A HEURISTIC APPROACH TO TEACHING ANALOG ELECTRONICS[1]

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Abstract: In this paper, a new educational technology for teaching the fundamentals of electronics is proposed. In opposite to the traditional approach, it relies mainly on human imagination, intuition and emotions. In the heuristic course proposed, circuits are not analyzed as ready-made circuit solution. Instead, first basic ideas behind circuits are revealed. Then, they are built systematically step-by-step, each new circuit based on the previous one. The heuristic approach is implemented by a set of interactive multimedia products where, in order to visualize the circuit operation, a set of innovative heuristic graphical tools is developed.

1. INTRODUCTION.

1.1. THE TRADITIONAL APPROACH.

As a rule, classic electronics courses [1] follow a traditional "scenario": first, electronic circuits are presented in their complete, final and perfect form; then, they are accurately analyzed by using classical formal methods. Unfortunately, this approach does not reveal the nature of circuit phenomena as mathematical models hide structure, causality and structure-function relations.
We teachers have not to forget that students are not computers. First of all, they are human beings possessing fantasy, imagination and enthusiasm. So, in order to really understand how abstract electronic circuits work, they need "human" qualitative tools before formal methods to be applied.

1.2. THE HEURISTIC APPROACH.

My teaching heuristic philosophy [2] is simple:
1. Electronic circuits are based on clear and simple basic ideas, which may be derived from our routine.
2. In order to really understand electronic circuits, we human beings have first to reveal these basic ideas.
3. In order to successfully present circuits to students, we teachers have to build them according to the basic ideas revealed.
4. In order to make students think creatively, we teachers have to reinvent circuits according to the basic ideas behind them.

Finally, we may apply formal methods, in order to determine circuit parameters.

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[1] I have been implementing this approach since 1986; so, I could not expose thoroughly it on the four page limited. In order to get a full notion about my work, you may visit an enlarged, more dynamic and live web version of this paper located at:
http://www.circuit-fantasia.com/my_work/conferences/ewme_2006/paper.htm

2. TECHNOLOGY.

Maybe, the best way to show how to put the heuristic approach in practice is to tell how I deal with circuits. Here is my story.

2.1. UNDERSTANDING CIRCUITS.

When I decide to really understand a new circuit I begin by breaking it up into smaller parts. For this purpose, I try to recognize separate groups of electronic components forming familiar simpler circuit building blocks (I have accumulated before some blocks in a circuit collection). Then, I try to discern familiar basic circuit ideas (I have also accumulated some ideas in a principle collection).
If familiar basic ideas do not exist, I begin looking for new ones. First, I browse through the other well-known circuits looking for similar concrete ideas. If I do not manage to find such "electrical" ideas, I begin looking for new "non-electrical" basic ideas in my routine. For this purpose, I look for everyday situations (analogies) in which a human being has a similar behavior.
Then I put myself mentally in device's place (i.e. I use empathy). For example, I replace real transistors and op-amps with “man-controlled” ones and begin performing their functions. Thus I get a taste of what the device “feels” and a picture of its behavior revealing cause and effect relations in its operation. I stir into action the circuit by stimulating mentally it and imagining how it reacts to this intervention. I do that mostly using my imagination rather than my reasoning, visualizing in my mind's eye how potentials rise and drop, currents flow from high to low potential point, resistors "shorten" and "lengthen", etc.

2.2. PRESENTING CIRCUITS.

After I have restored the evolution of electronic circuits, I begin presenting them to students in their logical succession. First, I pose the problem that the circuit considered has to solve. Then I show the basic idea, on which the circuit is grounded on and draw the corresponding block diagram. Further, I build the circuit step-by-step. For this purpose, I use more elementary building blocks from the circuit collection connecting them accordingly to the block diagram (i.e. I replace the general blocks with concrete electrical blocks).
Then, I explore the circuit operation. In order students to penetrate into circuit operation, I perform step-by-step controlled experiments: imaginary experiments on the whiteboard in the classroom, animated experiments on the web and real experiments in the laboratory. In these arrangements, I first replace the active electronic components (transistors, op-amps etc.) with “man-controlled” ones and begin performing their functions.
In order to visualize the circuit operation (i.e. the invisible electrical attributes voltage and current), I have developed a set of heuristic graphical tools. Voltage bars present voltages and voltage drops by corresponding height (length) of a bar, voltage diagrams show the voltage allocation over the resistive film inside resistor, current loops present currents by corresponding contour thickness, superimposed IV-curves display working points etc. These graphical tools are colored, sounded, step-by-step controlled (animated) and illustrated by explanatory balloons and links.

