About one approach to the study of the topic "Synthesis of combinational circuits using Carnot maps"

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Abstract. This article describes the technology of teaching the theme "Synthesis of combinational circuits using Carnot maps" of basic digital electronics course to first/second-year students based on the DL.GSU.BY website. The main advantages of the technology include training adapted to the student, many years of experience in practical application and effectiveness. The following issues are consistently considered in the article: the theoretical foundations of the topic; library of standard components; a system of step-by-step learning to solve problems on Carnot Maps, a technology for using these tasks.

Keywords: basic digital electronics, Carnot maps, website DL.GSU.BY, Gomel State University

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1 Introduction

Blended learning has been actively developed andbefore COVID, but with the advent of this disease it has become critical. Works [1,2] substantiate the need for a transition to blended learning, which combines the possibilities of traditional classroom learning and new information technologies. The works [3-8] describe examples of such blended learning on various topics: mathematics [3], English language [4], earth sciences [5], basic medical knowledge [6], anatomy [7], and chemistry [8].

The author has been using blended learning for disciplines related to teaching programming and digital electronics for many years at the Faculty of Mathematics and Programming Technologies (specialties: "Information Technology Software", "Informatics and Programming Technologies", "Applied Informatics") of Gomel State University named by F.Skorina [9-11].

To increase the effectiveness of training, the system for designing, simulation and debugging of digital electronics circuits HLCCAD [12] and the instrumental system for distance learning DL.GSU.BY [13] both developed under the guidance of the author are used. This work presents the author's approach to the introduction of blended learning in the basics of digital electronics.

2 Problem Formulation

In recent decades, the conditions for learning have been rapidly changing: computer tools and Internet technologies are being improved, the level of training and motivation of students is decreasing on average, and the requirements for knowledge and skills of university graduates are growing at the same time. This leads to the need to change the learning process, so that, on the one hand, theoretical knowledge is given in much more detail and in a much simpler language than was previously accepted, on the other hand, not only and not so much seminars with students were used to consolidate the knowledge gained, but rather solving practical problems. At the same time, a significant part of such tasks can be performed in systems that simulate projects developed by students. To involve poorly prepared students in the educational process, it is useful to use tasks of a control and training nature of various forms, when, in the process of performing a system of automatically checked tasks, the student implicitly receives training information. The technical basis of this approach to learning is the software packages developed at F. Skorina GSU under the guidance of the author.

This work is devoted to the description of such a modified methodology for teaching the topic "Synthesis of combinational circuits from truth tables", taking into account the trends described above. Before this topic, students have already studied the topics "Introduction to the subject" .

The topic "Introduction to the subject" is specifically intended for mastering the HLCCAD system, with which you can edit, simulate and debug the functional diagrams of digital devices, as well as to familiarize yourself with the basic logical operations NOT, AND, OR, XOR and the corresponding basic logic elements.

3 Problem Solution

3.1 Theoretical Background

The topic "Synthesis of combinational circuits according to truth tables", on the one hand, consolidates knowledge and skills in applying the basic logical elements NOT, AND, OR, XOR to solve problems for

the design of digital devices, on the other hand, develops the skills of analysis (and mental simulation) of circuits, composed of these basic logical elements, and on the third hand introduces the method of minimizing logical functions by means of Carnot maps.

Let us consider in more detail what a student should know to be able to solve problems on the topic "Carnot Maps". Let's start with the formulation of the conditions of the problems. It can be explicitly represented by a truth table, like so:

Design a circuit that works according to the following truth table

x4	x3	x2	x1	y4	y3	y2	y1
0	0	0	0	0	0	0	1
0	0	0	1	0	0	1	0
0	0	1	0	0	0	1	1
0	0	1	1	0	1	0	0
0	1	0	0	0	1	0	1
0	1	0	1	0	1	1	0
0	1	1	0	0	1	1	1
0	1	1	1	1	0	0	0
1	0	0	0	1	0	0	1
1	0	0	1	1	0	1	0
1	0	1	0	1	0	1	1
1	0	1	1	1	1	0	0
1	1	0	0	1	1	0	1
1	1	0	1	1	1	1	0
1	1	1	0	1	1	1	1
1	1	1	1	0	0	0	0

Figure 1. Truth table 1

Or represented by the description of the circuit operation algorithm, for example:

The 3-bit input is a binary number. Design a device that outputs the number of zero bits in the input number.

And then the student must make a truth table himself, for example like this:

x1	x2	x3	y1	y2
0	0	0	1	1
0	0	1	1	0
0	1	0	1	0
0	1	1	0	1
1	0	0	1	0
1	0	1	0	1
1	1	0	0	1
1	1	1	0	0

Figure 2. Truth table 2

The next step is for each output variables, enter the ones in the Carnot Map. For example, for the output y3 of the first task, the Carnot map filled with ones will look as shown in Figure 3.

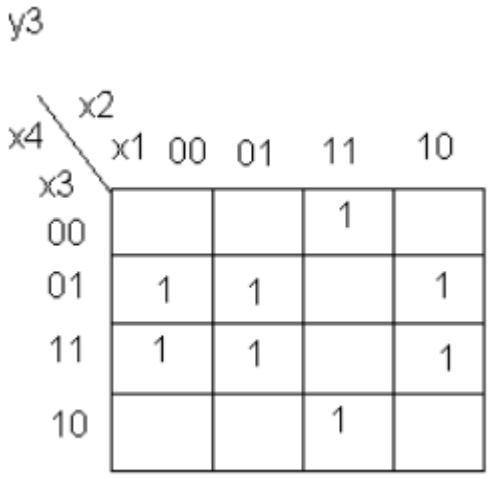

Figure 3. Carnot map

The next step is to cover all the ones with a minimum amountm of ships of maximum area. Each of these ships has an area equal to a power of two. They are shown in Figure 4.

