On Computer Support of the Course "Fundamentals of Microelectronics" by Specialized Software: the Results of the Pedagogical Experiment

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Abstract – **The awareness of the ideas about the work of modern computers is important for the future IT-specialists' preparation. Processes occurring in the middle of the computing system are based on the work of the physical devices, the modeling of which is advisable to carry out in simulation software. The authors consider the problem of choosing simulation software of physical processes. The experience of teaching microelectronics course allowed to choose two simulation software: Proteus and Multisim. The pedagogical experiment on the choice of the optimal simulation software to support the course of microelectronics, which is studied by future IT-specialists and computer science teachers, was conducted based on Makarenko Sumy State Pedagogical University (Ukraine). The comparative analysis of the individual characteristics of the simulation software prefers Proteus. However, the results of the pedagogical experiment confirm the feasibility of attracting Multisim.**

Keywords – **future IT-specialists' preparation, computer modelling, simulation software, Proteus, Multisim.**

1. Introduction

Informatization of the educational industry, among other things, contributed to the emergence of specialized software. It facilitates the assimilation of various notions, phenomena, processes, not only real, perceived by human senses, but also abstract and invisible to the human eye. Among such specialized software, we distinguish the environment simulation of physical phenomena and processes as a separate group that occur in areas of electrical circuits at the micro level (voltage, current, resistance, etc.). The quality of this simulation is laid in the development of a software and is not due to how many it costs (financial, human) to create, but due to the amount of tasks that have on the basis of such means to be solved. At the same time, users are not always aware of these tasks, and therefore often the most common, recommended or "imposed" by someone software is attracted. This sometimes leads to irrational time spent on the mastering of such a software in the educational process and its further use in professional activities. Therefore, we consider it an urgent problem of choosing specialized software to support the study of some courses.

A significant number of teachers and scientists have studied the problems of the introduction of specialized software in the educational process. We will point out the works associated with the use of office software for the development of didactic educational materials [1], [2], computer-based testing [3], [4], [5], specialized software of the subject direction, for example mathematics [6], [7], [8], virtual laboratories and physical process simulation software [9], [10], etc. The latter, as a rule, provides for the organization of a virtual experiment based on mathematical models of real physical objects, lack of material resources encourages teachers to use them to demonstrate experiments, data measurements, visualization of closed processes, etc.

2. Physical Process Simulation Software

2.1. Pros and Cons of Using Simulation Software

Nowadays, we have a large number of different simulation software: simple EasyEDA, LTspice and powerful Multisim, Proteus laboratories. The latter are often used to model electronic circuits, which are studied in the course of microelectronics [11], [12].

During the selection of software, attention is paid to the *mobility* of such software (independence from the technical support of the data processing system, operating system, network data processing technology, restrictions on operation in a network environment, the specifics of the subject area, etc.), *reliability* (stability in operation, accuracy of operations, the ability to diagnose errors, etc.), *efficiency* (from the standpoint of user requirements, in terms of the consumption of computing resources necessary for the operation of the software), *the presence of a help system* (providing the user interface, which provides tips, availability of additional documentation for the development and use of the functionality inherent in the software, error analysis and diagnosis, etc.), *possibility of modifying* (the possibility of making changes, for example, the expansion of processing functions, the transition to another technical base of processing, etc.), *integrability* (the ability to integrate with other software, ensuring the exchange of data in common presentation formats, etc.).

At the same time, among the advantages of modelling electronic circuits in simulation software, we note the *reliability of measurements*, since all of them are based on analytical calculations, and therefore with the same input data will have the same result. At the same time, there are no errors arising in the real experiment, only those parameters that are set by the user are taken into account.

The possibility of *saving time* is also important in this modeling. It is often impossible for various objective reasons (lack of parts, failure of elements or entire power supply units etc.) in real circumstances. The additional arguments in favour of simulation packages are: *convenience and safety* in carrying out measurements – we can add the required number of meters (ammeters, voltmeters, etc.) to the electrical circuit; *multiple tests* of one model; obtaining *results under different input conditions* is often difficult or even impossible in reality, unlike the virtual model; while the wrong construction of electronic circuits is *safe* for a person using virtual space, but it leads to extreme situations in reality.

