a means of teaching chemistry were considered by Aksela (Aksela, 2005), da Silva et al. (da Silva et al., 2019), Derkach (Derkach, 2021), Hernández et al. (Hernández et al., 2014), Husaruk (Husaruk, 2010), Lewis (Lewis, 2004), Martínez-Argüello et al. (Martínez-Argüello et al., 2018), Sadykov and Čtrnáctová (Sadykov and Čtrnáctová, 2019), Silva and Ramos (Silva and Ramos, 2016).

The realization of the purpose and tasks of specialized chemistry education is impossible without taking into account the principle of flexibility, which consists in providing opportunities and conditions for changing the content, methods and forms of organization of specialized education, in particular the main form of meeting individual student requests according to individual plans and programs (for example, in rural areas in the absence of students to form a class) – distance learning, which occurs mainly through the indirect interaction of remote participants in the educational process in a specialized environment that operates on the basis of modern psychological, pedagogical, and information and communication technologies.

The analysis of the experience of organizing specialized chemistry education has revealed a *contradictions* between the potential of computer-oriented chemistry education in the formation of research competencies of high school students and the lack of development of methods for using ICT in the process of forming research competencies in students of specialized classes, which gives rise to a socially significant problem, which is the focus of this research.

2 RESEARCH METHODOLOGY

Research object is information and communication technologies for teaching chemistry in general secondary education.

Research subject is the process of using information and communication technologies as a means of forming research competencies of high school students in specialized chemistry education.

Research aim is to substantiate the theoretical and methodological foundations of the use of information and communication technologies as a means of forming research competencies of senior pupils in specialized chemistry teaching.

The research hypothesis: the process of using ICT as a means of forming research competencies of senior pupils in specialized teaching of chemistry will be effective if

- the system of research competencies is designed as interrelated groups of general scientific, natural scientific and chemical research competencies;
- the selection of general and special purpose ICT tools aimed at forming research competencies of senior pupils in specialized teaching of chemistry;
- the model of forming research competencies of senior pupils is substantiated.

In accordance with the research aim, subject, and hypothesis, the following main *research objectives* have been identified:

1. Based on the analysis of scientific literature, to identify and reveal the theoretical and methodological foundations of the process of forming students' research competencies in specialized chemistry education.
2. To determine the content, structure and features of the system of research competencies of high school students in accordance with the tasks of specialized teaching of chemistry.
3. To identify and characterize information and communication technologies as a means of forming research competencies of students in specialized classes in chemistry.
4. To theoretically substantiate the model of forming research competencies of senior pupils in specialized chemistry teaching by means of information and communication technologies.

5. To develop and experimentally test the effectiveness of the methodology of using information and communication technologies as a means of forming research competencies of senior pupils in specialized chemistry teaching.

To solve the tasks, the following *research methods* were used:

- theoretical – analysis, generalization, systematization of scientific, methodological and psychological-pedagogical literature on topical research issues, current state standards of general secondary education, school curricula and textbooks to determine the theoretical and methodological foundations of the research, development of methods of using information and communication technologies as a means of forming research competencies of high school students; modeling to develop a model for the formation of research competencies of high school students in specialized chemistry teaching by means of information and communication technologies;
- empirical – diagnostic (targeted pedagogical observation, interviews with teachers and students, questionnaires, analysis of teachers' work experience) to determine the state of formation of research competencies of high school students;
- experimental (stating and formative stages of the pedagogical experiment) – to test the developed methodology for the formation of research competencies of high school students.

