Educational Computer Modelling in Natural Sciences Education: Chemistry and Biology Aspects

Svitlana Lytvynova [1] [0000-0002-5450-6635], Mariia Medvedieva [2] [0000-0001-9330-5185]

[1]Institute of Information Technologies and Learning Tools of National Academy of Educational Sciences of Ukraine, 9 M. Berlyns'koho st., 04060, Kyiv, Ukraine
s.h.lytvynova@gmail.com
[2]Pavlo Tychyna Uman State Pedagogical University, 2 Sadova st., 20300, Uman, Cherkasy Region, Ukraine
medvedeva-masha25@ukr.net

Abstract. The article analyzes the research that addresses the issue of using computer models in the educational process. It covers the aspects of the use of computer modelling in natural sciences subjects, namely: chemistry, biology. It analyzes the students' interest in choosing a future profession, connected with chemistry and biology. The article offers the definition and substantiation of the model of educational computer pattern and the definition of its components (graphic, mathematical, strategic, animation) and features (mono-subject, poly-subject / simulation, play-based, algorithmic / poster, laboratory, quest / variant / character-based / achievable). It substantiates the stages of designing a research task. It covers the methodical basics of computer modelling in the implementation of a STEM lesson in chemistry. It describes the methodological basics of using computer modelling to work independently at the lessons of biology. The present research also summarizes the results of the teacher survey on the usefulness and ease of use of computer modelling in the educational process. The priorities of the students in the study of subjects of the natural and mathematical cycle are determined. Computer modelling is found to be an effective tool for improving the quality of science education that requires the development of a teacher training system, cognitive tasks and organizational foundations of the educational process.

Keywords. Educational Computer Modelling, Natural Sciences, Chemistry, Biology, ICT in education, CMODS, STEM, Teacher Development, Simulation.

1 Introduction

The rapid introduction of STEM education has prompted foreign universities to create the latest resources and to reload existing educational needs of the 21st century, namely the creation of digital educational content, including digital educational computer models.

In 2017, the Institute of Information Technologies and Teaching Tools of the National Academy of Pedagogical Sciences of Ukraine conducted a survey in which 70% of teachers indicated that they did not use computer modelling in class. The main reasons for the low activity are the following: lack of access to computers, the need for access to the Internet, lack of methodological resource books for lessons.

During 2018-2019, the Stanford University CK-12 Foundation Team conducted a series of webinars on teacher training in computer models, electronic textbooks and online tests. The survey established that 75% of teachers did not use these resources in the educational process. It identified the main problems: lack of information, the need for constant access to the Internet and the lack of skills to use the latest technologies (https://www.ck12.org/).

Nowadays, the number of digital educational resources that a teacher should operate in his / her professional activity is as follows: digital texts, educational videos, interactive tasks, quizzes, question banks, thematic web resources, photo galleries, virtual museums, blended learning, digital laboratories, digital laboratories maps, computer modelling, etc.

As you can see, computer modelling is on this list and therefore remains an up-to-date method of scientific knowledge. The modelling method makes it possible to study objects, design logical constructions and scientific abstractions during the experiment. However, the lack of information and systematic teacher training (enhancing their IC-competences) led to a significant gap in the needs of the 21st century school and the teacher's professional growth in the use of the latest digital content and digital learning tools.

2 Analysis of latest research and publications

Students' acquisition of knowledge is more effective in the process of activity. Researchers at M.P. Dragomanov National Pedagogical University (O.V. Matviychuk, V.P. Sergienko, S.O. Podlasov) established that the development of computer models of physical phenomena could serve as such an activity. Creating a computer model, first of all, requires the student to have a deeper understanding of the mathematical description and the nature of the processes that take place. In this case, the process of building a computer model can be organized with a gradual complication and approximation to reality, in accordance with the didactic principle of "of simple to complex" [10].

However, most scientists are inclined to think that not only computer models are shaping students' perceptions of the world around them. The quality of education can be ensured by the systematic use of computer modelling in science subjects to solve educational cognitive tasks.

The interest of scientists in the use of computer modelling in the secondary education process is growing, due to a number of articles published in the last two years. Scientists have raised problems and substantiated the following directions of use of computer modelling in the educational practice: activation of students' cognitive activity in physics lessons by means of computer modelling [15]; criteria development

for selecting computer models for use in the educational process [2]; determination of ergonomic requirements for the use of computer models in general secondary education institutions [9], extensive discussion of the issue of the students' subject competencies formation by means of computer modelling [12]; theoretical aspects of simulation modelling in physics training [16], aspects of the students' safe work on the Internet, in particular in the process of computer modelling [1].

3 Methods of Research

The study was conducted within the framework of the "Computer Modelling System of Cognitive Tasks for Forming the Students' Competences in Natural Sciences and Mathematical Subjects" experiment. The methods used in the research process include the analysis of theoretical sources, generalization of the best pedagogical practices of foreign and domestic specialists regarding the use of computer modelling and its use in student learning; synthesis, generalization and conceptualization for the development of the main research provisions; design of the educational computer model, surveys of teachers; generalization of results.