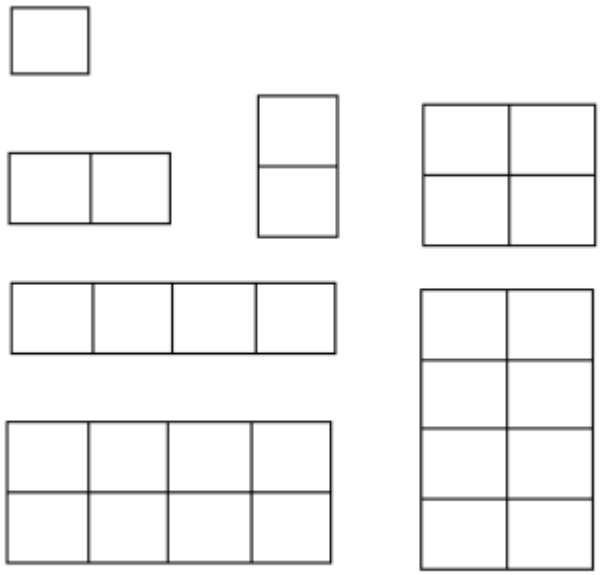

Figure 4. Covering ships

In the figure above, a vertical ship of four cells "did not fit".

When covering, the following considerations should be taken into account:

- You only need to cover ones, the ship cannot cover empty cells
- The Carnot map is considered glued around the edges (left to right, top to bottom).

Accordingly, the ship can be located on the left and right columns or on the top and bottom lines of the Carnot Map.

After completing the coverage by ships, it is required to write out the corresponding logical functions. For example, for the presented Karnot map of the output y3, such a function looks like this:

y3=x3^x2 V x3^x1 V ^x3x2x1

Here the conjunction sign between the variables is omitted to increase readability, the symbol V denotes the logical operation "disjunction", the symbol ^ denotes the logical operation "inversion". And the formula itself can be interpreted as follows: The variable y3 gets the value 1 if x3=1 and x2=0 or if x3=1 and x1=0 or if x3=0 and x2=1 and x1=1, which is consistent with the task truth table 1.

3.2. Schema validation technology

To check the correctness of the assignment, the student must draw the resulting scheme in the HLCCAD system, check its correctness by simulation and send it to the DL.GSU.BY website for automatic verification of the correctness of the designed scheme. There, the project received from the student is launched for simulating in the HLCCAD system on a set of tests prepared by the author of the problem. If the scheme gives correct answers on all tests, the task is accepted, otherwise it is not, and the student is informed under what input data his scheme gave incorrect answers. The correct answers are also reported.

3.3 Library of standard components

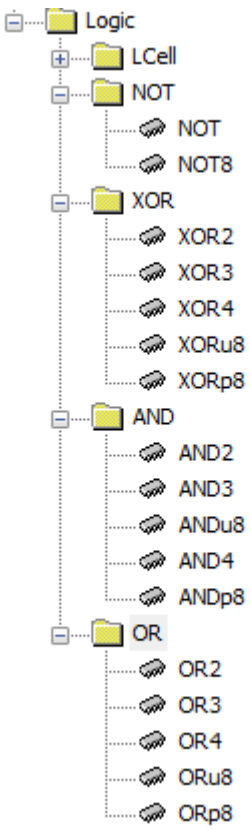

Figure 5. Library of standard elements

Figure 5 shows the table of contents of the library of standard logic elements that can be used in circuit design.

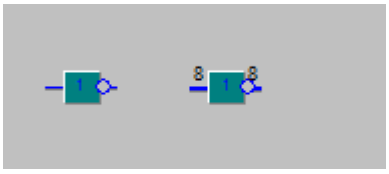

Figure 6. NOT and NOT8

The elements NOT and NOT8 (Figure 6) represent the inversion of one or 8 contacts (bit by bit).

We also note the presence in the HLCCAD system of the ability to change the dimension of the contacts to the required one, which is shown in Figure 7.

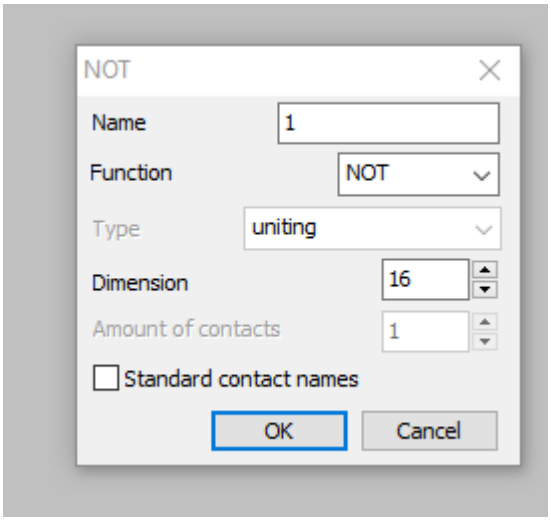

Figure 7. Changing the dimension of NOT

By changing the value in the Dimension field, you can get a 16-bit inverter (Figure 8).

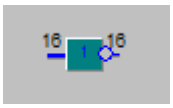

Figure 8. NOT16

Elements XOR2, XOR3, XOR4 (figure 9) represent, respectively, 2-, 3- and 4-bit XOR operations

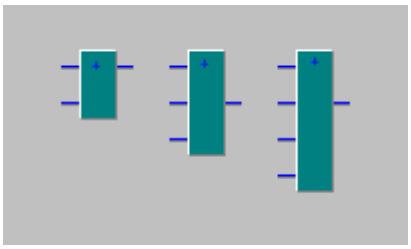

Figure 9. XOR2, XOR3, XOR4

At the same time, it is possible to establish the required number of contacts, for example 6, as shown in Figure 10.