Should be noted the possibility of high-quality visualization of electronic circuits and the results of their launch in the simulation software. As a rule, complex circuits require compaction for their perception as a whole. This can lead to errors in connecting conductors to the circuit elements. It is also often important to monitor the operation of blocks of circuits. It can be supported by coloured accents or a method of visualization (dotted lines, solid lines of different thicknesses), as well as the simultaneous output of appropriate graphs to study several dependencies.

Among the disadvantages of using simulation software are: sometimes we note the incomprehensible interface language, the inability to install on a particular operating system, the libraries do not always have the necessary electronic components (details), and a large number of software are not freely distributed, which becomes the main obstacle to their implementation in the educational process in Ukrainian educational institutions. At the same time, the experience of teaching the microelectronics course made it possible to choose two simulation software: Proteus and Multisim.

2.2. Proteus and Multisim

Proteus is a powerful computer-aided design system [13], which provides the ability to model analogue and digital devices and simulate their operation to detect design errors and tracing. The software consists of two modules: ISIS – electronic circuit editor, followed by simulation of their work; ARES – printed circuit board editor. After creating the circuit in ISIS modules, it can be transferred to the ARES module to create a printed circuit board, where 3D visualization is provided (Fig. 1.).
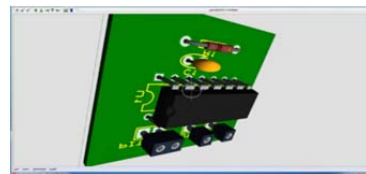

Figure 1. Example of 3D visualization (Proteus)

Multisim is a software for development and modeling electronic circuits. It is an extension of the well-known Electronics Workbench software and is offered in professional and education variants. The software consists of Multisim, Ultiboard, and Ultiroute modules. The latter two are provided for the creation of printed circuit boards, as well as 3D modeling (Fig. 2.). The main characteristics of Proteus and Multisim are presented in Table 1.
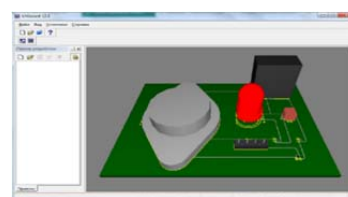

Figure 2. Example of 3D model in Ultiboard editor (Multisim)

Table 1. The main characteristics of Proteus and Multisim

Characteristics	Proteus	Multisim
Library content		
Current sources	23	11
Details of one transition (diodes)	2705	1023
Details of two transitions (transistors)	2353	1135
Details of three transitions (thyristors)	59	396
Analogue devices	1601	7645
Digital devices	343	6
Microcontrollers	80	42
Interactive buttons		
Resistors, motors	+	−
Relays, indicators, lamps	+	+
Simulation capability		
Simulation of generators work	+	+/- restricted
Usability		
Graphical analysis	+	+
The calculation of the differential resistance	+	+
Program connection	+	−
European system of designations	+	+
Analysis tools		
Digital/analogue transient analysis, mixed mode	+	+
Frequency analysis	+	+
Direct current transfer curve analysis	+	+
Noise and distortion analysis	+	+
Fourier analysis	+	+
Audio analysis	+	−
Interactive analysis	+	+
Digital analysis of the compliance	+	−
Direct/ alternating current scan analysis	+	−

A detailed analysis of the possibilities to use these software in the educational process gives grounds to choose Proteus (wider library, the presence of interactive buttons, simulation of generators, the connection of third-party software, the number of computer tools, including those for analysis, etc.). Moreover, most of the teachers surveyed are inclined to use it. At the same time, the opinions of practitioners on the choice of the simulation software differ. Proteus tools, although in a larger number, are hidden in the library, unlike Multisim, whose interface has buttons of typical or the most popular tools immediately on the toolbar (signal sources, voltmeters, ammeters, oscilloscopes, plotters, consumer items, etc.).