4 Research Results

4.1 Educational computer model design

A significant contribution to the development of the issue was made by the scientists of the Institute of Information Technologies and Teaching Tools of the National Academy of Pedagogical Sciences of Ukraine. During 2018-2019, within the framework of the "System of computer modelling of cognitive tasks for forming competences of students in natural sciences and mathematical subjects" scientific research, they developed a conceptual system of designing the educational computer model (Fig. 1), which is the key to understanding the direction development of IC-technologies, including computer modelling for the educational industry

By the educational computer model (ECM) we will mean software tools for animation visualization of phenomena and processes, creation of action strategies, execution of numerical calculations of any level of complexity and aimed at identifying and solving tasks of different types [7, 8].

The purpose of designing / developing a computer model: to study the properties of objects and processes.

Developer and user categories: a teacher, a student, a professional programmer.

The educational computer model encompasses the following basic components (graphic, strategic, mathematical, animated). *Graphic* – representation of objects, processes graphically (as an image). *Mathematical* – presentation of complex mathematical calculations in the process of experimentation. *Animation* – accompanying support of the experiment results with dynamic changes in the image. *Strategic* – further steps depend on the previous selection of the dataset.

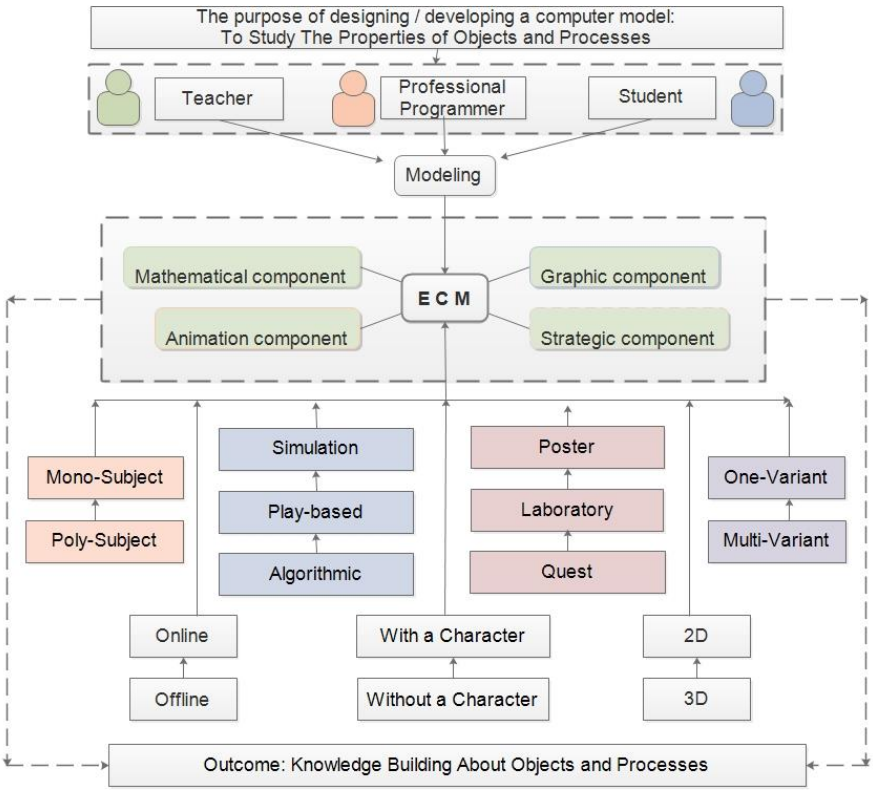

Fig.1. The system of designing the educational computer model.

Outcome: knowledge building about objects and processes.

The main classification features of the educational computer model are given in Table 1.

Table 1. Main classification features of the educational computer model.

Features	Content
Mono-Subject	Designed for one subject
Poly-Subject	One model can be applied to several subjects
Simulation	Performs a simulation of a process or phenomenon
Play-Based	Has an educational strategy, variability of choice of decisions
Algorithmic	Demonstration of the given algorithm execution
Poster	Implements one of the aspects: conformity, comparison
Laboratory	Performing a sequence of activities to get the result (creative elements included)
Quest	Considers the sequence of activities based on the previous result
Variant	Provides the problem-solving of one or more variants (one-variant / multi-variant)
Character-based	With / without a character
Achievable	Online / Offline

4.2 Application of educational computer models (ECM) in high school

Definition of the aims of ECM application:
- creation of a single educational information environment;
- formation of the student' information culture;
- formation of key and research competences of students in natural and mathematical subjects;
- formation of the individual trajectory of the student's development;
- preparation of students for independent educational and cognitive activity;
- improvement of the quality of knowledge acquisition.

Let's consider the application of educational computer models in chemistry and biology lessons

4.2.1.The use of the educational computer model at the STEM chemistry lessons

Chemical education is one of the important components of the general culture of a person living in the 21st century, who studies in the conditions of continuous creation of new chemical products and should be aware of environmental risks. The chemical knowledge gained by students in elementary school contributes to the discovery of the mysteries of the world through the knowledge of the processes of life of organisms at the molecular level, and computer modelling makes it possible to simulate these processes in the classroom.