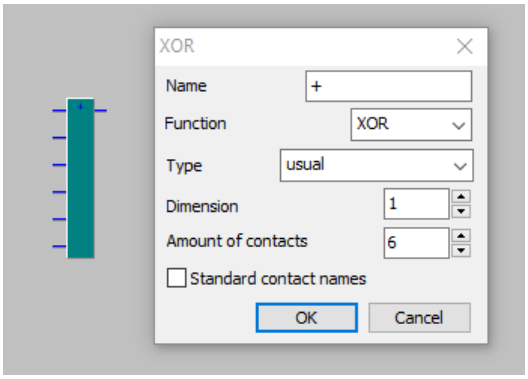

Figure 10. Changed XOR dimensions

Similarly, AND2, AND3, AND4 are elements that perform logical conjunction on 2, 3, and 4 bits, and OR2, OR3, OR4 are elements that perform logical disjunction on 2, 3, and 4 bits. In addition, for both types, as well as for XOR, you can set an arbitrary required number of input bits.

The elements XORu8, XORp8, ORu8, ORp8, ANDu8, ANDp8 are not used by students when working with Carnot maps, therefore they are not described in this article. Nevertheless, one can easily guess their purpose from their drawings (Figure 11).

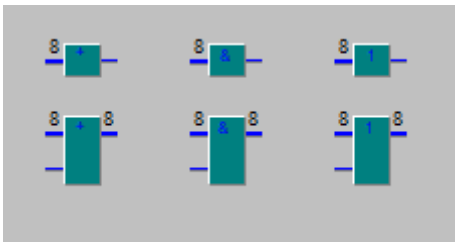

Figure 11. Additional XOR-AND-OR elements

HLLCAD also allows you to invert input and output contacts directly on the body of a standard element. For example, 4AND-NOT can be obtained like this (Model type DOT), which is shown in Figures 12 and 13.

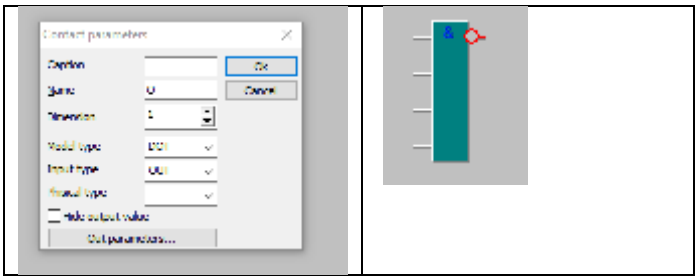

Figure 12. Inverting the output pin

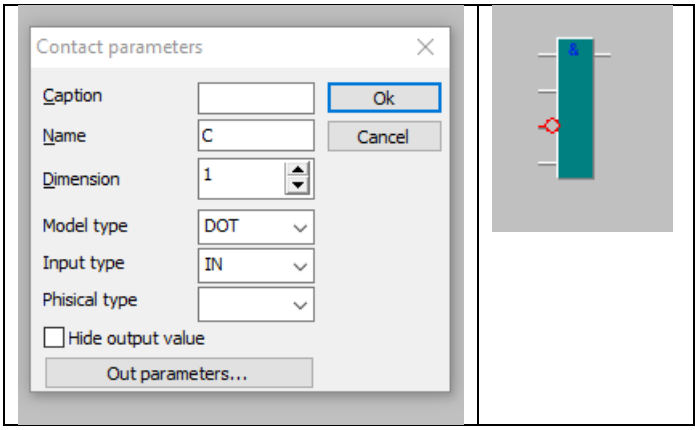

Figure 13. Inverting an input pin

To solve the task, students create a device body (Figure 14).

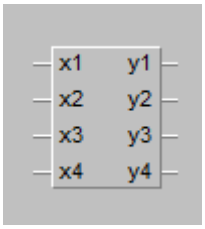

Figure 14. Device body

And then for each output contact draw a circuit. For example, for the previously given function y3, it might look like this (Figure 14):

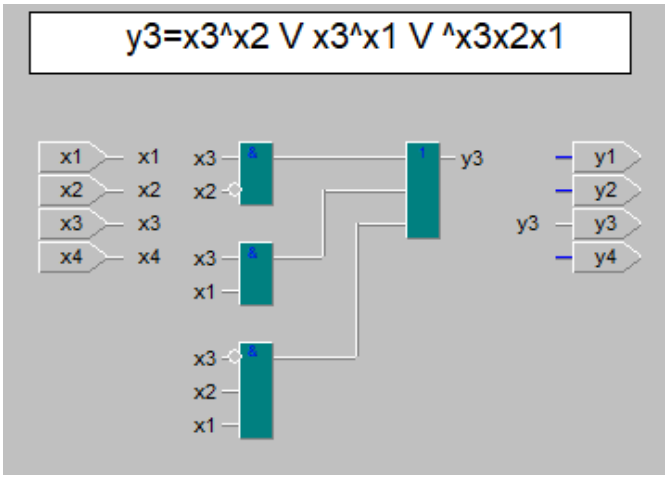

Figure 14. Device diagram

When drawing a circuit, you can use both visible lines and “invisible” ones by simply specifying the same name on the corresponding output and input pins. When drawing, you can also use branching, as shown in Figure 15.

