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The use of computer modeling in the educational process based on the example of studying Coulomb's law

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Abstract. The study analyzes computer modeling tools intended for use in educational and scientific contexts. The concept of modeling as a method of research and a teaching tool is examined, the emphasis is placed on computer modeling. It is shown how physical laws, particularly Coulomb's law, can be studied through modeling. The study uses pre-made simulators, spreadsheets, mathematical packages, as well as our own software in Object Pascal and Python. Experimental testing has confirmed the effectiveness of computer modeling in teaching natural sciences. A survey of students and teachers showed interest in further use of simulation tools in the educational process.

1. Introduction

Modern researchers see information culture as the level of development of information relations in society and as a characteristic of people's information activities. Sustainable computer skills are an important component of information culture. Digital competence is the awareness and the use of digital tools in accordance with the needs of personal, professional and social life (for more details, see [1]). Digital competencies include: the ability to search for, evaluate and process information, as well as understand and use data; the skills of using digital tools to communicate and collaborate effectively with others; the ability to create, edit, and integrate digital content in various formats; the ability to identify risks and take measures to protect themselves from digital threats; the ability to use digital tools to solve problems and make decisions [2, 3].

The modeling method is used to study complex processes and phenomena when conducting experiments is costly or impossible [4]. A model is a specially created object that replicates certain characteristics of the research object for the purpose of its analysis, and modeling is a method of recreating the characteristics of the research object in question. Models can be created both from physical objects (for example, wind tunnels for studying aircraft aerodynamics or simulators for flight and automotive training) and from abstract objects that can be represented by mathematical, graphical, symbolic, and conceptual models.

Computer modeling is the process of creating computer programs or objects in computer programs to depict and analyze various processes, phenomena, systems, or objects in an electronic environment. This approach is used to study and analyze phenomena that may be difficult or even impossible to study without the use of computer calculations.

Computer modeling can be used to study a variety of objects and processes, from climate change to the behavior of physical systems or economic phenomena. It allows us to analyze complex relationships and conduct research in conditions where real-world experiments would be difficult or dangerous. The existing capabilities of computer modeling make it possible to consider it as a visual tool for learning through research. This perspective is the rationale for studying the possibility of using computer modeling in educational activities.

The current state of computer modeling in education and research is a fundamental aspect of the development of educational and scientific practices. Given the rapid technological progress, it is not just a tool for visualizing concepts, but also an important component in solving complex problems that arise in the educational and scientific environment.

In education, computer modeling defines an activity-based approach to learning and development. Its use covers a wide range of subjects, from math and physics to the humanities. Virtual laboratories, simulations, and interactive exercises provide an opportunity to create a realistic learning environment where students can experiment, solve problems, and develop critical thinking. This promotes active participation and improves conceptual learning, which is essential for developing a deep understanding of the subjects.

In scientific studies, computer modeling plays a key role in solving various problems and studying complex systems [5]. From simulations of physical processes to the analysis of large amounts of data, this technology allows researchers to analyze complex relationships quickly and efficiently. Modeling expands the possibilities of experiments, allowing the study of phenomena that would otherwise be difficult, costly, or impossible. Thus, the current position of computer modeling in scientific research demonstrates its key role in advancing knowledge and developing the scientific field.

According to Jurakulov [6], physics has a very important place in science. Therefore, physics education should be conducted carefully and effectively. As studies have repeatedly shown, classical teaching models are so ineffective in physics education that the result at the end of the learning process is almost insignificant. Therefore, physics education should be based on models of active learning, the effectiveness and naturalness of which has been proven [6]. Such methods of active learning include the research method, which can be implemented through computer modeling.

The purpose of the study is to analyze the various computer modeling tools available for the study of physics, in particular, for the study of Coulomb's law.

2. Literary review

Modeling is a complex and multifaceted activity that requires certain knowledge, skills, and abilities. Nevertheless, it is not only advisable to use modeling for familiarization, but also to actively use it during secondary education. Teachers need to be trained for such activities, and the study by Velychko and Fedorenko is dedicated to this process for future computer science teachers [7]. The authors concluded that the content area "Modeling" in a school computer science course is used to develop algorithmic and structural thinking, to develop the ability to analyze various processes and phenomena and find out their cause-and-effect and structural relationships, to determine the sequence of actions to be taken to solve certain problems. Therefore, the preparation of future computer science teachers to teach this topic should be formed during the study of this section on certain educational components, including the educational component "Programming".

The study by Kaydan and Melnichuk highlights the process of creating conditions for

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improving and enhancing the results of the educational process through computer modeling in secondary school physics lessons using the MathCad system [8]. The authors claim that with the help of computer modeling in secondary school physics lessons using the MathCad system, we are able to solve most of the problems that arise in the learning process, such as the use of advanced information technologies; the change of forms of education and activities within one lesson; making it easier for the teacher to prepare for the lesson and involve students in these activities; the expansion of opportunities for illustrative support of the lesson, presenting physical processes in the form of graphs, etc.; the implementation of individual work; the implementation of integrated lessons that strengthen the links between subjects; the organization of interactive forms of control of skills, abilities and knowledge; the organization of research, independent, creative work at a fundamentally new level with the possibility of access to the global information space.

Bilousova et al. [9] addressed a similar issue in their study using GeoGebra as a modeling platform. A complex was developed for in-depth study of mathematics. The models in the developed complex are grouped into three sections. The first group consists of models that allow potential students to learn the basic essential mathematical concepts (objects). The second group is focused on the realization of transdisciplinary connections between mathematics and other subject areas. The third group covers models that provide solutions to real-world problems based on model research.

The general issues of creating a model for computing in physics education are addressed by Phillips et al. [10]. The researchers note that despite its disciplinary importance, the integration of computing in physics education remains a challenge and, moreover, tends to be viewed in a narrowly focused way. The authors extend the Physics Education Research concept of computing by constructing a metamodel as a model of modeling that provides insights into computational modeling from the perspective of philosophy of science and previous achievements. The metamodel is formulated in terms of practice, what physicists do, and how they inform each other. The authors implement the developed metamodel in the educational environment, through the production, creation of collaborative physical and digital artifacts designed to promote students' free will, creativity and self-expression along with the study of physics.