3. The Choice of the Optimal Simulation Software to Support the Course of Microelectronics

The described uncertainty caused the pedagogical research connected with the choice of the optimal simulation software to support the course of microelectronics, which is studied by future IT-specialists and computer science teachers.

The objectives of the experiment were:

1) the comparison of the average score of academic achievement for groups who are studying a course with the use of various simulation software (Student's test of comparison of average at the significance level of 0.05);
2) the comparison of the average time of laboratory work in different simulation software (Student's test of comparison of averages at the significance level of 0.05);
3) the analysis of the dynamics of the development of skills to use the simulation software to perform typical tasks of the course (the time of such tasks by means of the software, the time of solving typical tasks of the course, assigned to self-study during the exams).

The pedagogical experiment lasted from 2016 to 2018. It was conducted based on Makarenko Sumy State Pedagogical University, where the course "Fundamentals of Microelectronics" (4 credits, 64 hours of class time) is taught for specialties "014 Secondary education. Informatics", "122 Information technologies. Computer science" and Sumy National Agrarian University.

The first experimental group (EG1) studied the course using Proteus. The number of respondents was 42 people. The second experimental group (EG2) studied the course using Multisim. The number of respondents was 45 people.

At the beginning of the course, students did not study these packages and, as confirmed by the previous survey, did not hear about their use in the educational process and in the workplace.

Let us describe the features of teaching the very course and give a statistical analysis of the results of the experiment.

3.1. The course "Fundamentals of Microelectronics"

The purpose of the course is to form a complete picture of the world about the processes occurring in electronic devices at the micro level and the assimilation of the principles of flow control of charge carriers in electronic devices. This goal involves the solution of the following tasks: the development of knowledge about the physical processes associated with the work of semiconductor devices; the development of skills of computer modeling; the study of the features of applied applications of modern microelectronics in the framework of professional activities.

The results of the course have formed skills in the environment of electronic circuit simulator (the ability to use the built-in library in the simulator to select the necessary parts for the construction of filters, amplifiers, their correct connection and subsequent testing and research of the constructed circuit, etc.).

The curriculum includes lectures (18 hours) and laboratory works (44 hours) using the simulation software (Table 2.).

Table 2. Laboratory works of the course "Fundamentals of Microelectronics"

№	Topic of the work, purpose	Note for Proteus	Note for MultiSim
1.	*Calculation of the differential resistance of the diode (4 hours).* Purpose: to form a students' idea about the work of the diode at the micro level.	An electric circuit is created based on which the I–V curve of the diode is built and its differential resistance is determined. Only one circuit and I-V curve of the diode are required. You can immediately get the difference of the corresponding currents and voltages. You need to use the TRANSFER diagram.	An electric circuit is created with the addition of an ammeter to it. It is necessary to build two circuits. Calculations need to be performed independently. It is enough to take ammeter readings at different voltages and find the appropriate proportion.
2.	*Nonequilibrium and equilibrium bridges (4 hours).* Purpose: to form a students' idea about the structure and operation of bridges of different types.	This work requires the construction of electrical circuits of equilibrium and non-equilibrium bridges, which will be similar for Proteus and MultiSim, since the components for creating an electrical circuit in both software have the same form.	
3.	*Measurement of parameters of the bipolar transistor (4 hours).* Purpose: to form a students' idea about the structure and operation of a bipolar transistor, its low-signal parameters.	The calculation of the h_21 parameter requires the use of circuit and TRANSFER diagram. Differential parameters α and β are calculated.	The calculation of the h_21 parameter requires using only circuits. Integral parameters A and B are calculated.
4.	*Amplifiers (4 hours).* Purpose: to form students' understanding of the structure and operation of the resistive voltage amplifier, to teach students the basic skills of amplifier tuning and research with a common emitter.	This work requires the construction of electrical amplifiers, which will be similar to Proteus and MultiSim, since the components for creating an electrical circuit in both software have the same form.	
5.	*The basic elements of a TTL and CMOS (4 hours).* Purpose: to form a students' idea about the design and features of the basic elements of TTL and CMOS as amplifiers operating in class D mode.	This work requires the construction of wiring diagrams of the basic elements, which will be similar to Proteus and MultiSim, since the components for the creation of wiring in both software have the same form.	
6.	*Modelling of complex logical functions (4 hours).* Purpose: to demonstrate the use of CNF (Conjunctive Normal Form) and DNF (Disjunctive Normal Form) for the construction of complex logical functions in the simulation of the decoder.	It is implemented based on simulation of operation of the decoder of the binary code based on the truth table and the corresponding CNF [14]. Unlike Proteus, Multisim does not demonstrate the state of inputs and outputs.	