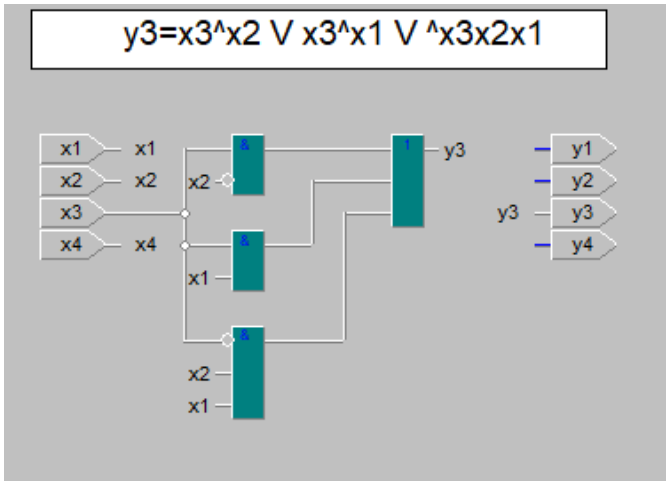

Figure 15. Branching on the device diagram

However, students are advised not to abuse such opportunities, so as not to complicate the perception of schemes.

After the circuit drawing is completed, the student can check the functionality of the circuit by running the simulation and entering input values, HLCCAD displays the resulting values on each input and output pin. This allows the student to analyze the correctness of the circuit, which is shown in Figure 16.

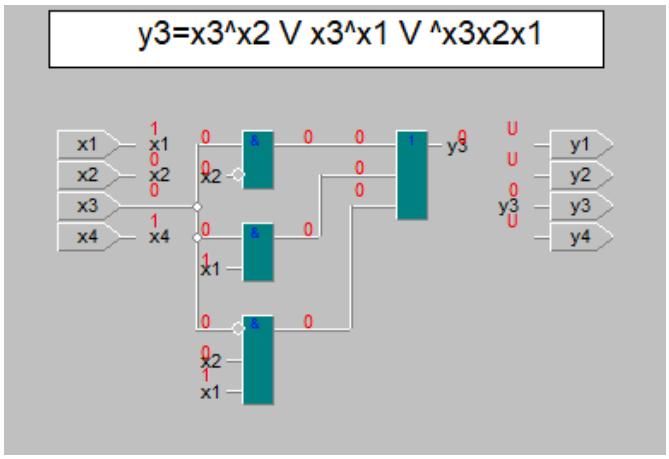

Figure 16. Device simulation

The symbol U means that as a result of the simulation it was not possible to calculate the value on this contact. In this case, this is expected, since the logical functions for the outputs y1, y2, y4 have not yet been introduced.

3.4 Technology of step-by-step learning to solve problems on Carnot maps

As noted, students have widely varying levels of training and motivation. For some students, a brief summary of the theory is enough, others require additional explanations, others "gain knowledge" by working on a problem in the HLCCAD system. However, there is a fourth group of students who do not have enough theory, additional explanations and work in HLCCAD. It is for them (as well as for those who missed the corresponding theoretical lesson) that a set of tasks has been developed that ensures the assimilation of the material by the students of this group. Further, the tasks of this group are sequentially presented and described.

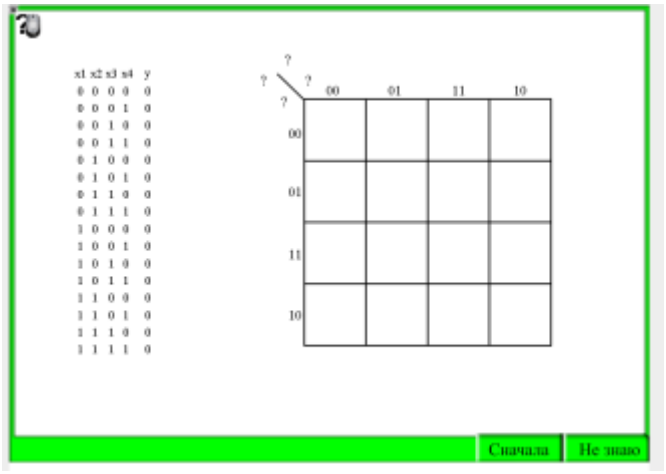

Figure 17. Variable names

In this task (Figure 17), you need to correctly label the variables in the Carnot Map. This is done by clicking on the ? under each of which is a list of variables to choose from (x1,x2,x3,x4). If the student does not know the correct answer, he must click on the "I don't know" button in the lower right corner of the task and then he will see the correct answers (Figure 18).

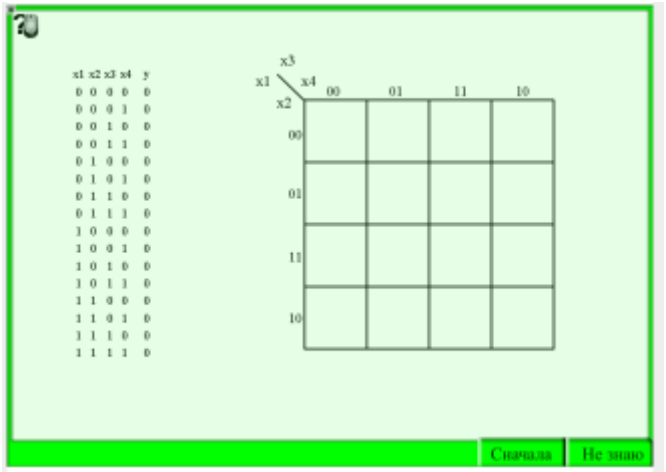

Figure 18. Correct answers of names

The student need to understand how they are obtained, remember and click the "Start" button, to the left of the "I don't know" button. After that, perform the task correctly. If the task is completed correctly, a check mark appears on the screen (Figure 19):