The theoretical and methodological foundations of the study are the philosophical positions on the unity of theory and practice, interdependence and interconnection of objective and subjective factors of personality formation; fundamental ideas of systemic (Afanas'ev, 1981; Aver'janov, 1985; Blauberg and Judin, 1973; González, 2011), personal and activity (Brushlinskij, 1979; Gal'perin, 2012; Davydov, 2008; Rubinstein and Myasoed, 2009; Talyzina, 1974), competence (Bibik et al., 2019; Il'chenko, 2015; Lokshyna, 2022; Ovcharuk, 2020; Tarasenkova et al., 2019; Khutorskaya and Korol, 2008), cognitive (Bruner, 1984; Piaget, 1980; Vygotsky, 2004) approaches; provisions of the theory of pedagogical systems (Bespalko, 2018; Härkönen, 2009; Derkach and Kuz'mina, 1993), theoretical foundations of modeling of training and education systems (Bykov, 2008; Cifuentes and Olarte, 2023; Dokuchaieva, 2022); scientific provisions of education informatization (Bykov et al., 2017; Gergei and Mashbits, 1986; Glushkov, 1976; Gurevych et al., 2020; Hrynevych et al., 2021; Kademiya and Kobysia, 2017; Kuzmina et al., 2022; Meniailenko et al., 2017; Panchenko, 2021; Polat, 2009; Robert et al., 2016; Semerikov, 2021; Vlasenko et al., 2020; Vakaliuk et al., 2022; Volkova et al., 2021; Zhaldak, 2012), in particular the use of ICT in the educational process of general secondary education (Monakhov, 1986; Morze et al., 2022a; Zhaldak, 2013); theoretical foundations of research-based teaching and learning (Rakov et al., 2009; Mongkonthan, 2021; Park et al., 2023); provisions of the theory and methodology of teaching chemistry at school (Garnett and Tobin, 1989; van Rens et al., 2010; Roehrig and Luft, 2004; Yaroshenko, 2021); conceptual provisions of specialized education (Chebykin and Maksymenko, 2008; Tarasenkova et al., 2020; Volkovyskii et al., 1987), in particular chemistry (Halkyard, 1944; Pak, 2012; Velychko and Fitsailo, 2010); psychological and pedagogical features of computerization of the educational process in general secondary education institutions (Lehka and Shokaliuk, 2021; Monakhov et al., 1986; Smulson, 2012).

3 THEORETICAL FOUNDATIONS OF THE FORMATION OF RESEARCH COMPETENCIES OF HIGH SCHOOL STUDENTS IN SPECIALIZED TEACHING OF CHEMISTRY

Modern trends in the development of the education system, due to the intensification of the development of all spheres of science and the establishment of new social requirements for the individual, are aimed at forming the skills of independent and continuous self-education in students. Based on the views of Bibik et al. (Bibik et al., 2019), Chebykin and Maksymenko (Chebykin and Maksymenko, 2008), Velychko and Fitsailo (Velychko and Fitsailo, 2010) on the content, purpose and ways of implementing specialized education, we note that specialized education in chemistry provides students with opportunities to deepen their theoretical knowledge and improve their practical skills in chemistry; to conduct individual and group research aimed at acquiring skills of independent scientific and practical, research and search activities by high school students; to develop their own intellectual, mental, creative, moral, social qualities, as well as the desire for self-development and self-education.

One of the main features of the school chemistry

course is the priority of the principle of unity of theory and practice (Pedersen, 1983; Podlasyi, 1982; Wiggins, 2011), the research approach to teaching (Lim, 2022; Morze et al., 2022b; Peltekova et al., 2014; Rakov et al., 2009) and the principle of differentiation (Gruber, 2008; Unt, 1981; Yaroshenko, 2021), which is reflected in the organization of various types of educational and *research activities* of students, which is understood as an activity aimed at mastering subjectively new knowledge and leading scientific methods of its acquisition, carried out in accordance with the methodology of scientific research in the chosen field, and in the widespread use of the research approach in teaching chemistry, in particular in the context of specialized education.

Based on the general theoretical provisions of the competence-based approach in school education (Bibik et al., 2019; Lokshyna, 2022; Lupión-Cobos et al., 2022; Ovcharuk, 2020) O. Savchenko, scientific views of Baizulaeva (Baizulaeva, 2010) and Golovan' (Golovan', 2012) on the structure and content of research competencies, *research competencies* are interpreted as qualitative new personality formations, the formation and development of which occurs in the process of students' educational and research activities with a gradual complication of its types.

Taking into account the fundamental ideas of the personality-activity approach (Davydov, 2008; Gal'perin, 2012; Talyzina, 1974), scientific principles of specialized education (Chebykin and Maksymenko, 2008; Tarasenkova et al., 2020; Volkovyskii et al., 1987) and features of the implementation of specialized teaching of chemistry (Pak, 2012; Velychko and Fitsailo, 2010; Yaroshenko, 2021), the key concept of the study – *research competencies of high school students in specialized chemistry teaching* – is defined as a systemic professionally oriented property of the student's personality, which combines knowledge, skills, experience of educational and research activities in chemistry and a positive value attitude towards it and is manifested in the willingness and ability to conduct educational chemical research using general scientific, natural scientific and special chemical methods.