№	Topic of the work, purpose	Note for Proteus	Note for MultiSim
7.	*Relaxation generators (4 hours).* Purpose: to form students' understanding of the generator as a system with positive feedback.	This work requires the construction of relaxation generators circuits, which will be similar for Proteus and MultiSim, since the components for the creation of the circuit in both software have the same form	
8.	*Triggers (4 hours).* Purpose: to form a students' idea about the trigger, its varieties and use in computer science.	This work requires the construction of electrical circuits triggers, which will be similar for Proteus and MultiSim, since the components for creating an electrical circuit in both software have the same form	
9.	*Modelling the work of the binary adder with the possibility of subtraction (6 hours).* Purpose: to build an electronic circuit of single-digit binary adder, adder with the possibility of subtraction using CDNF (Canonical Disjunctive Normal Form).	It is implemented based on modelling operation of the decoder of the binary code based on the truth table and the corresponding CNF [14]. Unlike Proteus, Multisim does not demonstrate the state of inputs and outputs.	

3.2. *The statistical analysis of the results of the pedagogical experiment*

We describe the statistical analysis of the results for each of the objectives of the pedagogical experiment.

3.2.1. The comparison of the average score of the progress

The course "Fundamentals of Microelectronics" previously required only knowledge of the general physics course, which was studied in the first year. Therefore, at the beginning of the experiment we analyzed the average score of the progress on the physics course and the overall average score for the last semester, prior to the study of the course "Fundamentals of Microelectronics" (Table 3. a-3. b).

The statistical similarity of student progress EG1 and EG2 at the beginning of the experiment is confirmed by the statistical χ^2 test and Student's test. In other words, at the beginning of the experiment the groups were statistically identical.

After studying the course "Fundamentals of Microelectronics", we again studied the average scores of progress (Table 3. c).

Thus, we found no impact of the use of some simulation software on the level of proficiency of students of EG1 and EG2 – average scores of the groups were statistically the same.

3.2.2. The comparison of the average time of laboratory work

We recorded the work time in the simulation software, which was necessary for students to perform each laboratory work (Fig. 3., the laboratory work № 1). The average time for each laboratory work and the average for the course were calculated (Table 4.).

Considering that time needed to use the simulation software is normally distributed, Student's test was applied to assess the difference of means: the empirical value of the test confirms the deviation of the hypothesis H_0 in favour of the alternative hypothesis H_α about the statistical discrepancy of means (except for the laboratory work № 3, where the means were statistically equal). This means that in general, students perform tasks faster in Multisim, and this is not an accident.

3.2.3. The analysis of the dynamics of skills to use the simulation software

Such analysis is carried out based on two indicators: 1) time of performance of similar tasks by means of the software; 2) time of the solution of standard tasks of a course by means of the software allocated for independent study.

The first indicator was determined as following. At each fourth lesson, students were asked to repeat the performance of one of the previously performed laboratory works (similar tasks were offered). The average time of work for each group was compared. The results are shown in Table 5.