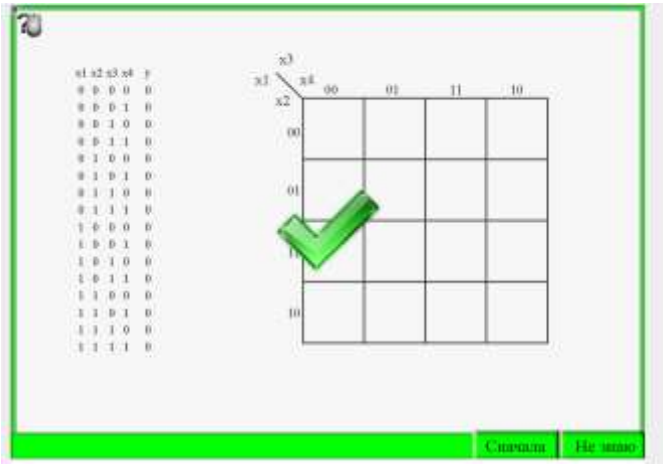

Figure 19. Correct execution checkbox

As long as she's gone, the task has been completed incorrectly. This is followed by the task "Borders of the Carnot Map" (Figure 20).

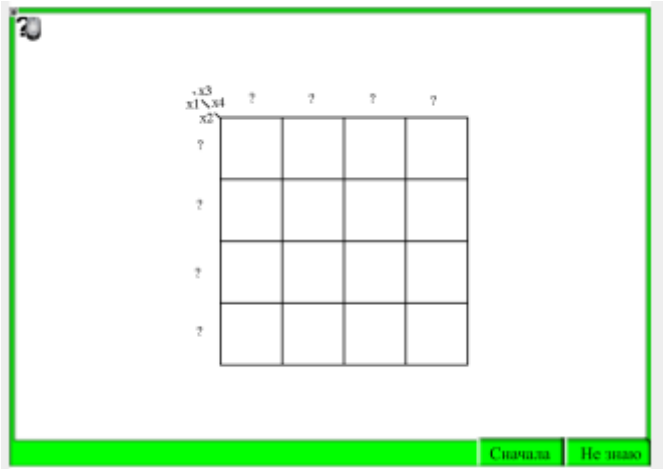

Figure 20. Carnot map borders

Instead of questions, it is required to enter the desired combination of numbers 00 01 11 10, which are characterized by the fact that each next combination differs from the previous one in exactly one digit, including the difference between the last and the first. In this task, as in the previous and all subsequent tasks, there is also a "Don't know" button in order to see the correct answers, and a "Start" button to return to the independent completion of the task until a check mark appears, meaning that the task has been completed correctly.

This is followed by the task "The scope of the function" (Figure 21), where it is required to systematically (in the order of binary counting) list all possible combinations of values of the input variables by clicking on the questions and choosing 0 or 1 in the corresponding position.

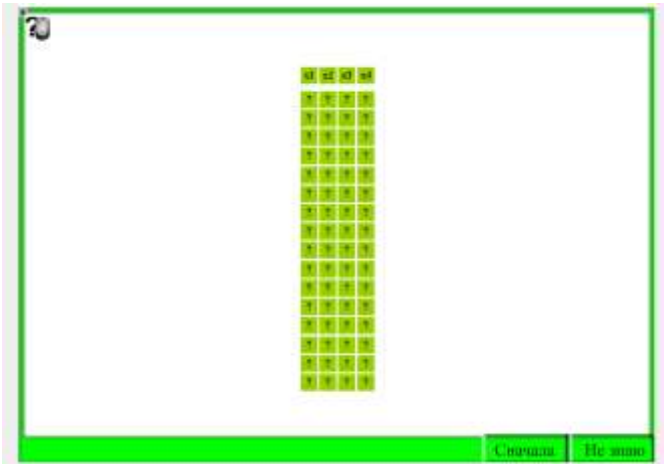

Figure 21. Specify all input combinations

The correct answers for this task are shown below in Figure 22:

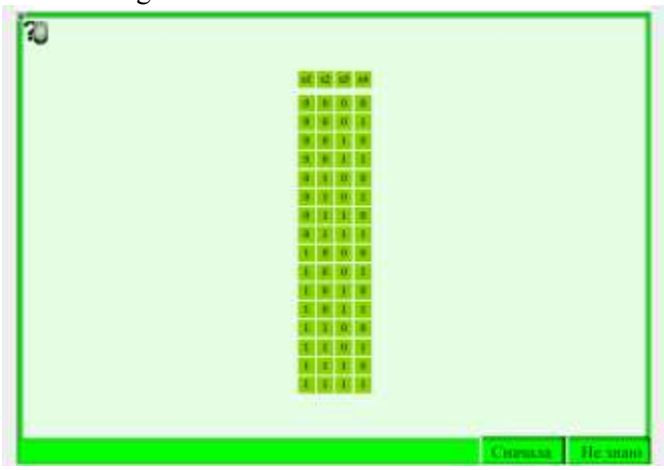

Figure 22. Valid input combinations

Students are encouraged to copy all tasks into their notebooks, both for better memorization of the material and for later use as hints when performing individual practical tasks.

In the next task, you need to enter for a specific output one from the truth table into the Carnot Map by clicking on the questions and choosing between a space (corresponding to zero) and one (Figure 23).

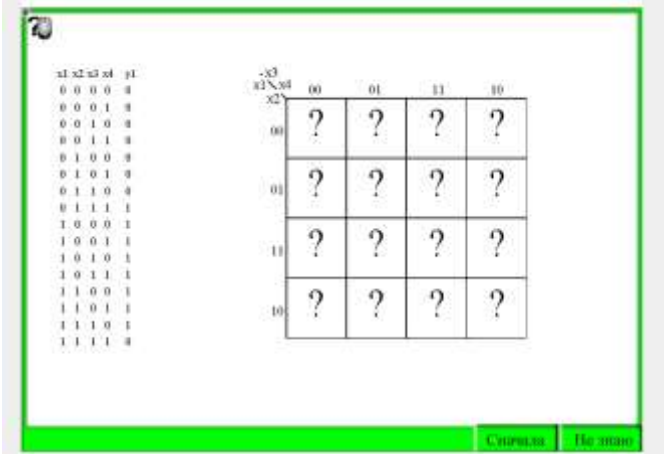

Figure 23. Enter ones

For example, for the task above, the correct answers are (Figure 24).