The main driving force in the formation and development of students' research competencies in chemistry is educational and research activities, the stages of organization of which generally correspond to the stages of organization of research activities, and specialized chemistry education is the optimal form of education for the formation and development of students' research competencies. It has been proved that the priority lesson forms of organizing educational and research activities in specialized teaching of chemistry, the use of which contributes to the formation of students' research competencies at a high level, are the solution of educational and research tasks and laboratory work, and the leading extracurricular forms are chemical workshops, educational and research projects, individual educational and scientific research, practical and home chemical experiments, the implementation of which is advisable during elective classes and in extracurricular scientific and educational activities.

Based on the research of Khutorskoi (Khutorskoi, 2012) on the structuring of competencies, Pometun and Remekh (Pometun and Remekh, 2019) on the connection of general subject and subject competencies, Il'chenko (Il'chenko, 2015) on the ways of forming natural scientific competencies of schoolchildren, Timirgalieva (Timirgalieva, 2013) on the essence and features of the development of chemical competencies of high school students, a system of research competencies of high school students in specialized chemistry education, consisting of three groups, is designed:

- general scientific research competencies (GRC), which are related to the mastery of universal research methods necessary for research activities in the process of studying any discipline, and include the following abilities: the ability to formulate the research hypothesis (GRC-01), the ability to plan the hypothesis testing (GRC-02), the ability to realize and justify the relevance of the research (GRC-03), the ability to evaluate the moral and social aspects of scientific research (GRC-04), the ability to find and use the reference materials that are necessary for the research (GRC-05), the ability to think critically (GRC-06), the ability to analyze and formalize the research results (GRC-07), the ability to formulate conclusions (GRC-08), the ability to substantiate the submission of research results, to protect the own opinion, to discuss (GRC-09), the ability to work together in the research process (GRC-10);
- scientific research competencies (SRC) related to the study of real natural objects and the relationships between them, which are necessary for research activities in the field of natural sciences and are represented by: the formation of representations about the stages of the cognitive activity in natural sciences, the elements of metrology (SRC-01), the ability to plan an experiment (SRC-02), the ability to carry out the individual operations competently during the experiment (SRC-03), the ability to conduct experiments in order to know the properties of bodies and substances, to identify the features of the growth, the development