Table 3. a. The beginning of pedagogical experiment. General physics course

	EG1	EG2
The average score for the general physics course	69,3	68,7
The hypothesis of similarity of score distribution at the significance level of 0.05 (χ^2 test)	Accepted $T_{crit}=7,815>T_{exp}=6,45$	
The hypothesis of means equality	Accepted $T_{crit}=1,98>T_{exp}=0,32$	

Table 3. b. The beginning of pedagogical experiment. The previous semester

	EG1	EG2
The average score for the general physics course	71	70
The hypothesis of similarity of score distribution at the significance level of 0.05 (χ^2 test)	Accepted $T_{crit} = 7,815 > T_{exp} = 5,57$	
The hypothesis of means equality	Accepted $T_{crit} = 1,98 > T_{exp} = 1,35$	

Table 3. c. The end of the pedagogical experiment. The course "Fundamentals of Microelectronics"

	EG1	EG2
The average score for the general physics course	72	70
The hypothesis of similarity of score distribution at the significance level of 0.05 (χ^2 test)	Accepted $T_{crit} = 7,815 > T_{exp} = 7,02$	
The hypothesis of means equality	Accepted $T_{crit} = 1,98 > T_{exp} = 0,87$	

TIME FOR STUDENTS TO PERFORM LABORATORY WORK №1 IN PROTEUS (EG-1), IN MINUTES
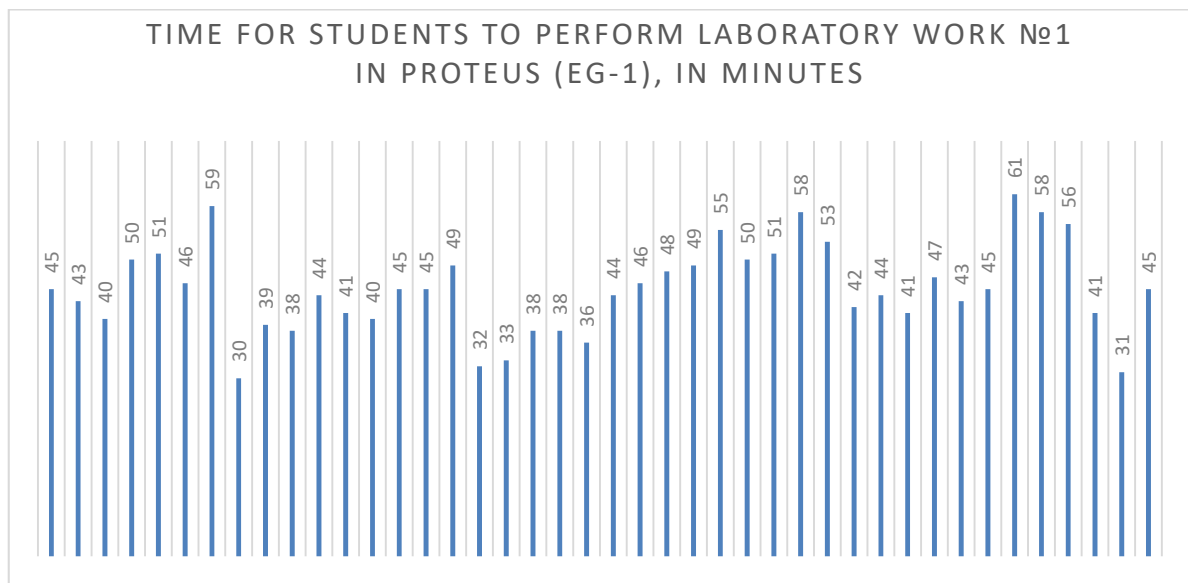
Figure 3. Time of Proteus use on the laboratory work № 1