The importance of graphical modeling as an important stage in solving a physical problem is shown in the publication by Lymareva et al. [11]. The authors note that the problem of visualizing input information during the study of physics is a significant didactic problem. The solution to it lies in the need to teach students to process different types of graphical information as efficiently as possible, to combine them with each other, to represent physical phenomena and processes in a graphical form (create physical models) and to use visual information to find answers to questions.

Dron studied the formation of research competencies in students during computer modeling of physical phenomena and processes in distance learning [12]. The author came to the conclusion that independent modeling of physical phenomena and processes in distance learning allows students to deepen their understanding of the basics of the studied natural phenomena and processes, the principle of operation and structure of modern technology by visualizing processes with different parameters of the physical model. In addition to high rates of qualitative learning, students' interest in studying the subject increases, which opens up wide opportunities for independent work, promotes the development of creative activity, the formation of research competencies, stimulates the acquisition of additional knowledge and its consolidation, which makes it possible to educate a well-developed personality with the skills of the 21st century.

The study of the modeling method as a means of forming information and analytical competence in the study of physics is covered in the publication of Isychko and Guryevska [13]. Comparing the use of the modeling method and the structural and logical scheme of the formation of scientific knowledge and the processes leading to the formation of information and analytical competence, we can conclude that when using the modeling method in the study of physics, all components of this competence can be formed in higher education students.

Methodical features of educational modeling of physical phenomena based on the example of implementing the model of oscillation of a system of coupled oscillators and the model of frequency interaction of two oscillators are studied by Holovina and Holovin [14]. To implement the models, the Python programming language is used with the use of the specialized Visual library. The author emphasizes the powerful influence of the model approach on the quality of natural science education. It is noted that this approach contributes to the formation of causal, abstract and logical, materialistic thinking. It contributes to a comprehensive vision of physics, mathematics and computer science as one closely connected structure of knowledge, in which each component carries its own meaningful load.

In STEM education [15], there is an activity pattern such as "design, make, explore". How to build learning activities based on this principle is shown in the publication by White [16]. This study describes research activities very closely, but in slightly different terms. Nevertheless, it is useful for understanding the necessary direction of building learning activities that will result in preparation for research of objects of any nature.

Advanced research on the problems of using simulation in the educational process has been considered at the international workshop Computer Simulation in Education since 2005. In 2021, a review of the results of the workshop was published by Kiv et al. [17]. In 2022, the review was completed by Papadakis et al. [18].

3. Theoretical background

Computer modeling is a method of solving the problem of analyzing or synthesizing a complex system based on the use of its computer model. This method is based on the fact that an existing model is used to find qualitative and quantitative results, the main requirement for which is the ability to reflect the main factors and mutual relations characterizing real situations, criteria and, if any, limitations [19].

A computer model is an information model implemented with the help of a computer. Meanwhile, information models, along with gnosiological and semantic models, are abstract (ideal) models that describe research objects using a certain language. In this case, abstractness means that it is logical concepts, such as diagrams, graphs, algorithms, equations, etc., that are the components of the model, not physical elements. The very essence of creating such models is to establish certain dependencies between groups of parameters of the object under study [20].

The actual implementation is performed using various tools. For this purpose, you can use a variety of instrumental software tools and environments (MathCad, MatLab, Maple, VisSim, Genius, etc.). The advantage of using mathematical packages is that they can be used as ordinary calculation tools, tools for simplifying expressions, and tools for generating graphics and sound. The means of interaction with the Internet, which are realized by generating HTML pages directly in the process of calculations, have also become widespread.

A qualified user who knows at least one of the programming languages can create the required program or even a whole set of programs independently. However, this approach usually requires a lot of labor to program, debug, and test each program, so to save time, it is advisable to use the specified application software packages, the areas of application of which largely overlap.

The next option is software packages for simulation modeling. Simulation modeling is a research method when the system under study is replaced by a model that can describe the real system with sufficient accuracy. And this model is used to conduct the necessary experiments, the purpose of which is to obtain information about this system. This type of modeling is used when it is not possible to experiment on a real object, build an analytical model, or create a simulation and track the behavior of the system in real time. This type of modeling is the most effective when designing and analyzing production systems, determining requirements for equipment and communication network protocols, modernizing various processes in the business field, etc. The most popular simulation modeling packages are: Arena by Rockwell Automation, AnyLogic by XJ Technologies, GPSS World by Minuteman Software, Process Charter 1.0.2 by Scitor, Powersim 2.01 by Modell Data AS, etc. The packages differ in the style of modeling, i.e., the environment with the help of which models are created: in Process Charter, the model is built using flowcharts, Powersim and Ethink use the System Dynamics notation system, and Extend uses component blocks.

Given the need for qualified specialists in various fields of modern production, it is advisable to involve computer-aided design (CAD, computer aided design) systems in the educational process. These systems allow for the design of technological processes with less time and money spent and an increase in the accuracy of the designed processes and processing programs. CAD technical support is based on the use of computer networks and telecommunication technologies, personal computers and workstations, and mathematical support is characterized by a variety of methods of computational mathematics, statistics, mathematical programming, discrete mathematics, and artificial intelligence. CAD software systems are among the most complex modern software systems based on the operating systems Unix, Windows, programming languages C, C++, Java and others, modern CASE technologies, relational and object-oriented database management systems (DBMS), open systems standards and data exchange in computer environments. One example is AutoCAD, the best-known of Autodesk's products, a universal computer-aided design system that combines two-dimensional drawing and three-dimensional modeling. AutoCAD speeds up the work of creating plans, increases the speed and accuracy of their execution, and the available visualization tools, such as animation and realistic tinting, allow you to identify shortcomings at the early stages of design.

4. Research methodology

The methods of scientific literature analysis, comparative analysis of software tools and expert evaluation of computer modeling capabilities were used to study computer modeling tools.

The analysis of the scientific literature made it possible to identify the main areas of application of computer modeling in education and science, as well as the potential advantages and limitations of different approaches. A search was conducted in the databases of scientific publications using keywords related to the research topic.

The comparative analysis of computer modeling tools involved consideration of the capabilities of the most common programs, both general and specialized. Functionality, usability, etc. were analyzed. The experts were teachers, physics teachers, pupils and students studying physics.