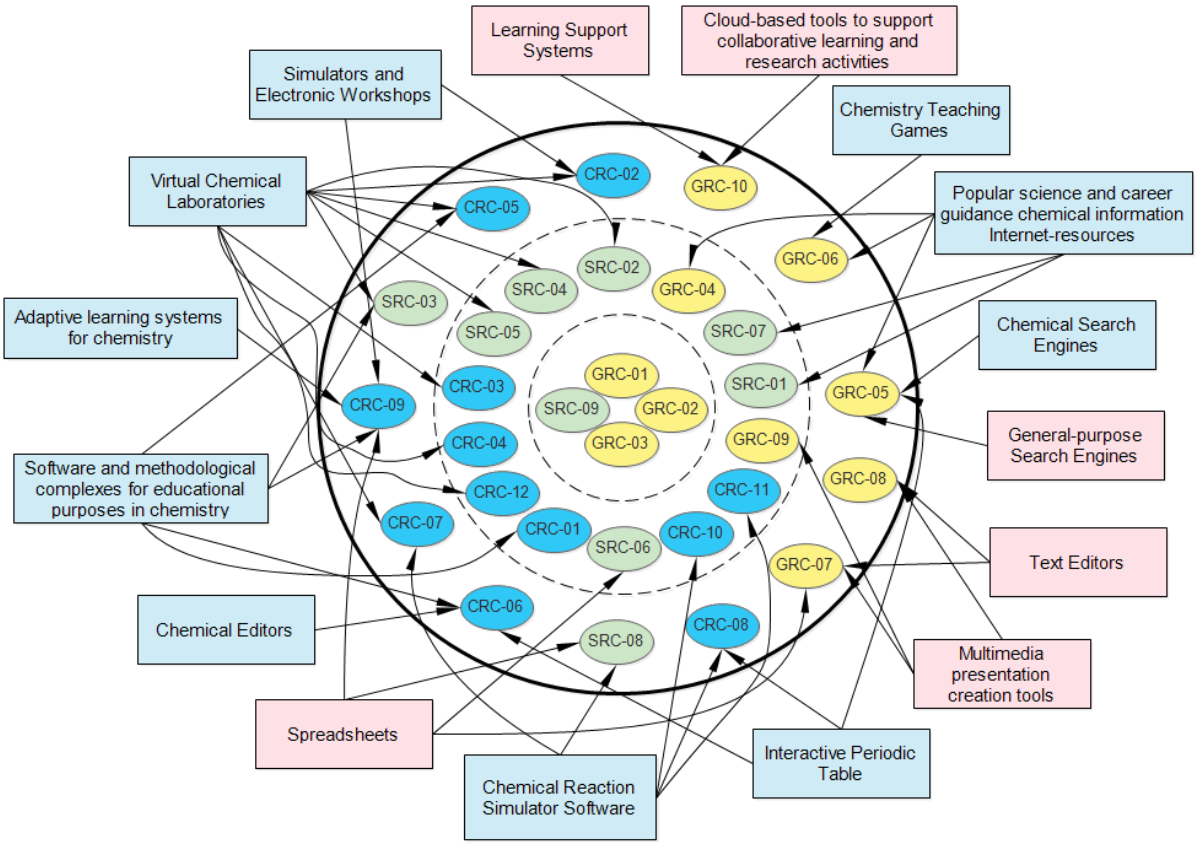

Figure 1: Interrelation of ICT tools with the formation of a system of research competencies of high school students in specialized chemistry education.

and the behavior of organisms (SRC-04), the ability to adhere to the safety rules during the experiment (SRC-05), the ability to perform the mathematical analysis of the experimental research results (SRC-06), the formation of representations of the general laws of nature and the natural sciences picture of the world, the general structure of the universe, the integrity of nature (SRC-07), the ability to use the experimental and statistical methods and the modeling in the study of objects of live and inanimate nature (SRC-08), the ability to distribute work in the process of experiment that the purpose of optimization (SRC-09);

- chemical research competencies (CRC), which are related to the mastery of special chemical research methods necessary for research activities in the fields of chemical sciences, include the ability to: the ability to distinguish the chemical phenomena of nature from the others (CRC-01), the ability to use the chemical dishes and equipment correctly (CRC-02), the ability to adapt the existing chemical dishes and equipment for the experiment needs (CRC-03), the ability to compose and use the devices for carrying out the experiments (CRC-04), the ability to perform the laboratory operations correctly: heating, cooling, filtering, mixing, weighing, etc. (CRC-05), the ability to use the chemical symbols, the formulas, the modern Ukrainian chemical nomenclature (CRC-06), the ability to predict the course of chemical reactions, based on the properties of the substances that are taking part in them, and the conditions of the reaction (CRC-07), the ability to justify the relationship between the structure of matter and its properties (CRC-08), the ability to perform the various types of chemical calculations (CRC-09), the ability to draw conclusions about the properties of matter, based on the structure of the molecule substances (CRC-10), the ability to draw conclusions about the structure of substances based on their properties (CRC-11), the ability to solve the experimental problems in chemistry (CRC-12).

The different groups of the system of research competencies of high school students in specialized chemistry education are shown in figure 1.

4 METHODOLOGICAL FOUNDATIONS OF USING INFORMATION AND COMMUNICATION TECHNOLOGIES AS A MEANS OF FORMING RESEARCH COMPETENCES OF SENIOR PUPILS IN SPECIALIZED TEACHING OF CHEMISTRY

Theoretical analysis of the conceptual provisions on informatization of education (Fedorenko et al., 2019; Li, 2021; Liu and Wang, 2021; Mynbayeva and Anarbek, 2016; Qi et al., 2009; Wang and Xing, 2011; Wen, 2022; Yan and Yang, 2021), the use of ICT in the educational process of general secondary education (Gil-Flores et al., 2017; Lai and Pratt, 2004; Mooij and Smeets, 2001; Webb, 2002; Wikan and Molster, 2011), taking into account the psychological and pedagogical features of computerization of the educational process of schoolchildren, the results of the analysis of the theory and practice of specialized teaching of chemistry gave grounds to distinguish two main groups of ICT learning tools in accordance with the tasks of specialized teaching of chemistry, in particular: general-purpose tools used to support the teaching of any discipline, and special-purpose tools that are specific means of supporting the teaching of chemistry.