However, the analysis of the results of the external independent testing showed that the number of graduates who choose the subject of chemistry to take EIT tests is decreasing annually: 2017 – 8%, 2018 – 6.3%, 2019 – 4% (of the total number of participants) (http://testportal.gov.ua/reg/).

This situation is conditioned by the fact that education needs transformation regarding the formation of educational environment and educational activity of students in the 21st century. The digital environment of students requires the formation of a digital educational environment, new perspectives on the knowledge of the surrounding world, values. Nowadays, the transformation of the educational environment has become a major systematic factor in the development of general secondary education. In order to understand the relevance of STEM education for general secondary education institutions, it is advisable to analyze the digital environment of students in everyday life: mobile phones, Internet, personal electronic cash desks, school electronic access system, electronic diary, blogs and websites, distance courses, electronic cards for travel, etc.

It is the introduction of STEM education that allows for the modernization of methodological foundations, content, volume of educational material of subjects of the natural and mathematical cycle, technological process of learning and formation of educational competences of a qualitatively new level [13]. It also contributes to the better preparation of students for further education, which requires different and more technically sophisticated skills, including the application of mathematical knowledge and scientific concepts.

The implementation of STEM education by teachers is carried out with the help of information and communication technologies that have changed the educational environment and opened new opportunities for organizing educational activities of stu-

dents in chemistry lessons. STEM education involves the orientation and fulfillment of practical tasks in the learning process using modern information and communication technologies, including computer modelling [16].

Computer modelling in chemistry lessons is used to study chemical phenomena and experiments that require sophisticated laboratory equipment or related to the use of explosive and expensive substances, to form research skills, cognitive interest, enhance motivation, and develop design thinking. The student can investigate the phenomenon by changing the conditions of the experiment and its course, comparing the results obtained, analyzing them, drawing conclusions and using them to self-test their knowledge [11].

The requirements for education of modern students are changing due to the trends of the development of education. Nowadays it is important not only to provide the student with a theoretical material, but also to form a competency for him/her to solve cognitive tasks (research, problem, applied) in the subject of chemistry. Other important aspects are the development of creativity in students, persistence in the search for solutions, team learning, the use of modern tools and devices to solve the task [6].

During a STEM lesson, students can use mobile phones and tablets, and the elements of computer modeling can be mastered in additional lessons. They may also get acquainted with the principles of computer modeling systems (CMODS) such as MANLab, STEM Alliance, Scientix, STEM Lesson Microsoft Education, Minecraft: Education Edition, PhET, computer models on the portal CK-12.org, GoLab and others.

The group work used during the STEM lesson enables students to develop the following skills: express their own opinions, defend their position, collaborate in a team, perceive the point of view of another team member. Introducing STEM lessons will teach students how to solve research problems, formulate assumptions / hypotheses, apply original ways of finding information, and develop analytical and critical thinking.

Let us consider an example of the students' group work using educational computer models during a STEM lesson.

The teacher prepares tasks for each team in the form of a QR-code.

The design of tasks is carried out according to the following procedure (Fig. 2): The first stage – formulation / description of the life situation.

The second stage – hypothesis formulation, assumption formulation.

The third stage – search for more information to solve the problem.

The fourth stage – selection of effective ways of solving the problem (refutation or confirmation of the hypothesis).

The work in the classroom begins with the announcement of the topic of the lesson: "Chemical equations" and the formation of working groups: scientists, technologists, engineers, mathematicians.

Group of scientists: analyzes theoretical material, generates messages for the class about the discovery and application of the Law of Conservation of Mass of Substances.

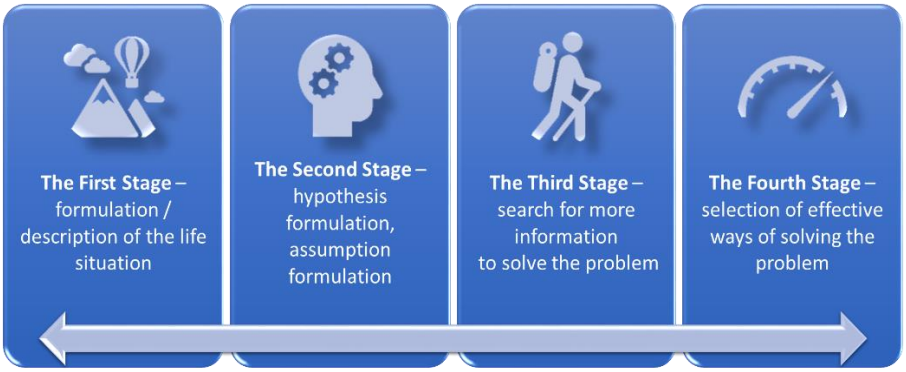

Fig. 2. Stages of the research tasks design.

Group of technologists: makes models of substances molecules involved in chemical reaction from plasticine.

Group of engineers: performs tasks on the board – balances chemical equations.

Group of mathematicians: calculates the number of atoms, molecules involved in a chemical reaction.