5. Research results

Computer modeling requires tools that can best investigate the model created. Depending on the complexity and objectives of the model study, these tools can include ready-to-use software simulators, data storage and processing tools (e.g., spreadsheet processors), computer algebra packages, or even custom software. We are studying the process of teaching computer simulation, and therefore it is necessary to consider all of these tools in order to try to formulate the advantages and disadvantages of each.

In order to make the review more substantive, let's define a topic from the school physics course – Coulomb's law.

Simulators that can be used in school physics courses cover a significant amount of educational material. The most well-known collections include [21]: PhET (`https://phet.colorado.edu/uk/`), LabXchang (`https://www.labxchange.org`), Concord (`https://concord.org`), PraxiLabs (`https://praxilabs.com`), Labster (`https://www.labster.com`), MERLOT (`https://www.merlot.org/merlot/`), Physics at School kit (`https://www.vascak.cz`), etcs. They are interesting both for organizing and conducting e-learning and for self-education. The simulations presented here also include simulations for the topic we have chosen (figure 1). It is clear that each simulation represents an appropriate methodological approach to the study of Coulomb's law. This can be demonstrated on physical devices or on imaginary objects. In any case, the choice of simulation depends on the prevailing teaching technology and the availability and accessibility of simulations for use.

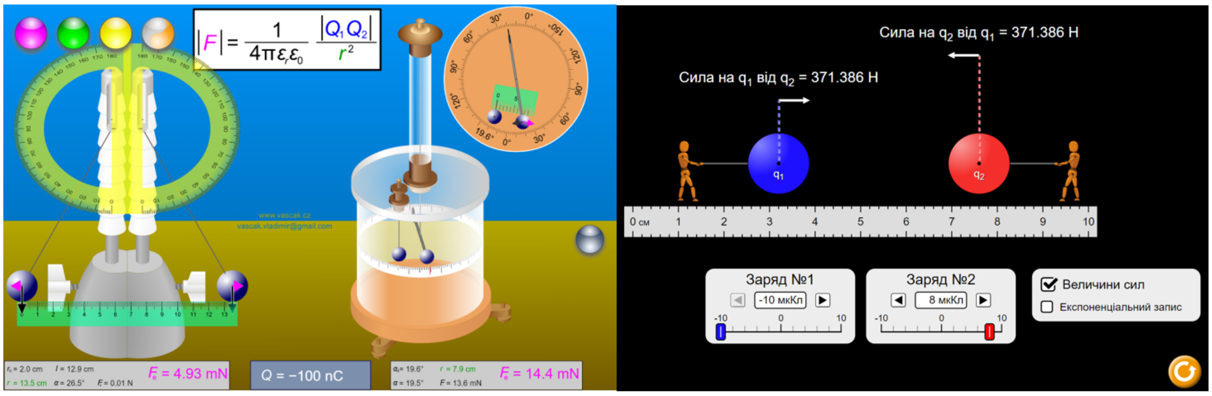


Figure 1. Simulation of Coulomb's law in the "Physics at School kit" and "PhET" collections.

The analysis allows us to identify some intermediate results. The possibilities must include:

(i) Realism of the created models. Modern simulators of physical processes make it possible to create very realistic models, reflecting various physical phenomena with great accuracy. This contributes to the faithful reproduction of the real world and allows you to conduct research in conditions that mimic reality.

(ii) Interactivity and the ability to conduct experiments. Simulators provide an opportunity to study physical phenomena in an interactive environment. Users can change parameters, observe changes, and reproduce experiments without real equipment.

(iii) Flexibility of model parameters settings. Users can easily customize the simulation parameters to suit their needs and study the impact of different conditions on the results of physical processes.

The existing limitations include the following. First, it is the complexity of modeling. Some physical phenomena can be difficult to model accurately. For example, quantum phenomena are often difficult to account for in simulations. Second, there is cost and resources. Creating high-quality simulations can require significant financial and technical resources. This can present a limitation to access to modern and powerful simulators. Third, there is the need for expertise. To use physical process simulators effectively, users often need to have some expertise in the area under study in order to interpret the results and configure the simulation parameters correctly.

Spreadsheets (or spreadsheet processors) are not only a tool for calculating accounting spreadsheets. Spreadsheets are an excellent all-purpose tool for calculating, storing and analyzing results. They are more suitable than any other application software as a platform for computer modeling. The user can arrange the data they need for research, perform transformations on it, sometimes quite complex ones, implement a computer model, check its response to possible changes in parameters, analyze the results, etc. The main thing when using spreadsheets in modeling is to understand how to implement a computer model.

Spreadsheets are available both as desktop programs and as services. Popular spreadsheets today include Microsoft Excel (Microsoft 365), LibreOffice Calc (LibreOffice), ONLYOFFICE Spreadsheet Editor (ONLYOFFICE), WPS Spreadsheet (WPS Office), and others. The above examples are also available for mobile platforms. Among the cloud services, it is necessary to mention such resources as Google Sheets, Microsoft Excel Online, ZOHO Sheet, ONLYOFFICE Spreadsheet Editor online and others. Most of them are available under free licenses or licenses with some restrictions. Thus, we can state that there is a significant list of available spreadsheet processors for secondary education and the issue of their availability is not currently an issue. Thus, we can consider the advantages and limitations of using spreadsheet processors in computer modeling. The advantages include:

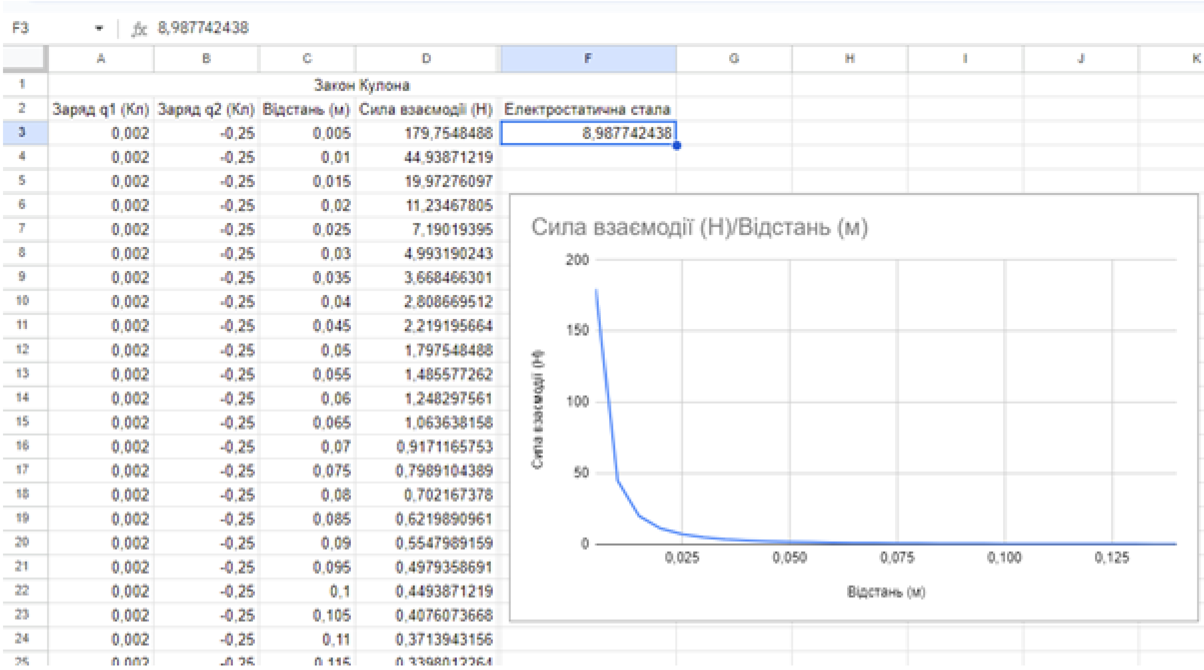
(i) Ease of use. Spreadsheet processors such as Microsoft Excel or Google Sheets are known for their ease of use. They have an intuitive interface that allows users to quickly create and edit data. In addition, there is a large number of reference materials that answer a particular question, including in the form of training videos.
(ii) Calculations and Formulas. Spreadsheet processors allow you to use a variety of formulas and functions to automate calculations. This makes them effective for performing mathematical operations and creating models. It is calculations that we need in order to conduct modeling, study the model by various parameters, and use built-in functions.
(iii) Flexibility. Users can easily manipulate data, add new columns and rows, sort and filter information, which allows them to quickly change model parameters. Or even create a new model based on the results of previous calculations and research.
(iv) Easy introduction. In the first stage of learning, solving complex problems is possible without programming, using tasks and copying formulas on the worksheet. This stage is important for step-by-step learning.
(v) Step-by-step implementation. When solving various problems, a new aspect appears that is critical for mastering the material which is the display of the solution process, not just the final result. This approach allows you to feel how the calculation process is carried out, to study the impact of the argument on the speed of convergence. This helps transform a student from an observer to a researcher.
(vi) Data visualization. The simplicity of creating charts to visualize the results helps to deepen the understanding of data visualization, provides the necessary experience, stimulates creative search and develops creative thinking.

The disadvantages and limitations of using spreadsheet processors in computer modeling include the following:

(i) Limited complexity of models. Spreadsheet processors often face a limitation in terms of modeling complexity. They may not be powerful enough for highly detailed and complex physical or mathematical models. However, this limitation in no way affects the use of spreadsheet processors in modeling training.
(ii) Lack of realistic model behavior. Spreadsheet processors do not always provide a high level of realism in simulations. They may not accurately reproduce complex physical or system interactions. They cannot animate the results, etc.
(iii) Possibility of errors with large amounts of data. With large amounts of data and complex calculations, spreadsheet processors can be slow and error-prone, especially if a large number of formulas and cell-to-cell references are used, and formulas and data are moved and copied. Potential cyclic dependency of the data.

(iv) Limited functionality related to the versatility of spreadsheet processors. Spreadsheet processors usually have limited functionality compared to specialized computer modeling tools. This can make it difficult to solve tasks that require advanced functionality.

Here are some examples of how spreadsheets can be used when studying Coulomb's Law. First of all, we can show in practice what a direct relationship and an inverse relationship are. To do this, it will be enough to calculate the value of the force of interaction between charges at constant values of charges and a variable part of the distance between them. Using the obtained values, we will construct a line graph and demonstrate that the graph will not be a line (figure 2).


F3 fx 8,987742438

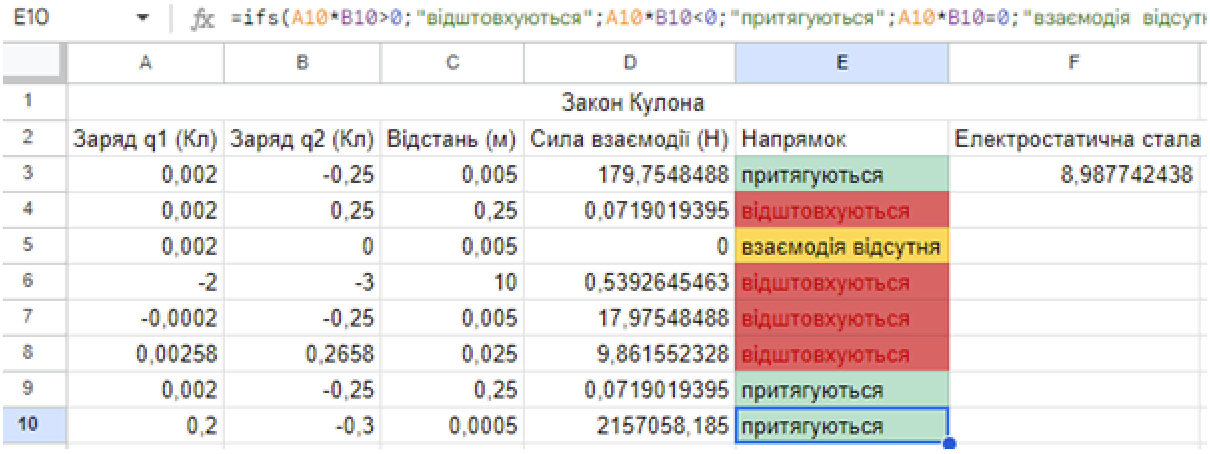
	A	B	C	D	F
1	Закон Кулона				
2	Заряд q1 (Кл)	Заряд q2 (Кл)	Відстань (м)	Сила взаємодії (Н)	Електростатична стала
3	0,002	-0,25	0,005	179,7548488	8,987742438
4	0,002	-0,25	0,01	44,93871219	
5	0,002	-0,25	0,015	19,97276097	
6	0,002	-0,25	0,02	11,23467805	
7	0,002	-0,25	0,025	7,19019396	
8	0,002	-0,25	0,03	4,993190243	
9	0,002	-0,25	0,035	3,668466301	
10	0,002	-0,25	0,04	2,808669512	
11	0,002	-0,25	0,045	2,219195664	
12	0,002	-0,25	0,05	1,797548488	
13	0,002	-0,25	0,055	1,485577262	
14	0,002	-0,25	0,06	1,248297561	
15	0,002	-0,25	0,065	1,063638158	
16	0,002	-0,25	0,07	0,9171165753	
17	0,002	-0,25	0,075	0,7989104389	
18	0,002	-0,25	0,08	0,702167378	
19	0,002	-0,25	0,085	0,6219890961	
20	0,002	-0,25	0,09	0,5547989159	
21	0,002	-0,25	0,095	0,4979358691	
22	0,002	-0,25	0,1	0,4493871219	
23	0,002	-0,25	0,105	0,4076073668	
24	0,002	-0,25	0,11	0,3713943156	
25	0,002	-0,25	0,115	0,3398012264	