Based on the results of the expert survey (Nechypurenko et al., 2021), 17 ICT tools were selected, the use of which contributes to the formation of research competencies of high school students in specialized chemistry teaching: seven general-purpose tools (spreadsheets; tools for monitoring and self-monitoring of learning achievements; tools for creating multimedia presentations; general-purpose search engines; learning support systems; text editors; cloud-based tools for supporting collaborative learning and research activities) and ten special-purpose tools (adaptive automated learning systems in chemistry; virtual chemical laboratories; electronic periodic systems; computer modeling of chemical processes; educational games in chemistry; popular science and career guidance chemical information resources on the Internet; software and methodological complexes for educational purposes in chemistry; simulators and electronic workshops; chemical search engines; chemical editors).

It has been proved that most research competencies correspond to one or more leading ICT tools to support their formation. It has also been found that 16 selected ICT tools are leading in the process of forming at least one research competence, with general-purpose ICT tools being necessary for the formation of primarily general scientific ones, and special-purpose tools – for the formation of chemical and natural scientific research competences of high school students in specialized chemistry education. Schematically, the types of these connections are shown in figure 1.

ICT tools for the formation of senior students' research competencies in specialized chemistry education have become one of the key elements of the developed model of the formation of senior students' research competencies in specialized chemistry education by means of ICT, which consists of four blocks (figure 2).

Thus,

- the goal unit contains components that define the goal – the formation of research competencies of high school students using ICT (rapid growth of chemical knowledge and the need of society for highly qualified specialists in chemistry, computerization of all types of chemical activities, pre-professional training in chemistry in high school and research-oriented teaching of chemistry);
- the conceptual unit reflects modern approaches to the implementation of a competence-based approach in specialized chemistry teaching and contains normative documents (international and state standards), the content of chemistry teaching, an expert survey as the main selection tool and a designed system of research competencies of high school students in specialized chemistry teaching;
- the technological unit contains a set of ICT tools for the formation of research competencies of high school students in specialized chemistry teaching, which is interconnected with the methods of specialized chemistry teaching and forms of organization of students' research activities in chemistry and determines the ways to achieve the goal;
- diagnostic and result unit includes the predicted result of applying the model – increasing the level of high school students' research competencies in specialized chemistry education and a set of assessment criteria, indicators, levels and means of diagnosing the formation of students' research competencies, designed to determine the effectiveness of achieving the result.

The components of the model that ensure the interconnection of all units are information and communication technologies, methodological approaches