The teacher announces the next stage of the lesson – independent work. All students open gadgets and, with the help of an educational computer model, begin to perform the following tasks (Fig. 3-4):

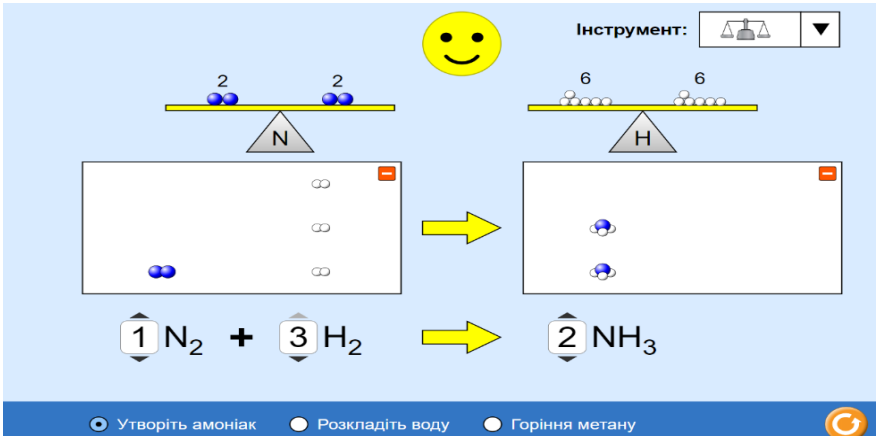

Fig. 3. Task “Balance the chemical equation” (https://phet.colorado.edu).

– Balance the chemical equation.
– Experimentally check if the number of atoms of each element is retained in the chemical reaction.
– Describe the difference between coefficients and indices in the chemical equation.
– Explain the transition from symbolic to molecular representation of the matter.

After mastering the basic skills, students return to their working groups to discuss the results and formulate conclusions.

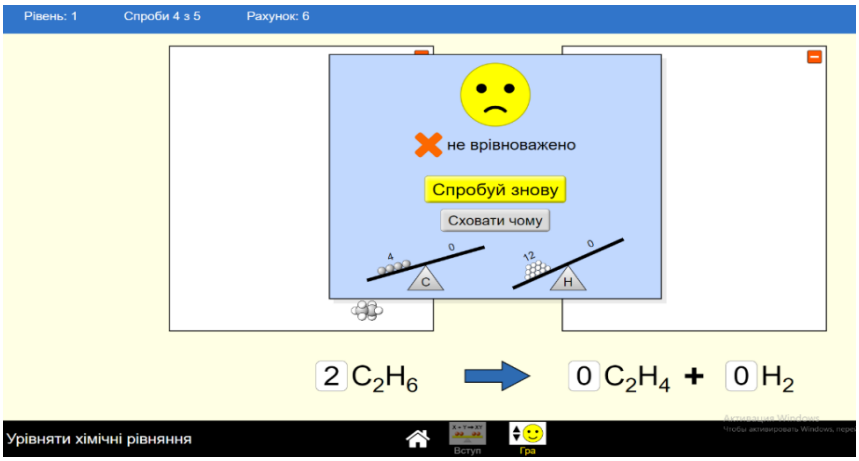

Fig. 4. The outcome of the task "Balance the chemical equation" (https://phet.colorado.edu)

The teacher uses the formative assessment technology to test students' learning in the classroom. This could be a signal card, a smiley-face emoji, quick-fire questions or a demo on an interactive test board before a lesson developed in LearningApps (https://learningapps.org/).

4.2.2.The use of the educational computer model at the lessons of biology

The analysis of the results of external independent testing allowed us to conclude that the number of graduates who choose the subject of biology for the EIT tests is decreasing annually: 2017 – 33.9%, 2018 – 25.3%, 2019 – 24% (of the total number of participants) (http://testportal.gov.ua/reg/).

The students point out that the subject is interesting but difficult to understand, as it is hard to understand that you do not see. Drawings, posters, mock-up models, which are displayed on separate topics, do not give a complete picture of the content of the subject. It is possible to activate the cognitive activity of students with the help of interactive visual aids. The development of IC-technologies, in particular mobile applications, has given impetus to developers to create such educational interactive visual aids, in particular in biology subject.

Teaching students through the use of mobile applications is not common in general secondary education institutions. In addition, the gadget in the hands of the child does not serve him/her as a means of learning – there is no scientific and methodological support for the use of mobile applications in the educational process. However, the development of Internet technologies, educational mobility, and widespread access to mobile applications give impetus to the use of mobile phones in the study of particular research projects and the use of computer modeling in the study of object characteristics and natural processes at the lessons of biology.

The use of models in the process of teaching biology and ecology school subjects has always been an up-to-date method. But they mostly used to be mock-up models (made of cardboard, plastic or wood). The innovative approach lies in the use of com-

puter models and modelling of natural processes, which increases the cognitive activity of students, broaden their outlook, and promotes better assimilation of the educational material.

The developers offer the following mobile applications: human anatomy, internal human organs, biological processes, bacteria, molecular genetics and more. They also provide tests for the school course in biology and the complex preparation for the EIT in biology (Fig. 5).

