Computer-Based Education in the Course “Digital Electronics” Teaching the Topic “Adders-Subtractors”

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Abstract – The paper presents different computer-based tools for teaching the topic “Adders-Subtractors” in four courses for students-bachelors of five specialties in the University of Ruse. The courses introduce the students to the main issues of digital electronics. The aim of these courses is connecting the functional capabilities of the digital components with their microelectronic base and their applications in constructing pulse and digital devices. For the purposes of the courses, students use different software tools for studying the topic. The paper presents a way of presenting the topic of arithmetic circuits to the students making the classes more attractive using active learning.

Keywords – Computer-based education, Adder-subtractor, Active learning, MS Excel, Logisim, FPGA, Xilinx.

I. INTRODUCTION

During the last years, computers have changed the way people live, study and work. There is no field in which computers do not play a very important role. Education has grown beyond learning from textbooks [1].

Computer-Based Education (CBE) refers to teaching methodologies using computers as a key component of information transmission. For example, computers can be used to present the content of the lesson to the students in more interesting way or used in test-taking to simplify grading and evaluation [2, 3].

The paper presents various computer-based tools for teaching the topic “Adders-Subtractors” in the courses “Synthesis and Analysis of Logic Devices”, “Digital Circuits”, “Pulse and Digital Circuits” and “Pulse and Digital Devices” introducing the students-bachelors of the specialties “Computer Systems and Technologies”, “Electronics”, “Internet and Mobile Communications”, “Computer Control and Automation”, and “Information and Communication Technologies” in the University of Ruse “Angel Kanchev” to the main issues of digital electronics making the connection between the functional capabilities of the digital elements, their microelectronic base and their applications in constructing various digital devices.

For the purpose of these courses, students use software tools for studying the topic “Adders-Subtractors”, such as MS Excel [4], Logisim [5], ISE Project Navigator [6], etc.

During the classes the students create an application in MS Excel illustrating the principle of operation of 2-bit, 3-bit and 4-bit adders-subtractors, built on the basis of full adders and additional XOR logic gates. Then the students implement these devices in Logisim, “an educational tool for designing and simulating digital logic circuits” [5] for exploring the operation of the device when changing the input signals. In the end, the students use FPGA design of these devices, built on the basis of full adders and additional XOR logic gates on a FPGA laboratory board.

The paper describes a way of presenting the topic of arithmetic circuits realizing the operations of addition and subtraction of binary numbers to the students making the classes more alluring for students using active learning.

II. ACTIVE AND INTERACTIVE LEARNING METHODS USED IN THE TRAINING PROCESS

The passive teaching method is a form of interaction between the teacher and the students where the teacher is in the center of the lesson and the students are passive listeners. Feedback in such lessons is organized through tests, independent problems, surveys, etc. The passive teaching method is considered as the most ineffective method in terms of material usage, but the advantages of this method include the ability to prepare less labor-intensive and less time-consuming lessons in advance and provide plenty of information in a short time [7].

The active teaching method is a form of teacher-student interaction in which both the teacher and the students participate equally. In this form of learning, the students are no longer passive learners, but active participants in the training process. Many teachers choose this method of teaching due to its advantages. In some cases, this method is efficient when used by experienced teachers with students who have clearly defined learning objectives [7].

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The interactive method can be considered as a modern version of the active teaching methods, focused on closer student-teacher relationships, where students are more active in the learning process. The difference between active and interactive methods is that, interactive learning involves the interaction of students not only with the teacher but also with each other, i.e. it implies interaction in dialogue mode. In other words, the interactive teaching method is a form of learning and communication activities in which students participate in the learning process and reflect on what they know and what they think of. Unlike the traditional teacher-oriented teaching method, whose primary function is to support and facilitate the students, interactive learning focuses on the needs, abilities, and interests of students. Based on the teacher’s knowledge and experience, the students categorize, analyze, synthesize, accept opinions, acquire new skills and develop their attitudes to facts and events [7]. Some interactive teaching activities include self-learning, while others – pairs or groups of students, like shown in Fig. 1 [8, 9].