Table 4. The average time of use of the simulation software, in minutes

№	The topic of the laboratory work	Average execution time (minute)		Testing the hypothesis of the equality of means at the significance level of 0.05
		EG1 (Proteus)	EG2 (Multisim)	
1.	The calculation of the differential resistance of the diode	45	40	Rejected, $T_{crit} = 1,98 < T_{exp} = 2,87$
2.	Nonequilibrium and equilibrium bridges	60	72	Rejected, $T_{crit} = 1,98 < T_{exp} = 6,28$
3.	Measurement of parameters of the bipolar transistor	22	20	Accepted, $T_{crit} = 1,98 > T_{exp}\ 1,87$
4.	Amplifiers	65	61	Rejected, $T_{crit} = 1,98 < T_{exp} = 3,47$
5.	Basic elements	38	21	Rejected, $T_{crit} = 1,98 < T_{exp} = 5,63$
6.	Modelling of complex logical functions	51	45	Rejected, $T_{crit} = 1,98 < T_{exp} = 5,41$
7.	Relaxation generators	32	-	
8.	Triggers	55	51	Rejected, $T_{crit} = 1,98 < T_{exp} = 2,98$
9.	Simulation of the binary adder with the possibility of subtraction	65	55	Rejected, $T_{crit} = 1,98 < T_{exp} = 6,83$
	Generalised averages	48,1	45,6	

Table 5. Results of re-performed laboratory work

№	The topic of the laboratory work	Average execution time in Proteus (minute)		Average execution time in Multisim (minute)	
		First	Again	First	Again
1.	*The calculation of the differential resistance of the diode*	45	37	40	27
2.	*Nonequilibrium and equilibrium bridges*	60	51	72	56
3.	*Measurement of parameters of the bipolar transistor*	22	18	20	15
	Generalised averages	*42,3*	*35,3*	*44*	*32,7*

Statistical analysis confirmed the hypothesis about the positive dynamics of the development of skills to use any simulation software (in both software the time spent on the tasks was statistically reduced). At the same time, the comparison of the generalized averages confirmed a significant decrease in the time to perform work in Multisim (the dynamics for EG-1 vs. EG-2 almost doubled – 7 vs. 11.3).

The second indicator was determined in the process of checking the independently performed works (the time of their execution was recorded in a certain simulation software). There were two control measurements:

1) to simulate the operation of a resistive amplifier based on a unipolar transistor. It was performed by analogy with the previously performed work with the study of a resistive amplifier on a bipolar transistor based on Multisim or Proteus. It was proposed to perform a draft setting of the nonlinear element mode and determine the gain in the visual control of the absence of distortion of the output signal;

2) to simulate the work of the majority element. It is performed on the basis of Proteus (Multisim) according to the standard procedure: state table – CDNF or CKNF – schematic diagram of connections –control of the ability to work with manual control of the inputs state.

For these tasks the average value of the spent time was also measured. The first task performed on average during 63 minutes in Proteus and 60 minutes in Multisim. On the second task 34 minutes and 29 minutes on average were spent respectively. The use of Student's test confirmed the hypothesis of statistical discrepancy of the average time needed to perform tasks in both software ($T_{crit}=1.98<T_{exp}=4.35$ for the first task and $T_{crit}=1.98<T_{exp}=3.64$ for the second). This means that: 1) students are able to use the simulation software to solve microelectronics problems on their own; 2) when solving tasks on their own, a different time to perform tasks in different packages is spent on average, in particular, the use of Multisim is more economical.

4. Conclusions

The use of simulation software during computer modeling of devices work is appropriate, because it makes it possible to: create and repeatedly test circuits that are difficult to reproduce in real life; quickly obtain the numerical characteristics of its individual components; save money and time; conduct experiments without the risk of negative consequences for human health or the environment.

Proteus and Multisim are the most acceptable among the simulation software for the study of microelectronics in the opinion of teachers in higher education institutions. Comparative analysis of their individual characteristics (content of libraries, availability of computer tools, possibility of simulation of individual processes at the micro level, ease of use, availability of analysis tools, etc.) prefers Proteus.

At the same time, the conducted pedagogical experiment confirms the expediency of involving Multisim. Under statistically identical initial conditions of studying the basics of microelectronics by students, future IT-specialists (the same average scores), the average time required to perform laboratory work is less for Multisim. It is confirmed by Student's test at the significance level of 0.05. At the same time, during the use of both software, a positive development of skills to use the tools of each software to solve various problems of the course "Fundamentals of Microelectronics" is recorded: the implementation of such tasks requires less and less training time. This, in particular, determines the recommendations of using Multisim during the distance learning.

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