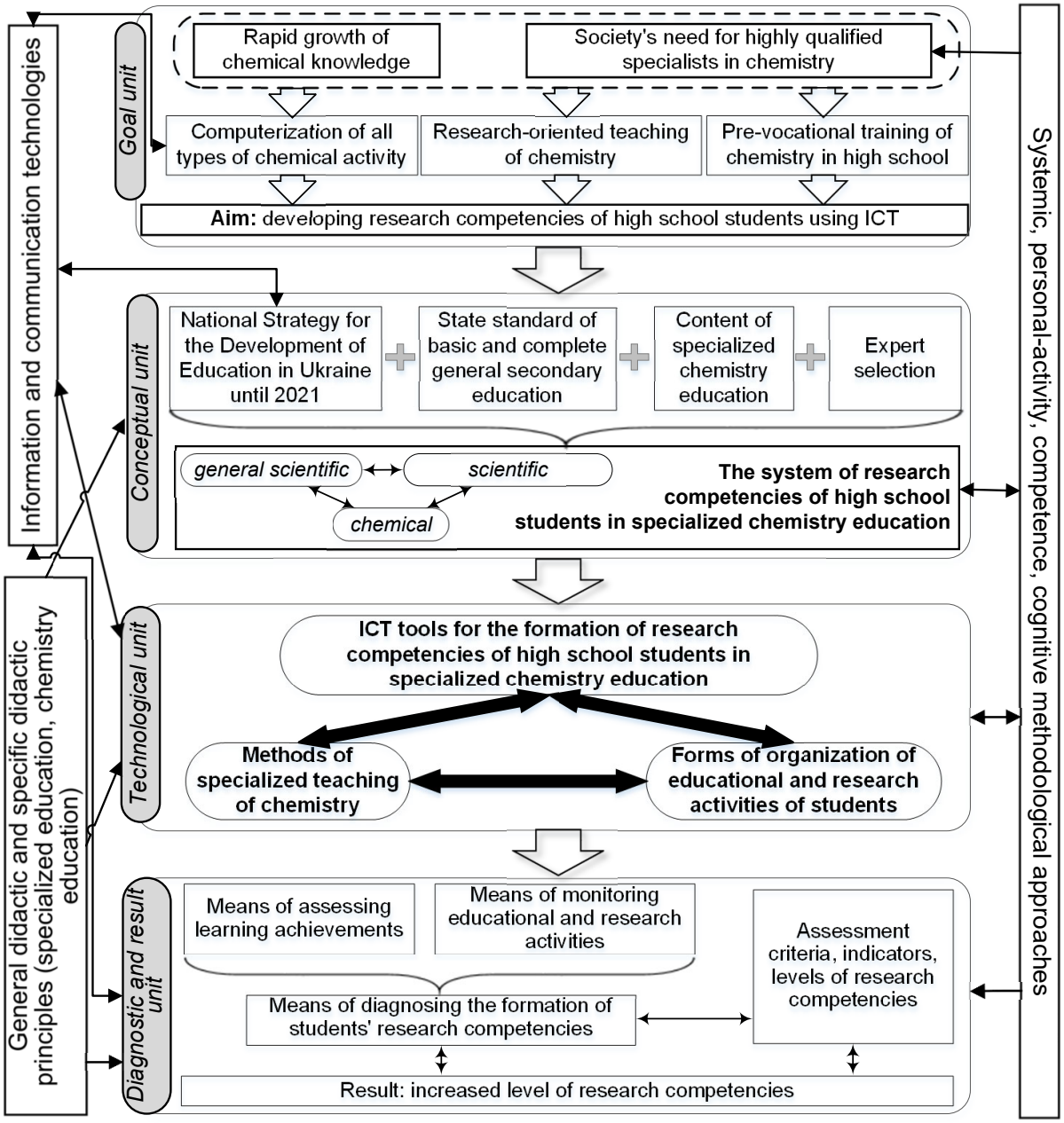

Figure 2: The model of research competence formation of high school students in specialized chemistry teaching using ICT.

(systemic, personal-activity, competence, cognitive) and principles (general didactic and specific didactic – specialized education, chemistry education).

In accordance with the model of forming research competencies of high school students in specialized chemistry teaching using ICT, a methodology for using ICT as a means of forming research competencies of high school students in specialized chemistry teaching has been developed, consisting of a target block (formation of students' research competencies), content block (teaching the basics of quantitative chemical analysis) and technological block (ICT tools, methods and forms of their use in specialized chemistry teaching). Proceeding from the fact that the formation of a system of research competencies of high school students is effective provided that the appropriate selection of ICT tools and conditions for their use for the formation of each of the research competencies, the developed methodology was tested in the process of teaching the optional course

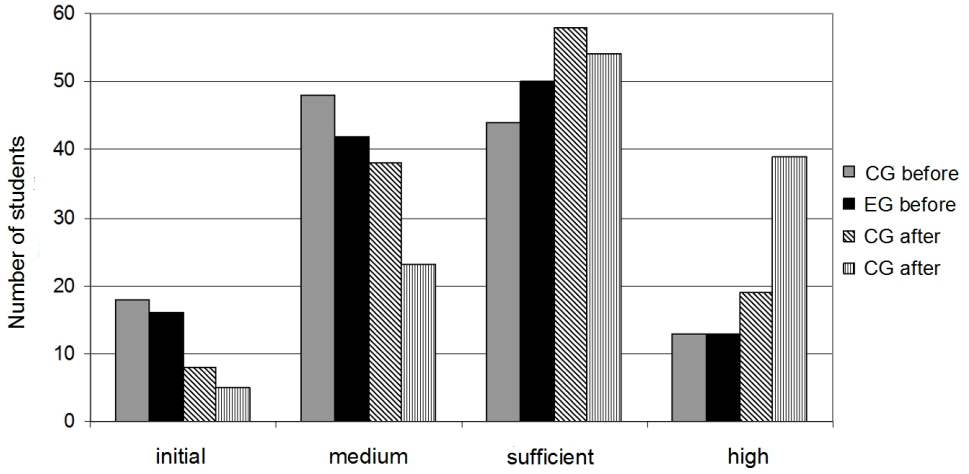

Figure 3: Levels of research competencies of high school students of high school students in the control (CG) and experimental (EG) groups at the beginning and end of the pedagogical experiment.