Individual student activities are:

- Short written (one-minute) exercises, known as exit slips – students need to write for one minute on a specific question, a generalization of “what is the most important thing learned today”.
- Correct answer when given a false fact, known as misconception check – students need to identify the correct answer, when given a false fact.
- Green, yellow, red card – each student has three cards (green, yellow and red), representing how students feel about the material studied. For example, the green card means “I get it! I can do this by myself and even explain to others”, the yellow one means “I need a little more help” and the red one is “I don’t get it, I need a lot of help”.
- Ask the winner – students first solve a problem individually. After finding the answer, those who got it right will raise their hands (and keep them raised). Then, all other students will talk to someone with a raised hand to better understand the question and how to solve it next time.

Examples for students’ pair activities are:

- Pair-share-repeat – the students are paired up and each pair of students has enough time to reach a conclusion and share it in voice; also, students can find a new partner and share the wisdom of the old partnership to this new partner.
- Wisdom from another – after a creative activity or an individual brainstorm, students can be paired to share their results. Students are often more likely to share the work of their fellow students publicly than their work.
- Forced debate – in this situation, students debate in pairs and they must defend the opposite opinion of their personal ones; it stimulates them to move away from their own beliefs and teaches them to look through different colored glass from time to time.
- Peer teaching – students need to work as a teacher to teach their peers considering a given question.

The active and interactive teaching methods were introduced in the considered courses for the first time 3 years ago. Previously, the students did not like the courses and they showed poor results during the exam. The disciplines were classified as so-called “barrier”. In addition, there was no possibility of exemption from the exam, thus demotivating students to study during the semester, which further complicates the learning process. All this motivates the teaching team to change the approach for teaching, from teacher-centered to student-centered, and for this purpose various computer-based tools were introduced.

Especially for students majoring in “Computer Systems and Technologies” and “Computer Control and Automation”, studying the disciplines “Digital Circuits” and “Pulse and Digital Devices”, the widespread use of computer-based tools during their studies made the disciplines closer to the topics they studied and their professional orientation, as they showed greater interest in the material and, accordingly, showed better results during the tests and the classes.

III. SYNTHESIS AND ANALYSIS OF ADDERS-SUBTRACTORS USING COMPUTERS IN EDUCATION

The theory and implementation of arithmetic circuits realizing the operations of addition and subtraction of binary numbers are presented in more details in [10 – 12]. The half-adders, full one-bit adders and two-bit adders are considered in [10, 11] and the half-subtractors, full one-bit subtractors and two-bit subtractors are given [10, 12]. Their implementation in Logisim and FPGA design based on the schematic view as well as active learning methods used in the training process for attracting the students’ attention to the topic “Arithmetic circuits for addition and subtraction” are presented in [11, 12]. Using this research [11, 12], MS Excel, Logisim and FPGA implementations of 2-bit, 3-bit and 4-bit adders-subtractors, built on the basis of full adders and additional XOR logic gates are presented in this paper.

During the practical exercises in the courses “Digital Circuits” and “Pulse and Digital Devices”, the students are divided into groups of four students and their training is based on project and team work. The process of preliminary preparation for the lesson is illustrated in Fig. 2. Each team should familiarize themselves with the material that will be considered during the exercise in advance (at home). To do this, students use Internet or
reference literature provided by the teacher. Students can communicate with each other to clarify the material, as well as consult with the teacher by e-mail in case of confusion in the material. At the end of their preparation, they must answer the question “What did I learn about this exercise?” within about 2-3 minutes. About the topic “Adders-Subtractors”, students should recall from the past exercise the issues about synthesis and analysis of half-adders / half-subtractors, full one-bit adders / subtractors and two-bit adders / subtractors, as well as students should become familiar with the theoretical formulation from the textbook used for their preliminary preparation [10], including the following issues: 1) controlled inverter (Fig. 2, block 1); 2) adder-subtractors (Fig. 2, block 2); 3) four-bit adder-subtractor (Fig. 2, block 3) built with integrated circuits from TTL (Transistor-Transistor Logic) family [13], the library 74xx [14] (integrated circuits of Texas Instruments).