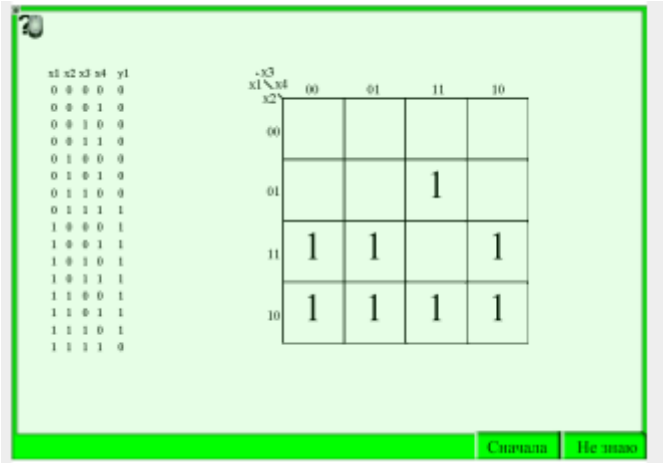

Figure 24. Correct answer to “Deposit ones”

Then similar tasks follow for the other three output contacts. The next training task is to “Cover the Carnot Map” (Figure 25).

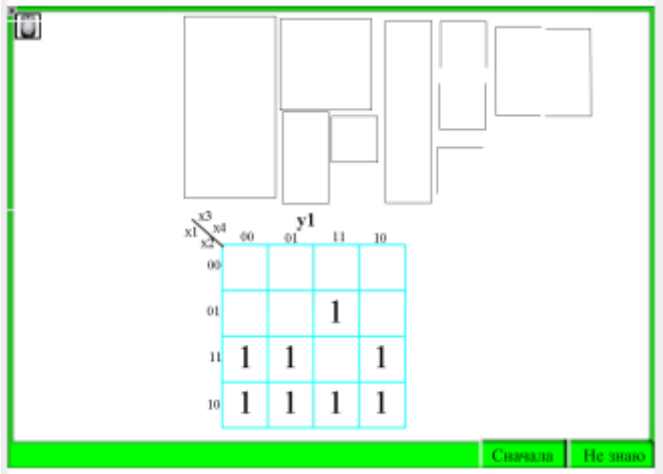

Figure 25. Cover Carnot Map

The figures of ships in the upper part of the screen can be moved with the mouse and rotated with the arrows "Right" and "Left". It is required using the minimum number of ships of the maximum area to cover all ones (and only ones). The correct answer is (Figure 26):

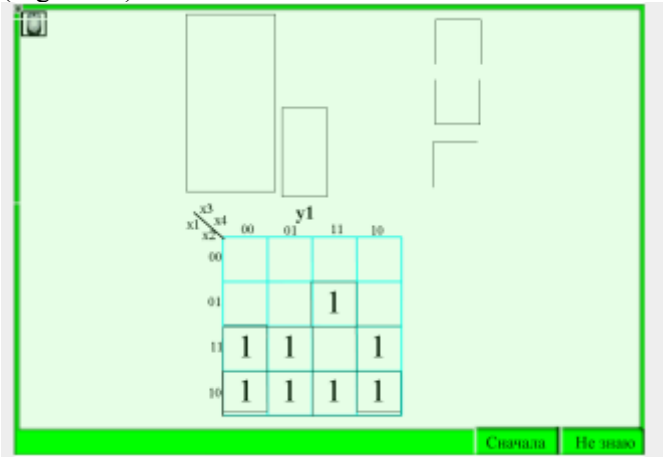

Figure 26. Proper coverage

Four ships were used:
Quadruple horizontal on the bottom line.
Square 2*2 on the bottom left.
Square 2 * 2, in the lower left and lower right corner.
Single ship covering cell 01-11.

This is followed by the same tasks for the rest of the output variables.

Then comes the task “Logic functions” (Figure 27), in which it is required to enter in the input fields the logical functions of the specified terms first separately, and then their disjunction for the output contact.

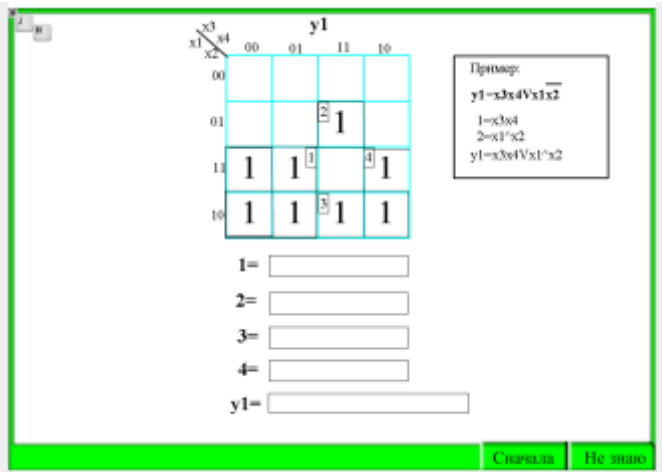

Figure 27. Enter Boolean Functions

Note that there are two types of hints here:

1) Color, while the input is correct it is green, the first incorrect character is highlighted in red.
2) As in all tasks, you can click the “I don’t know” button in the lower right corner of the task.