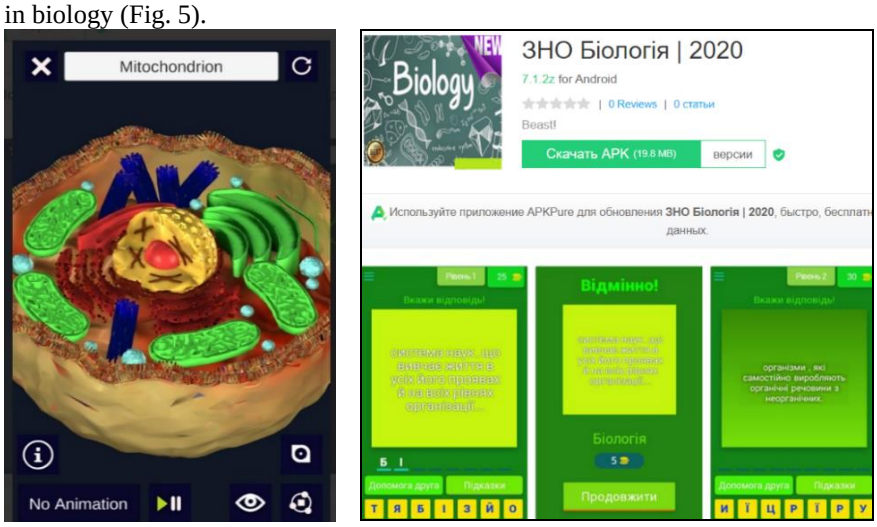

Fig. 5. Mobile applications in biology.

The applications offered by the developers can be subdivided into four groups: theoretical material, tests, dictionaries, 3D models (Fig. 6).

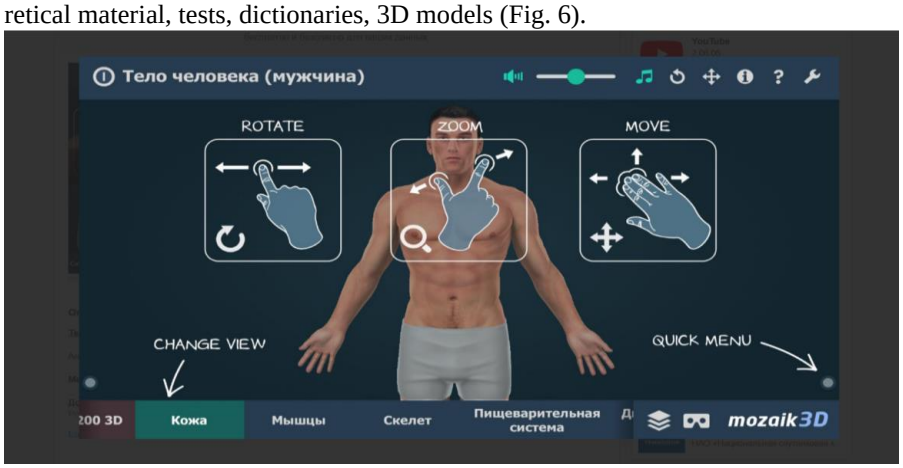

Fig. 6. Human body. 3D model.

There are very few computer models that can be used to perform modelling to study the characteristics of objects.

With the advent of computer models on the PhET portal, it is possible to carry out research tasks in the context of a school biology study. Toad preparation, 3D tour of the human body, immersion in different biomes – all these incredibly complex biological studies can be done with mobile applications and computer models.

The advantages of computer modelling in biology include: finding different ways to confirm / refute hypotheses; repeated experiment with different input data.

The main tasks of computer modelling while studying biology are the following: obtaining solid knowledge of the subject; study of complex issues in biology; search skills development, analysis and synthesis skills; study and application of modelling method in practice.

Experience shows the appropriateness of using PhET computer models in biology lessons in the process of mastering new material (processes illustration, their modelling, motivational training); testing knowledge; developing skills; conducting laboratory and practical classes; organization of research activities; integration of subjects; STEM training; while the most effective perception of information is provided by a combination of verbal and visual forms of its presentation [3].

When a student works with his/her own mobile phone, he/she usually does independent work. Independent work is a learning activity that is carried out by the student on his/her own for the purpose of mastering knowledge or mastering skills. Here are the signs of independent work: the presence of a specific task; performance evaluation criteria; forms of checking the performance; the obligation to do the work without assistance.

While planning the independent work using computer models in class the teacher should identify: its place in the lesson structure; the volume of work depending on both the level of students' readiness and the complexity of the research tasks; difficulties that may arise in the course of performing independent work; ways to check and evaluate students' performance.

It is desirable to discuss the results of students' independent work during the lesson: working in pairs (comparing results), mini groups (drawing conclusions), formative assessment (signal cards, quick-fire questions).

In the course of working on research assignments, it is advisable to organize group work for students, which requires the development of additional instructions.

To determine the degree of mastering the material and to clarify difficult moments in the process of mastering basic knowledge, the teacher conducts independent students' work, develops the tasks (Table 2) and formulates the problematic question: "What happens if you change your diet and use more protein and less carbs, but still maintain the same amount of calories?" and checks if the computer equipment (cell phones, tablets) is available to students.