"Fundamentals of Quantitative Chemical Analysis", as well as individual topics of the high school chemistry course at the specialized level.

5 EXPERIMENTAL WORK

The research and experimental work consisted of three stages: analytical and stating (2007 – 2009), design and search (2010 – 2013) and formative and generalizing (2014 – 2017). At the first stage, the problem was identified and the research hypothesis was formulated.

At the second stage, the structure of research competencies and indicators for diagnosing the level of their formation were determined, which was carried out through observations, conversations, questionnaires, studying the products of students' activities, high school students' performance of psychological tests, sets of test tasks and written tests in the subject. This made it possible to determine the levels of research competencies on a four-level ordinal scale (initial, intermediate, sufficient and high) using research competency matrices that were filled out for each student. The level of formation of the system of research competencies of high school students in specialized chemistry education was determined based on the level of formation of each individual research competency and its contribution to the formation of the system of research competencies.

At the third stage, in order to test the effectiveness of the developed methodology of using ICT as a means of forming research competencies of high school students in specialized chemistry teaching, the curriculum of the optional course "Fundamentals of Quantitative Chemical Analysis" was developed (Nechypurenko and Soloviev, 2018); the selection of ICT tools was carried out, the use of which ensured the formation of research competencies of high school students in the process of their study in the optional course; control (CG) and experimental (EG) groups were formed, in which the process of formation of research competencies was monitored.

The results of the pedagogical experiment showed no significant difference in the distribution of CG and EG students by levels of research competencies at the beginning of the experiment and the presence of such a difference after its completion against the background of a general increase in the number of students with sufficient and high levels of research competencies in both groups (figure 3).

The statistical processing of the pedagogical experiment data was carried out using Pearson's χ^2 test. The results of the statistical processing confirmed the assumption that there were no significant differences between the distribution of CG and EG students at the beginning of the experiment by the levels of formation of research competence groups ($\chi^2_{emp} = 0.943$; 1.751 and 1.243 for general scientific, natural scientific and chemical research competencies, respectively) and the system of research competencies in general ($\chi^2_{emp} = 0.884$) and showed the presence of significant differences at the level of $p = 0.01$ in the distribution of CG and EG students by the levels of formation of the system of research competencies in general ($\chi^2_{emp} = 11.470$) and significant at the level of $p = 0.05$ differences in the distribution of CG and EG students by the levels of formation of chemical research competencies ($\chi^2_{emp} = 8.649$) after the peda-

gogical experiment, which confirmed the research hypothesis.

6 CONCLUSION

The article presents a theoretical generalization and solution to the scientific problem of using ICT as a means of forming research competencies of high school students in the process of specialized chemistry teaching. The research results give grounds to draw the following conclusions:

1. Based on the results of the analysis of scientific literature, regulatory and legislative documents, it was found that in general secondary education the priority task is to update the content, forms and methods of organizing the educational process; create conditions for strengthening the professional orientation of students by providing specialized training and individual educational trajectory of students in accordance with their personal needs, interests and abilities; improving the quality of the educational process through the introduction of ICT as an effective means of forming research competencies.

   The theoretical and methodological foundations of the process of forming students' research competencies in specialized chemistry education are revealed, which include a definitional analysis of the key concepts of the research, a theoretical substantiation of the model of forming research competencies of high school students in the process of specialized chemistry education, a designed system of research competencies of high school students in accordance with the tasks of specialized chemistry education, a description of ICT as a means of forming research competencies of students in specialized classes in chemistry.

2. Based on the fundamental ideas of competence, personality and activity approaches, scientific principles of specialized education and taking into account the peculiarities of its implementation in the process of teaching chemistry, the key concept of the study – research competencies of high school students in specialized teaching of chemistry – is defined as a systemic professionally oriented property of the student's personality, which combines knowledge, skills, experience of educational and research activities in chemistry and a positive value attitude towards it and is manifested in the readiness and ability to conduct educational chemical research using general scientific, natural science and special chemical methods.