Then there are three similar tasks for three other output contacts.

Next come the tasks that provide propaedeutics for subsequent work in the HLCCAD system.

The first of them suggests that on the diagram in which the connecting lines are drawn, put them in the correct positions of the body (Figure 28). At the same time, the diagram also shows the logical functions that should be drawn.

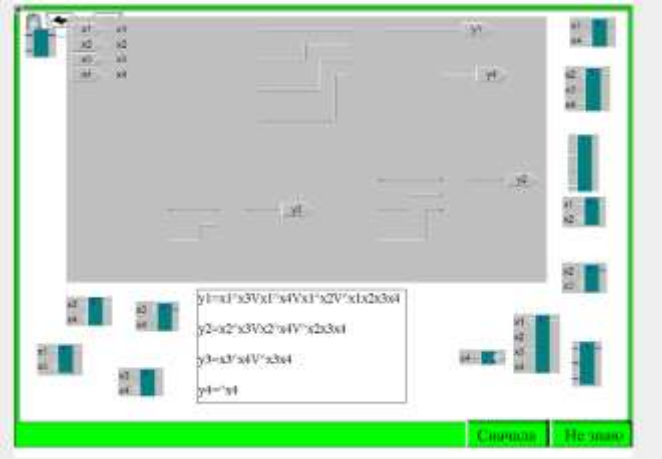

Figure 28. Insert elements

The correct answer for this task can also be seen by clicking the “I don’t know” button (Figure 29)

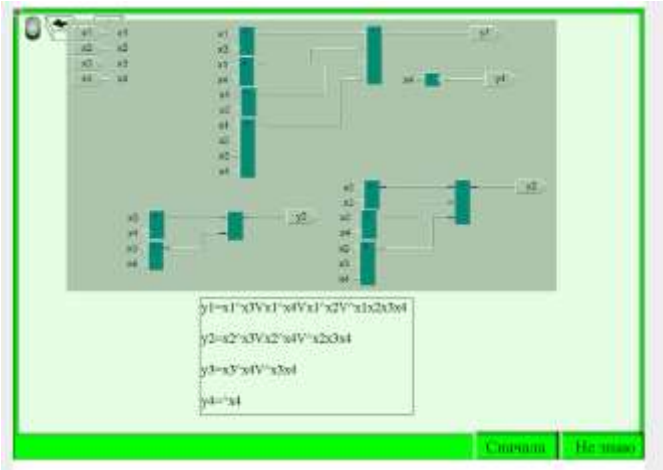

Figure 29. Correctly entered elements

Three similar tasks follow for three other output contacts.

The next task is called “Make a diagram like a puzzle” (Figure 30).

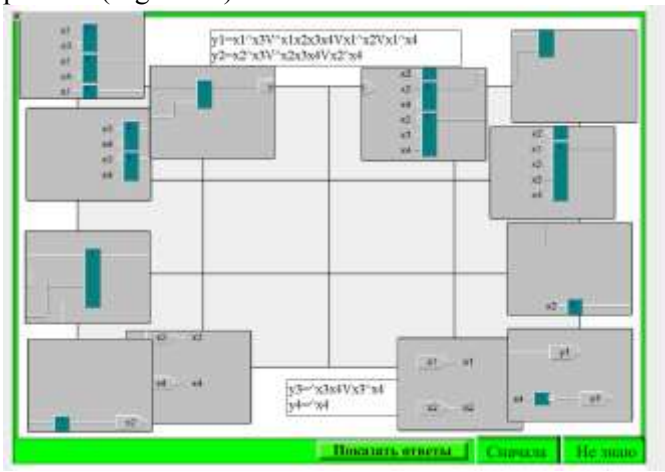

Figure 30. Make a diagram as a puzzle

The correct scheme can be seen by clicking on the leftmost button “Show answers” (Figure 31).

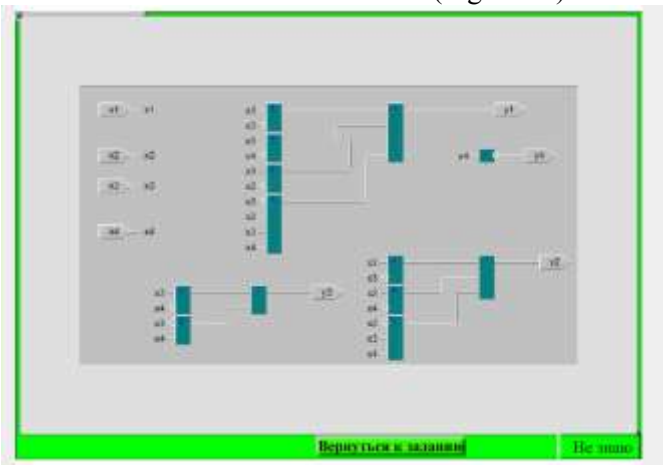

Figure 31. Completed puzzle

The “Return to task” button allows you to return to the task.

Next are the last two tasks “Calculate the scheme” (Figure 32). Each of them has input values on contacts x1, x2, x3,x4. Student clicks on symbols ? should replace them with 0 or 1 for all intermediate and output values.