Table 2. Card for "Food and exercise" computer model.

Cal/day	2000	2000
Proteins	600	806
Carbs	800	559
Fats	600	634
Conclusions:		

To find the correct answer, students should suggest assumptions / hypotheses to use the PhET computer model (Fig. 7) to test them.

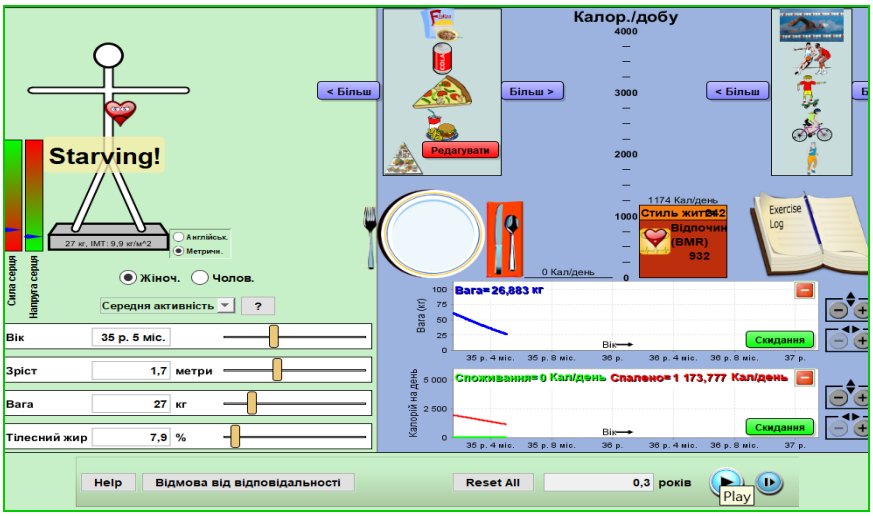

Fig. 7. "Food and exercise" computer model (https://phet.colorado.edu)

It is followed by the summary of the results and the formulation of the conclusions, which the students write in the table.

At the stage of formative assessment, students show the correct answer with signal cards: red card - weight will decrease; yellow card - weight will increase; green card - the heart rate will increase; blue card - the changes depend on the balance of your exercise and calorie intake, so there is not enough information.

5 Discussing of the usefulness and ease of using the educational computer modelling in teachers' work

In order to find out the usefulness of computer models in teachers' work, surveys were conducted in 39 Ukrainian educational institutions.

28.2% of teachers answered "no" when asked whether computer modelling would facilitate the work of a teacher while presenting new material (Fig. 8). Its use does not facilitate the work of the teacher: it takes extra time to develop tasks (2-3 options), organize student access to computers. Moreover, computer modelling is not integrated in the curriculum, there are no tasks in the textbooks, the academic time is not provided for such a kind of educational activity.

Analyzing the answers to the question of whether computer modelling is useful in the professional work of teachers, it was found that 87% of teachers, however, considered it useful (Fig. 9).

An important aspect for the development of computer modelling is the availability of the latest IC-technologies, the ease of their use as tools and their harmonious integration into the educational process. Analyzing the answers to the question of

whether computer modelling is easy to teach to students, it was found out that more than 74% of teachers consider it simple (Fig. 10).

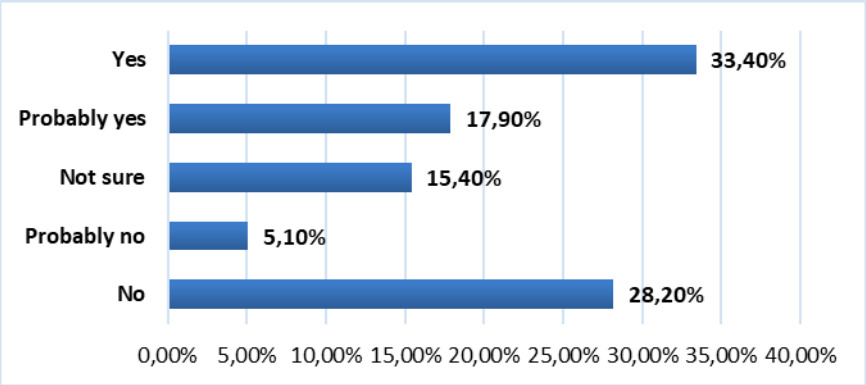

Fig. 8. Assessment of changes in the organization of the teacher's work.

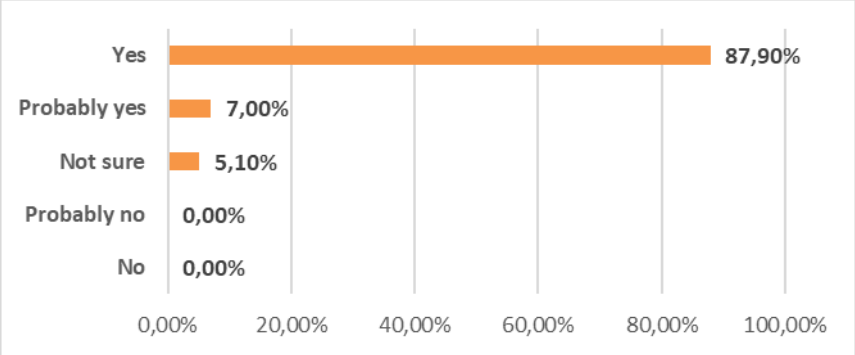

Fig. 9. Assessment of usefulness for the educational process.