   It has been proved that the main driving force for the formation and development of students' research competencies in chemistry is educational and research activity, which is considered as an activity aimed at mastering subjectively new knowledge and leading scientific methods of its acquisition, carried out in accordance with the methodology of scientific research in the chosen field, and the stages of its organization correspond to the stages of organization of research activity. On the basis of a methodologically sound combination of traditional and innovative technologies, it is established that the priority forms of its organization are the solution of educational and research tasks and laboratory work, and the leading extracurricular forms are chemical workshops, educational and research projects, individual educational and scientific research, practical and home chemical experiments, the implementation of which is advisable during optional classes and in extracurricular scientific clubs.

3. Taking into account theoretical provisions on the structuring of competencies, the relationship between general subject and subject competencies, ways of forming natural scientific competencies of schoolchildren, the essence and features of the development of chemical competencies of senior pupils, a system of research competencies of senior pupils in specialized teaching of chemistry is designed, consisting of three groups: general scientific research competencies related to the mastery of universal research methods; natural scientific competencies that provide for the development of scientific research. The article investigates the links between different groups of the research competencies system and establishes that the formation of some research competencies indirectly determines the development of others, which requires the selection of means for the formation of research competencies of high school students in specialized education, taking into account the interrelated development of all three groups of competencies with an emphasis on those that have the most connections with other competencies and can be considered key research competencies.

4. The research identifies 17 ICT tools that contribute to the formation of research competencies of high school students in specialized chemistry education, including seven general tools (spreadsheets; tools for monitoring and self-monitoring of learning achievements; tools for creating multimedia presentations; general-purpose search engines; learning support systems; text editors;

cloud-based tools for supporting collaborative learning and research activities) and ten special-purpose tools (adaptive automated learning and teaching tools).

It has been proved that the most significant ICT tool for the formation of research competencies is virtual chemical laboratories, which are appropriate for the formation of the largest number of research competencies of high school students in the process of specialized chemistry education (Nechypurenko and Semerikov, 2017; Nechypurenko et al., 2019, 2020).

5. The developed model for the formation of research competencies of senior pupils in specialized teaching of chemistry using ICT consists of the following interrelated units: goal, the components of which determine the purpose of forming research competencies of senior pupils using ICT; conceptual, reflecting modern approaches to the implementation of a competence-based approach to specialized teaching of chemistry; technological, which contains a set of ICT tools for the formation of research competencies of high school students in specialized chemistry teaching, interconnected with the methods of specialized chemistry teaching and forms of organizing students' research activities in chemistry; diagnostic and result, representing the predicted result of the model.

   The components of the model that ensure the interconnection of all blocks are information and communication technologies, methodological approaches (systemic, personal and activity, competence, cognitive) and principles (general didactic and specific didactic – of specialized education and chemistry education).

6. The methodology of using ICT as a means of forming research competencies of high school students in specialized chemistry teaching consists of a target block (formation of students' research competencies), a content block (teaching the basics of quantitative chemical analysis as a universal course for different chemical profiles) and a technological block (ICT tools, methods and forms of their use in specialized chemistry teaching).

   The experimental verification of the developed methodology in the form of a sequential pedagogical experiment and the results of statistical processing of the data confirmed the assumption that there were no significant differences in the distribution of students of the control and experimental groups at the beginning of the experiment in terms of the levels of formation of research competence groups ($\chi^2_{emp} = 0.943$; 1.751 and 1.243 for general scientific, natural scientific and chemical research competencies, respectively) and the system of research competencies in general ($\chi^2_{emp} = 0.884$) and showed the presence of significant differences at the level of $p = 0.01$ differences in the levels of formation of the system of research competencies in general ($\chi^2_{emp} = 11.470$) and significant at the level of $p = 0.05$ differences in the levels of formation of chemical research competencies ($\chi^2_{emp} = 8.649$) after the completion of the pedagogical experiment, which confirmed the hypothesis of the study.

The research results can be used in the process of organizing research teaching of chemistry using ICT in general secondary and higher education institutions of various profiles; in the process of professional training of future chemistry teachers; in the system of postgraduate pedagogical education and advanced training of science teachers; in the self-educational activities of high school students.

7 FUTURE WORK

The study does not exhaust all aspects of the problem under consideration. Further scientific research into its solution is advisable in the following areas: development of methods for using expert systems as a means of generalization and systematization in teaching chemistry; development of adaptive systems for teaching chemistry; design of a system of cloud-based virtual chemical laboratories and development of methods for their use; theoretical and methodological foundations for designing a computer-oriented environment for the professional training of future chemistry teachers.

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