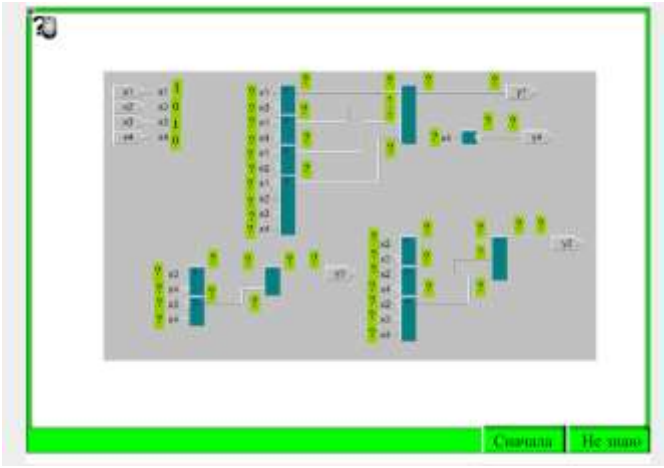

Figure 32. Calculate the scheme

For example, for the diagram above, the correct answer is shown in Figure 33.

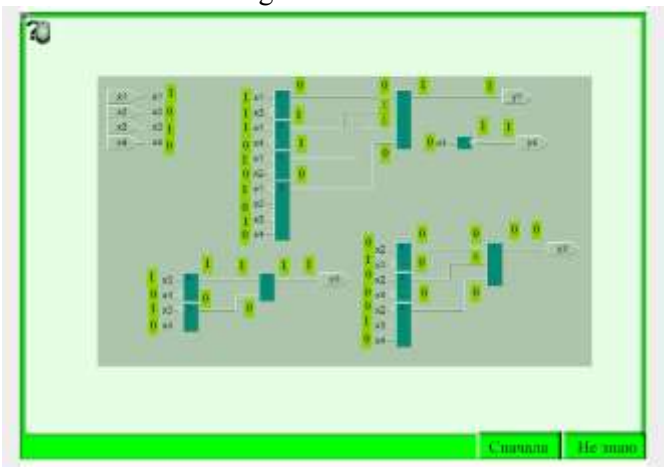

Figure 33. Correctly calculated scheme

3.5 Technology of using practical tasks

After presenting the theory on this topic at a lecture, students are invited to solve the corresponding tasks, for which they need to sequentially create Carnot maps, perform coverage, write out logical functions, draw and simulate the corresponding device in the HLCCAD system and send it for verification in the DL.GSU.BY. In case of errors, find and fix them using the received tests and resubmit the solution for verification. If successful, move on to the next problem.

If the student is not ready to independently complete the tasks, he proceeds to the implementation of the system of the above-described introductory tasks, the successful completion of which also leads to the design of the circuit in HLCCAD and sending it for verification.

Students can also use these tasks during practical exercises and self-study.

4 Conclusion

This article describes the methodology developed by the author and repeatedly tested for studying the topic "Synthesis of combinational circuits

using Carnot maps" focused on working in groups of students with fundamentally different levels of motivation and preliminary training. A serious technical basis of the methodology is the developed instrumental system of distance learning (Distance Learning Belarus - http://dl.gsu.by). The introduction of this teaching methodology provided significant changes in the quality of education, especially for the least prepared and motivated category of students. At the same time, the most prepared students are also satisfied with this approach to learning.

References

[1] Aznam N., Perdana R., Jumadi J, Nurcahyo H., Wiyatmo Y. The Implementation of Blended Learning and Peer Tutor Strategies in Pandemic Era: A Systematic Review // Advances in Social Science, Education and Humanities Research, Vol. . 541, 2021, pp.906-914

[2] Kakeshita T., Ohtsuki M. Survey and Analysis of Computing Education at Japanese Universities: Non-IT Departments and Courses // Olympiads in Informatics, Vol. 13, 2019, pp.57-80

[3] Jones K., Ravishankar S. Higher Education 4.0. The Digital Transformation of Classroom Lectures to Blended Learning // Springer Singapore, 2021

[4] Zaugg H., Graham C., Lim C., Wang T. Current and Future Directions of Blended Learning and Teaching in Asia // chapter 16 in the book "Blended Learning for Inclusive and Quality Higher Education in Asia", 2021 , pp.301-327

[5] Stahl G. Redesigning Mathematical Curriculum for Blended Learning // Education. Sciences, Vol. 11, 2021, pp.165-177

[6] Astarilla L., Warman D. The Effect of Google Classroom in Blended Learning on University Students' English Ability // Journal of English for Academic, Vol 8, No 1, 2021, pp .12-23

[7] Antwi-Boampong A. Blended Learning Adoption in Higher Education: Presenting the Lived Experiences of Students in a Public University from a Developing Country // The Turkish Online Journal of Educational Technology, Vol. 20, Issue 2, 2021, pp.14-22

[8] Oktaria S., Sasongko R., Kristiawan M. Development of Blended Learning Designs using Moodle to Support Academics of The Curriculum in University of Bengkulu // Jurnal Studi Guru dan Pembelajaran (Indonesia), Vol. 4, no. 1, 2021, pp.118-126

[9] Dolinsky M. Teaching Algorithms and Programming First Year University Students on Base of Distance Learning System DL.GSU.BY // WSEAS Transactions on Advances in Engineering Education, vol. 19, pp. 52-57, 2022

[10] Dolinsky M. Experience of Blended Learning the Fundamentals of Digital Electronics for First/Second Year University students On Base of Distance Learning System DL.GSU.BY // International Journal of Education and Learning Systems, vol. 7, pp. 59-64, 2022

[11] Dolinsky M Experience of Blended Learning in the Subject - Architecture of Computers // Journal of Information Technology and Digital World, vol. 4, issue 3, pp. 167-182, 2022

[12] Dolinsky M. Tool HLCCAD for Blended Learning the Fundamentals of Digital Electronics" // International Journal of Circuits and Electronics, vol. 7, pp. 47-55, 2022

[13] Dolinsky M. Instrumental System of Distance Learning DL.GSU.BY and Examples of its Application // Global Journal of Computer Science and Technology Interdisciplinary, vol. 22, issue 1, pp. 45-53, 2022

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