Figure 2. Coulomb's law in Google Sheets.

Second, we can demonstrate whether the charges will attract or repel at different values. To enhance the visualization, we can use conditional formatting (figure 3)

Computer algebra systems are as useful a tool for computer modeling as spreadsheets. The ability to store data, calculate various values, including through the use of programming elements, built-in functions, and additional modules, make it possible to consider these systems as a full-fledged implementation of a computer model. The available data visualization tools and the absence of a workflow, which is surprisingly important for research, indicate the advantages of computer algebra systems in modeling. The caveats include the need to master the systems at the level of a confident user, since each of them has its own specifics, set of commands, etc. The computer mathematics package Scilab is an excellent tool for conducting research that requires calculations. This package can be applied in our case. Despite the fact that the system, as already mentioned, requires some knowledge, its consideration is already included in the curriculum and relevant textbooks on computer science at the secondary level in Ukraine. We can define either a simple variant of calculating the value of the interaction force according to Coulomb's law or a more complex variant for an array of values and then experiment with the parameters (figure 4).

Within the framework of academic freedom, each teacher is not prohibited from using not only different methodological approaches to teaching, but also the choice of teaching aids. It is clear



E10 fx =ifs(A10*B10>0;"відштовхуються";A10*B10<0;"притягуються";A10*B10=0;"взаємодія відсут

	A	B	C	D	E	F
1	Закон Кулона					
2	Заряд q1 (Кл)	Заряд q2 (Кл)	Відстань (м)	Сила взаємодії (Н)	Напрямок	Електростатична стала
3	0,002	-0,25	0,005	179,7548488	притягуються	8,987742438
4	0,002	0,25	0,25	0,0719019395	відштовхуються	
5	0,002	0	0,005	0	взаємодія відсутня	
6	-2	-3	10	0,5392645463	відштовхуються	
7	-0,0002	-0,25	0,005	17,97548488	відштовхуються	
8	0,00258	0,2658	0,025	9,861552328	відштовхуються	
9	0,002	-0,25	0,25	0,0719019395	притягуються	
10	0,2	-0,3	0,0005	2157058,185	притягуються	

Figure 3. Coulomb's law in Google Sheets.

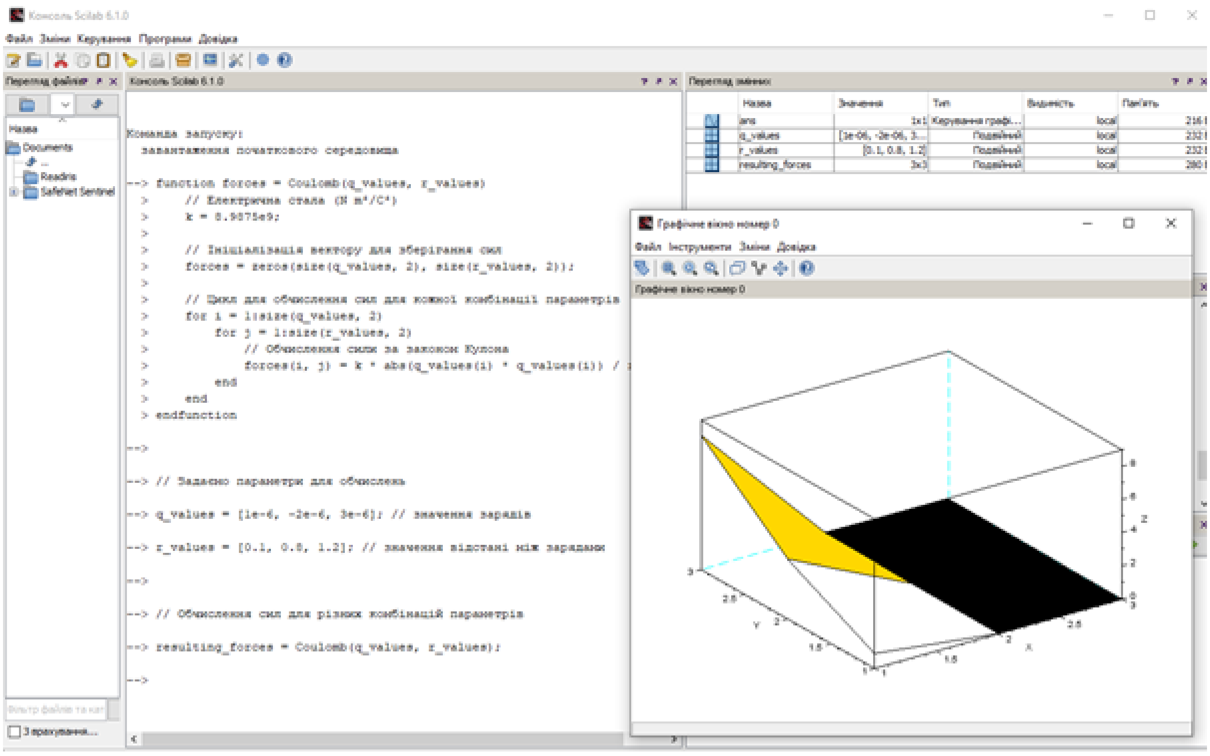


Figure 4. Study of Coulomb's law in the Scilab package.