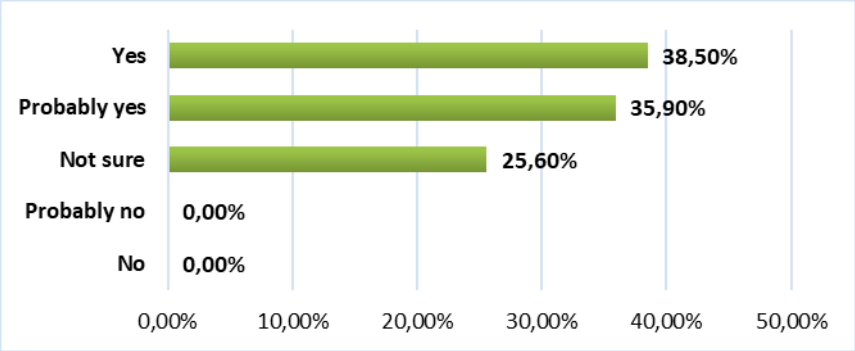

Fig. 10. Ease of use in the educational process.

The analysis of the results (Fig. 11) regarding the ease of computer modelling use in the educational process show that 25% of teachers recognized that there was a need to

work out such skills with students (lack of experience). Teachers also have fears that something may not turn on or download during the lesson.

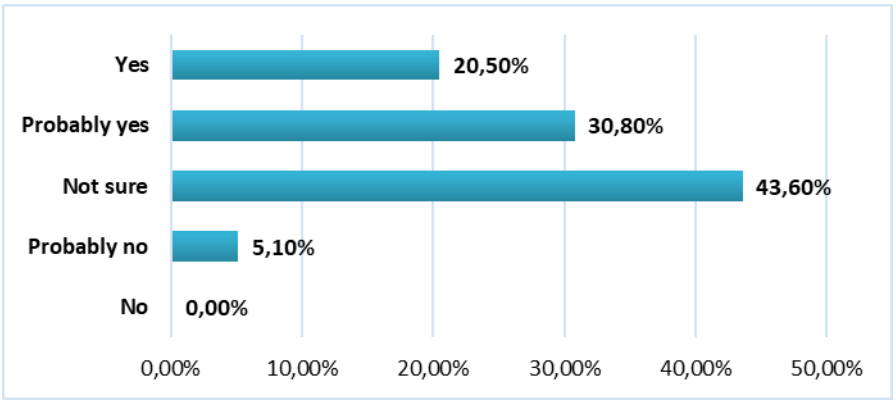

Fig. 11. Ease of the tool use.

There is a need to introduce changes both to the organization of the educational process and to the content of teaching natural and mathematical sciences for computer modelling to become an effective, easy to use tool for teachers. An important factor is the teachers' training in using the latest IC-technologies [7].

Therefore, systematic training of teachers to use computer modelling in the educational process is relevant, highly sought and timely. Such an impetus for the development of the teacher, improvement of his/her skills to work with the latest technologies will help to improve the quality of teaching, his/her digital and professional competence.

6 Conclusions and recommendations for further research

The use of computer modelling in the educational process is one of the priority areas for improving the quality of science education in general secondary education institutions. Not only will computer modelling help to better understand the content of the subject and to display environmental information, but it will also open up new opportunities for the teacher to organize the educational process, to form an individual trajectory for students' development, to organize independent and group work.

Chemistry and biology school subjects are not priorities for students in general secondary education, but they are important for the development of economy, society, and such fields as health care, ecology, agriculture.

Therefore, this contradiction must be resolved at the stage of the child's personality formation – at the school age. To this end, the content and the learning process should be improved.

The educational environment of these subjects should be filled not only with mock-up models and test tubes, but also with new equipment for students' research, including computer equipment and an Internet access point.

The use of computer modelling in STEM chemistry lessons will make it possible to use study time effectively, interestingly and productively. Under such conditions, students' theoretical knowledge will be backed up by practical skills.

The system of research assignments will enable the student to understand the processes occurring in nature, to check assumptions in practice, to draw conclusions and to discuss them with classmates [14], [17]. All these processes will activate the students' cognitive interest, accordingly, increase the quality of the educational process.

The use of computer modelling at the lessons of biology will simulate biological processes and phenomena, make virtual observations of biological objects, examine in detail their structure, the functioning of individual organs and systems, study the processes occurring in living organisms at the cellular and molecular levels [4], [5],[8].

Interactive models open cognitive opportunities for students by turning children from passive observers into active participants in virtual experiments.

Therefore, computer modelling is an effective tool for improving the quality of natural sciences education that requires the development of a teacher training system, cognitive tasks and organizational foundations of the educational process.