For checking the preliminary preparation of students for the exercise the lecturer uses short written one-minute exercises. During the classes, pair-share-repeat, wisdom and this helps the lecturer to check if students understand the topic.

During the class, each student determines the output functions of one of the stages of the 4-bit adder-subtractor, built on the basis of full one-bit adders and XOR logic gates, with an additional SUB input to control the operation to be performed: for addition – $S_{UB} = 0$ and for subtraction – $S_{UB} = 1$, as follows student S1 – for stage 0 ($D_0, C_0$), student S2 – for stage 1 ($D_1, C_0$), student S3 – for stage 2 ($D_2, C_2$), and student S4 – for stage 3 ($D_3, C_3$), then exchange information with each other and check their authenticity. The determination of the output functions is based on the output functions of the full one-bit adder considered in the previous exercise. This process is illustrated in Fig. 3.

Students learn best by doing, and if one student is ready with his/her task, he/she can teach others, so peer teaching is also used during the exercise. The usage of interactive learning methods helps students to understand better and quicker the essence of the studied material.

The activities of each student during the classes are shown in Fig. 4 ... Fig. 7, representing the implementation schemes, respectively the process of education on the topic of adder-subtractors in the subjects. Within the schemas (Fig. 4 ... Fig. 7), the actions of the individual students as well as the software used are indicated.

During the class, the first student S1 must develop a MS Excel application, as shown in Fig. 4, using the tools for: 1) validating the data (Fig. 4, block 1); 2) inserting formulas (Fig. 4, block 2); 3) conditional formatting (Fig. 4, block 3). The MS Excel-based application allows the user to select from a drop-down menu the operation to be performed, addition or subtraction, and the bits of the two operands A and B, also using drop-down menus to select one of the two possible values 0 or 1 (Fig. 4, block 1). After selecting an operation, the value of the SUM parameter (column I of the table in MS Excel) is automatically changed: $SUM = 0$ for addition and $SUM = 1$ for subtraction. The output functions of each stage are implemented by using built-in functions in MS Excel that allow the use of Boolean functions, such as OR, AND, and XOR, and IF function in order to correctly visualize the result 0s or 1s (instead of False and True) (Fig. 4, block 2). Finally, conditional formatting is used in order to display 0s and 1s with different font and background (Fig. 4, block 3) for better presentation of the information. The formulas defined in the cells of MS Excel are based on the formulas determined by the students (Fig. 3). Using software for this type of exercise gives students confidence that if they make a mistake, nothing will be actually broken, so they can use these mistakes to learn better the principles of adder-subtractors.

Students TEAM

Teacher

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Figure 2. Preliminary preparations of the students for the lesson
Four-bit adder-subtractor

\[ D = A \oplus (B \oplus SUB) \oplus SUB \quad C_{out} = A \cdot (B \oplus SUB) \lor A \cdot SUB \lor (B \oplus SUB) \cdot SUB \]

\[ D = A \oplus (B \oplus SUB) \oplus C_{in} \quad C_{out} = A \cdot (B \oplus SUB) \lor A \cdot C_{in} \lor (B \oplus SUB) \cdot C_{in} \]

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During the classes, the second student S2 draws the circuit of the 2-bit adder-subtractor (Fig. 5, block 1) in Logisim based on the output functions of the individual stages previously determined by the students (Fig. 3). For this purpose, the student S2 uses logic gates of type AND, OR and XOR. Based on this 2-bit adder-subtractor,
they can easily build the circuits of 3-bit adder-subtractor and 4-bit adder-subtractor (Fig. 5, block 2).