that not every teacher will create their own implementations of a computer model, but this is a possibility and should be included in the comparison of computer modeling tools and methods in secondary education. To implement a computer model without using existing general and special-purpose application software, knowledge and experience in programming are required. Moreover, this experience should correlate with the students' programming experience, because it is one thing to demonstrate the created model when familiarizing the material in general. To provide students with the opportunity to experiment with the implemented computer model, including during self-education activities, is a completely different issue.

In the course of studying the content area “Modeling, Algorithmization and Programming” of the subject “Computer Science”, students are introduced to several programming languages and programming paradigms. Even at the initial stage of studying computer science, the concept of a model is present in problem solving. Later on, modeling is distinguished as a separate method of solving problems, and thus modeling can be used in secondary education. Today, school textbooks cover the Pascal (Object Pascal) programming language for the Lazarus and Python development environments, which can be used to perform computer modeling. Programming languages are fundamentally different, and accordingly, their application will be radically different. Pascal uses a compiler, so we can create application software and only then use it for research. To save data, you need to use files, and there is an acceptable code execution speed.

An interpreter is used for the Python programming language, so in the course of the modem experiment, we can change the preliminary research plan depending on the results obtained or our own vision of further steps. For long-term data storage, it is necessary to use files, there is a possibility to use modern data structures and methods of their processing, and slow execution of instructions. An equally important point when using Python is the use of a sufficient number of extension libraries. We use Pandas, NumPy, SciPy, Matplotlib, Seaborn, and other libraries. With these libraries, an interactive session in the Python environment turns into the same full-fledged data processing environment as MATLAB, Octave, R-Lab, and SciLab.

Speaking of our topic “Coulomb’s Law,” we can use Object Pascal to create an application that calculates the value of the interaction force for the entered values of charges and distances (figure 5). In addition, we can plot the dependence of the interaction force on the distance between charges.

If we look at our topic ”Coulomb’s Law”, we can create an application in Object Pascal that will calculate the value of the interaction force for the entered values of the charges and distances (figure 5). In addition, we can plot the dependence of the interaction force on the distance between the charges.

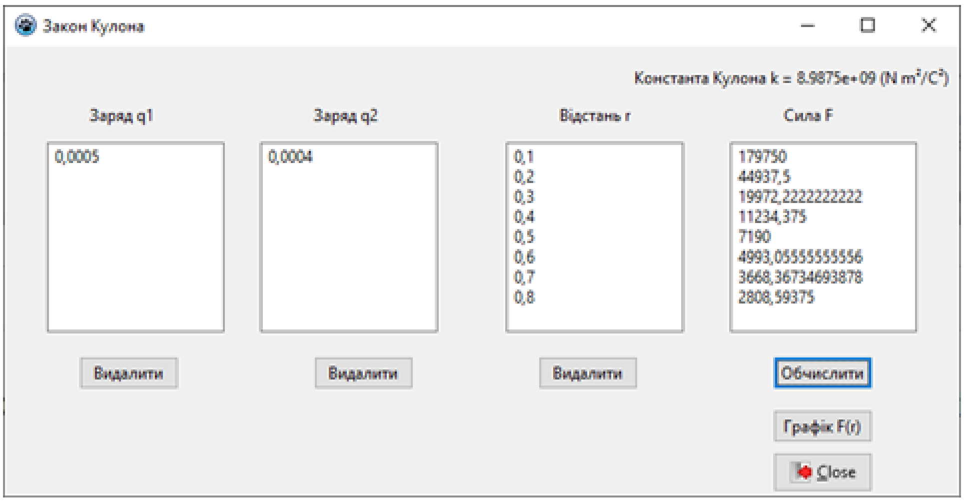


Figure 5. Calculation of the value of the Coulomb force by an application running in the Lazarus development environment.

To visualize the interaction of point electrostatic charges, power lines are usually drawn to show how the charges interact with each other. For such a visualization, one can also use the Python programming language using appropriate libraries or ready-made developments (figure 6, figure 7).

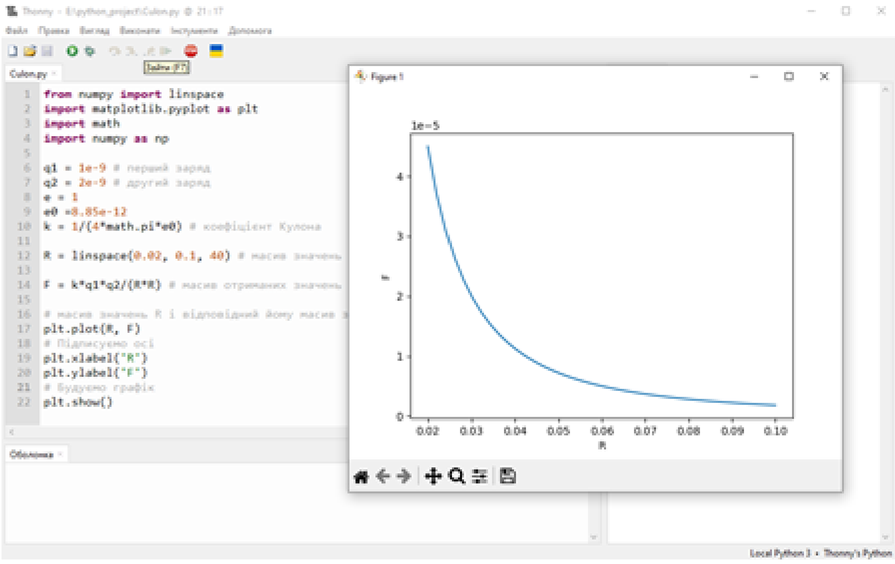


Figure 6. Calculation of the value of the Coulomb force by an application made in the Lazarus development environment.