References

1. Bykov V., Burov O., Dementievska N.: Cybersecurity in a digital learning environment. Information technology and training tools, vol. 70. №2, pp. 313-331. (2019). (in Ukrainian).
2. Dementievskaya N. Selection of Internet resources for the formation of students' research competences in the study of physics at school. Collection of materials of a scientific conference, Kyiv: IITLT of the NAES of Ukraine, pp.78-80. http://lib.iitta.gov.ua/715956. (2019). (in Ukrainian).
3. Dementievska N.: PhET online simulation site as a reliable and safe environment for building students' competences in the natural sciences and mathematics. Materials of the scientific conference (March 27, 2018). Kyiv: IITLT of the NAES of Ukraine, pp. 139-141. (2018). (in Ukrainian).
4. Kaheru, S., Kriek, J.: The effect of computer simulations on acquisition of knowledge and cognitive load: A gender perspective. African Journal of Research in Mathematics, Science and Technology Education, vol. 20 (1), pp. 67–79, doi:10.1080/10288457.2016.1150558. (2016).
5. Korotun, O.V., Vakaliuk, T.A., Oleshko, V. A. Development of a web-based system of automatic content retrieval database. Proceedings of the 2nd Student Workshop on Computer Science & Software Engineering, vol. 2546, pp. 182-197. http://ceur-ws.org/Vol-2546/paper13.pdf. (2019).
6. Kunnath, B., Kriek, J.: Exploring effective pedagogies using computer simulations to improve Grade 12 learners' understanding of the photoelectric effect. African Journal of Research in Mathematics, Science and Technology Education, vol.22 (3), pp. 329–339, doi: 10.1080/18117295.2018.1531500. (2018).
7. Lytvynova S., Melnyk O. Professional Development of Teachers Using Cloud Services During Non-formal Education. Proceedings of the 13 International Conference on ICT in Education, Research and Industrial Applications. Integration, Harmonization and Knowledge Transfer, vol. 1614. pp. 648-655. http://ceur-ws.org/Vol-1614/paper_51.pdf. (2016).

8. Lytvynova S.: The Model of the use of Computer Modeling System for Formation Competences of Natural and Mathematical Subject Students. Physical and Mathematical Education, vol. 1(19), pp. 108-115, doi:10.31110/2413-1571-2019-019-1-017. (2019). (in Ukrainian).
9. Lytvynova, S., Burov, O., Slobodyanyk, O.: The Technique to Evaluate Pupils' Intellectual and Personal Important Qualities for ICT Competences. Proceedings of the 15th International Conference on ICT in Education, Research and Industrial Applications. Integration, Harmonization and Knowledge Transfer, vol-2393, pp. 170-177. http://ceur-ws.org/Vol-2393/paper_382.pdf. (2019).
10. Matvijchuk, O., Sergiyenko, V., Podlasov, S.: Realization of interdisciplinary connections of physics and computer science on the basis of study of computer simulation of physical processes. Collection of scientific works. Pedagogical Series: Innovations in the Teaching of Physics and Disciplines in the Technological Educational Industry: Kamianets-Podilskyi, vol.14, pp. 24-26. (200)8. (in Ukrainian).
11. Nxumalo-Dlamini, N., Gaigher, E.: Teachers' Use of Computer-based Simulations in Teaching Electrolysis: A Case Study in Eswatini. African Journal of Research in Mathematics, Science and Technology Education, vol. 23, №3. (2019)
12. Pinchuk O. P., Sokolyuk O. M.: Teaching and learning activities of students in the use of Internet-oriented educational technologies. Eleventh International Scientific and Practical Conference IES-2018. pp. 266-267. (2018). (in Ukrainian).
13. Pinchuk O., Burov O., Lytvynova S.: Learning as a Systemic Activity. Advances in Intelligent Systems and Computing, vol. 963, pp. 335-342, doi.org/10.1007/978-3-030-20135-7_33). URL: link.springer.com/content/pdf/10.1007%2F978-3-030-20135-7_33.pdf. (2019).
14. Slipukhina I., Kuzmenkov S., Kurilenko N., Mieniailov S.: Virtual Educational Physics Experiment as a Means of Formation of the Scientific Worldview of the Pupils. Proceedings of the 15th International Conference on ICT in Education, Research and Industrial Applications. Integration, Harmonization and Knowledge Transfer, vol-2387, pp. 318-333. (2019).
15. Slobodianyk O.: Computer Simulations in the Study of Atomic Physics in General Secondary Education. Science Notes. Series: Pedagogical Sciences. Kropyvnytskyi. CUSP University named after V. Vinnychenko, vol.179, pp.146-151 (2019). (in Ukrainian).
16. Slobodianyk O.: Theoretical aspects of simulation modeling in teaching physics. Science Notes. Series: Pedagogical Sciences. Kropyvnytskyi. CUSP University named after V. Vinnychenko., vol.173. pp.183-187. (2018). (in Ukrainian).
17. Spirin O., Burov O. Models and applied tools for prediction of student ability to effective learning. 14th International Conference on ICT in Education, Research and Industrial Applications. Integration, Harmonization and Knowledge Transfer. CEUR-WS, vol-2104, pp. 404-411. (2018).