During the classes, the third student S3 is familiarized in advance with the two used integrated circuits (Fig. 6, block 1), the integrated circuit SN7483 (4-bit binary full adder with fast carry) [15] and SN7486 (Quad 2-Input Exclusive-OR Gate) [16], and draws the circuit of the 4-bit adder-subtractor using TTL integrated circuits of the library 74xx mentioned above (Fig. 6, block 2), using the circuit given in the textbook [10].

During the class, the fourth student S4 examines the circuit implemented in ISE Project Navigator (Fig. 7, block 1) in advance and determines the output functions of the device (Fig. 7, block 2). Only the first two output functions are determined $Y_0$ and $Y_1$ (Fig. 7, block 2). Then, the student looks for a match between the inputs ($x_0...x_9$) and outputs ($Y_0...Y_9$) of the laboratory layout and the inputs ($A_i, B_i, SUB, for i = 0...3$) and outputs ($D_i, C_i, for i = 0...3$) of the device (Fig. 7, block 3). The following activity of the student S4 is testing the device with the laboratory layout for combinations given by the teacher using the “bit” file, generated in the environment of ISE Project Navigator using the schematic view of the device (Fig. 7, block 1).

After using various software products, which gives students more confidence, they have the opportunity to use real equipment. This will provoke them to acquire practical skills to work with application software and specialized equipment.

A photo of the laboratory board is presented in Fig. 8. It is based on Spartan-6 FPGA Family and it is developed at the University of Ruse “Angel Kanchev” by the authors of the paper. This board allows FPGA implementation of different devices of combinational and sequential type.

\[
\begin{align*}
D_0 &= (A_0 \oplus B_0) \oplus C_{in} \\
D_1 &= (A_1 \oplus B_1) \oplus C_{in} \\
D_2 &= (A_2 \oplus B_2) \oplus C_{in} \\
D_3 &= (A_3 \oplus B_3) \oplus C_{in} \\
Y_0 &= x_0 \oplus x_1 \oplus E_0 \Rightarrow x_0 = A_0 \land Y_0 = D_0 \\
Y_1 &= x_0 \land E_0 \land E_1 \land x_2 \land x_3 \Rightarrow Y_1 = C_{in} \\
Y_2 &= x_0 \land E_0 \land E_1 \land \overline{x_2} \land x_3 \Rightarrow Y_2 = D_0 \\
Y_3 &= x_0 \land E_0 \land E_1 \land \overline{x_2} \land \overline{x_3} \Rightarrow Y_3 = C_{in} \\
\end{align*}
\]
The practical exercises using different computer-based tools for investigating real digital devices help the students to develop skills important for the future engineers, such as problem-solving, working in groups (teams), applying project-based approaches for learning to use various software products and engineering equipment. They gain skills for synthesizing, analyzing, and evaluating scientific information and problems. Therefore, it is really important for the university lecturers to develop effective pedagogical methods to involve students in the teaching and learning processes based on active learning strategies.

The use of interactive teaching methods provides the participation of the students in the training process, which is the main source of learning. The main difference between the traditional and the interactive activities is that the students do not only revise and enhance their knowledge, but also construct and complement it with new material.

The teacher assigns different combinations for the bits of the two four-bit numbers to the students, and the students test and record the results of the two operations (addition and subtraction), comparing the results they received – each with their own computer-based tool.

In this part of the exercise students are encouraged to discuss and debate, also to ask themselves questions and to look for answers among them.

In the end of the exercise the teacher uses the activity to ask the winner for summarising the material and to check if all the students understand it.

Next week, each student uses another computer-based tool for investigating digital devices (for example, the student S1 uses Logisim, instead of MS Excel, etc.).

The experiment conducted with our students in the 2019/2020 academic year also proves that students perceive the material more easily by using active teaching methods. About 89% of the students showed enviable participation of the students in the training process, which is the main source of learning. The main difference between the traditional and the interactive activities is that the students do not only revise and enhance their knowledge, but also construct and complement it with new material.

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