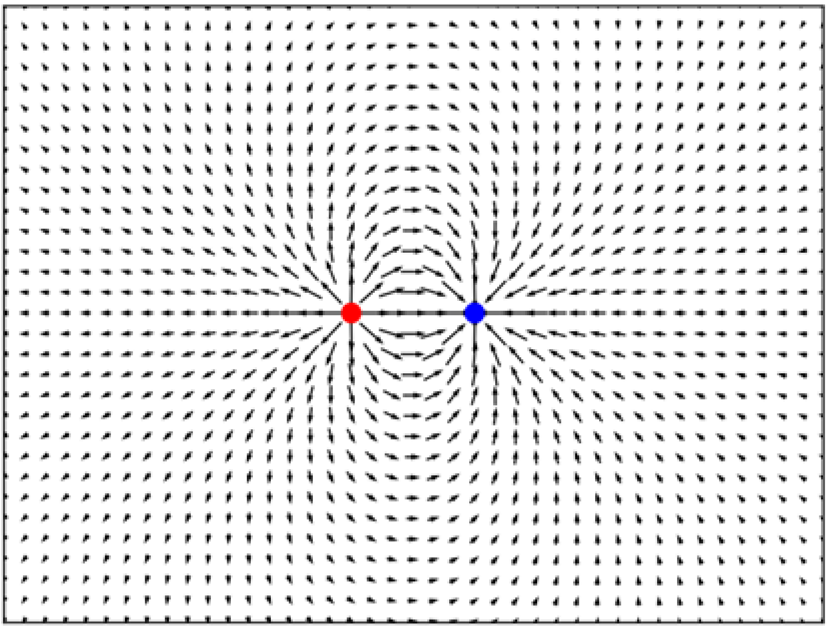


Figure 7. Vector graph of the electric field from the electrostatics 0.2.0 package [22].

It is advisable to combine the analysis of the impact of the use of computer modeling tools on the results of educational activities with the analysis of the results themselves, which depend on the purpose of the educational process. These results depend mainly on the level of education and profile. To a certain extent, the results of studying physics at the level of general education, vocational, professional pre-university and higher education are united by the fact that as a result, a single physical picture of the world should be created, which is a prerequisite for the formation of a scientific worldview. In addition, the structure of ideas about processes in the world around us is formed, which allows us to form technical thinking, which in turn helps us to adapt to the current pace of development of science and technology. However, depending on the chosen profile of study, the depth of such a technical outlook will vary. It is logical to conclude that the amount and depth of knowledge gained depends on the chosen future specialization, and this allows us to assert that the range of knowledge should range from the level of possession of information about how the world around us works to a complete understanding of all laws and processes with the ability to independently analyze and synthesize information and apply the acquired knowledge. Thus, the use of computer modeling tools should also correspond to these limit cases.

The easiest way to use computer simulation is to visualize the learning material. This approach is effective because most of the information a person receives is through the perception of an image. And in the case when it is only necessary to create an idea of a certain process, it is enough for students to see and understand the cause-and-effect relationships that correspond to this process. This type of activity is better suited for the initial stages of learning physics or when physics is not a core subject (school, vocational education, colleges). That is, at a simpler level of use, it makes sense to emphasize the use of ready-made simulations. In the case when a student has to master the educational material in more depth, along with developing the skills of practical application of the acquired knowledge, it is necessary to move on to the creation of appropriate mathematical models, which in itself is the first step towards creating the necessary computer models by the student. This approach is better suited for college and university students.

If we take into account this differentiation of the approach to the use of computer modeling, then in general we get a gradual increase in the complexity of the learning material itself, from simple observation to the development and implementation of certain products (simulations, computer programs for calculating process parameters, applications, etc.). This approach has a positive impact on the quality of education, and, in addition, it allows for the creation of a certain basis for the development of creative abilities, which are realized through mastering the processes necessary for scientific research. In fact, by using computer modeling as a means of obtaining the student's own results, we encourage them to develop their own learning system, which can later become the basis for their own system of scientific research.

6. Discussion of results

We used the expert method to evaluate the considered modeling tools for studying the interaction between charged particles. We had two groups of experts (Donetsk, Khmelnytskyi, and Odesa regions), the first group consisted of professors and teachers of physics, and the second group consisted of students and pupils. The questionnaire consisted of the following questions for both the first group and the second group from the following list:

1. Is it reasonable to use electronic educational resources in the process of teaching physics?
2. Does the modeling method help to activate cognitive activity?
3. Will you use the computer modeling method in the future?
4. Did you get any ideas about the use of computer modeling in the further study of physics?
5. Rank the applications in descending order of attractiveness to you:
   (a) off-the-shelf simulators
   (b) spreadsheets
   (c) computer math packages
   (d) own developments in programming languages

A total of 12 physics teachers and professors and 72 students took part in the survey. The results of the survey are shown in figure 8. The majority of teachers and lecturers agree that e-learning resources are a useful teaching tool. Teachers expect computer modeling to

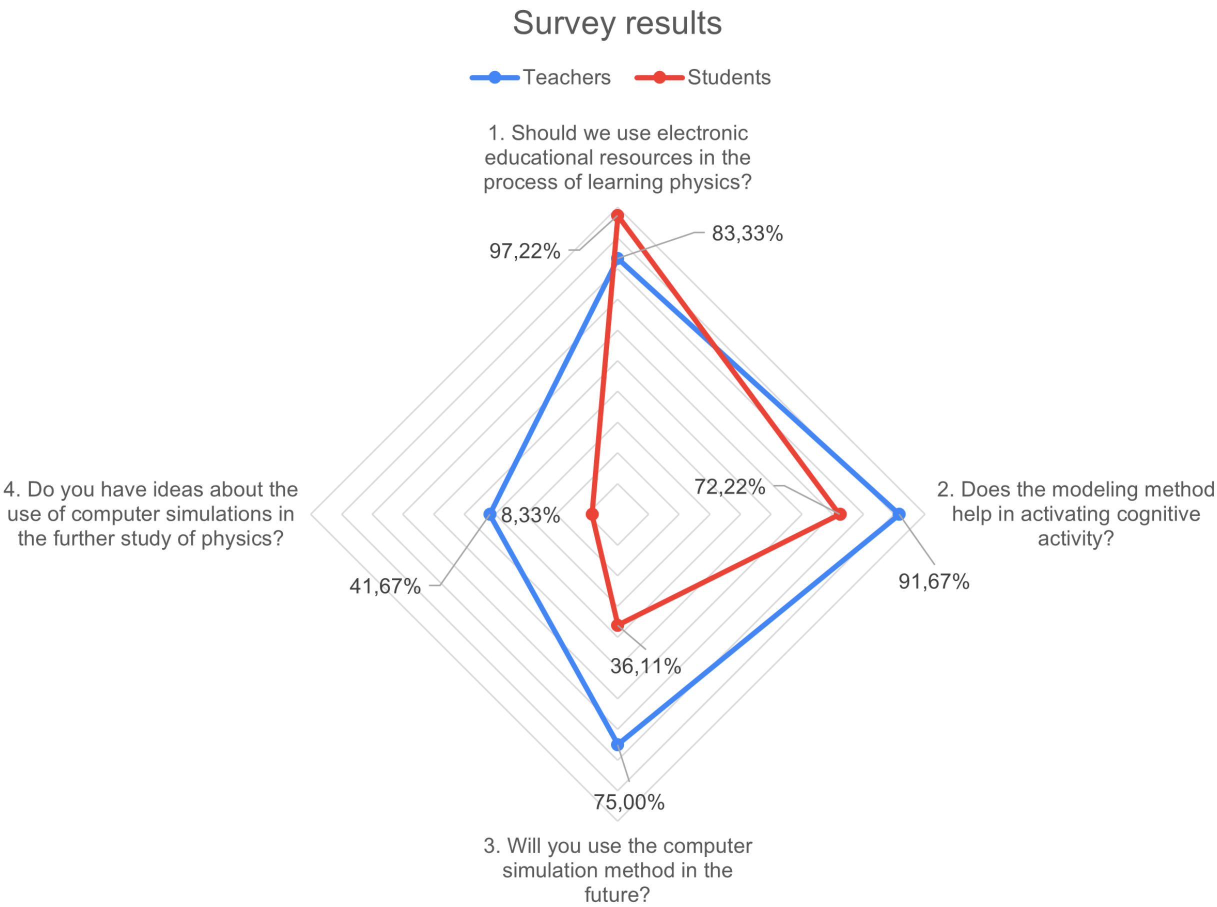


Figure 8. Survey results.

be interesting for students. Teachers agree that it is a useful method of both problem solving and cognition, but they are not willing to take the initiative to promote it themselves. For students, new things in physics class are always interesting, and therefore they are happy to use electronic educational resources. The majority of students agree that e-learning resources are useful for understanding the material. Only a third of students perceived the computer modeling method as interesting and useful for learning. And only 6 students out of 72 are ready to continue self-educational research activities using the computer modeling method.

The rating is almost identical in the opinion of both teachers and students (figure 9). The highest rating was given to off-the-shelf simulators because they are "bright" and "ready to use". The lowest rating was given to their own developments in programming languages, because "it's programming, so it is difficult".

7. Conclusions

Based on the analysis of scientific publications, it can be concluded that computer modeling is an effective tool for solving a wide range of problems in education and research. In particular, it allows conducting virtual experiments, visualizing complex processes, building predictive models, etc.

A comparative analysis of modeling tools has shown that mathematical packages are the most functional and convenient for use in the educational process. At the same time, off-the-shelf simulations also provide opportunities for modeling, although they are not as versatile.

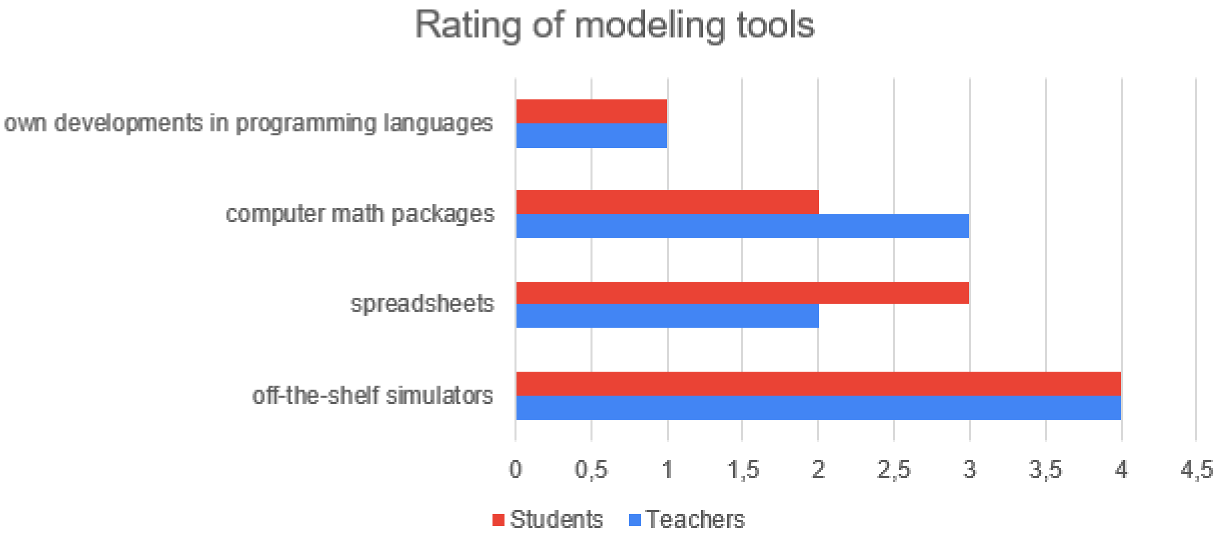


Figure 9. Rating of modeling tools.

General-purpose application software, in this case spreadsheets, is suitable for using modeling as a method of solving problems and improving research competence. Attention should also be paid to the use of programming languages in computer modeling, despite the fact that it is necessary to have appropriate programming competence.

Therefore, the use of computer modeling tools in education and research is appropriate and effective. At the same time, attention should be paid to the selection of optimal modeling tools and means for specific tasks.

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