In the laboratory, I carry on interactive computerized experiments where the "live" graphical representations on the screen are controlled by the real circuits investigated. In other experiments, live analogies (graphical representations of everyday situations on the screen) are controlled by real circuits.

2.3. INVENTING CIRCUITS.

I use it mostly to present circuits to creatively thinking students. In the beginning, applying a few inventive techniques, my students and I "invent" the simplest possible circuit building blocks. For this purpose, we assign consecutively the basic electrical attributes in the elementary Ohm's circuit as a circuit input and output (i.e. we change the causality between voltage and current), combine the elementary blocks reinvented into more complicated compound blocks etc. Only, a problem (contradiction) arises in the imperfect passive circuit and we begin trying to find a remedy. Usually, we looking around for analogies where a similar phenomenon appears (in the process of reinventing we give temporarily more meaningful and live names of the phenomena). Gathering enough examples, we generalize them into a basic principle and a functional block diagram. Then, according to the general idea, we build initially a "man-controlled" electrical circuit and explore it step-by-step. Finally, we replace the "man-controlled" active components with real ones (transistors, op-amps etc.) thus getting a classical electronic circuit.

3. IMPLEMENTATION.

3.1. CIRCUIT-BUILDING COURSE ON ANALOG ELECTRONICS.

Following the heuristic technology above I have gradually managed to build my own course as an alternative to the classical courses in the area of analog electronics. I have been applying this course in the class and laboratory exercises since 1987. Lately, I decided to support the class exercises of my students by a supplementary web-based building analog electronics course [3] located at http://www.circuit-fantasia.com.

At the beginning of the course, my students and I were deriving from the simple Ohm's circuit the most elementary passive resistive analog devices with current and voltage output. Then, following the building idea, we used them to build compound resistive circuits with voltage input/output and also some classic time dependant circuits with reactive elements. After, we added electronic components to the passive circuits thus getting basic diode and transistor circuits. Next, we applied the powerful negative feedback principle to the transistor circuits obtaining classic transistor amplifying circuits. Similarly, applying a feedback to the op-amp amplifying circuits, we got basic op-amp amplifiers with negative feedback. Then, we converted the imperfect passive circuits into almost ideal op-amp circuits.

3.2. CIRCUIT STORIES ON THE WHITEBOARD.

In this new part of the site, I visualize my ideas on a classic whiteboard; then I snap and place them on the web. In these stories, I show three viewpoints at the circuits on the whiteboard: how to understand circuits (intended mainly to

students and hobbyists), how to build circuits (to teachers) and how to invent circuits (to inventors and teachers).

3.2. CIRCUIT-BUILDING MULTIMEDIA TUTORIALS.

A few years ago, I was fascinated by the power and interactivity of Macromedia Flash; then, I began creating with enthusiasm variety of multimedia products.

Reinventing Op-amp Voltage Summer. I created the first circuit-building tutorial, in order to show how to present circuits by reinventing them. It consisted of four units dedicated to the famous analog circuits voltage-to-current converter, current-to-voltage converter, passive voltage summer and op-amp voltage summer. In this chain of circuits, every next circuit was build by using the previous more elementary circuits. Every unit was based on one and the same 7-step circuit-building "scenario": problem, analogies, generalizing, building, exploring, imperfections and applications.

Build to Understand Circuits. In 2003 I was invited by Poptronics to develop a building tutorial for their web site. Then I was inspired to make an extremely interesting multimedia product and began working with fervor. Only, I just managed to create Unit 1 when Poptronics ceased and this undertaking failed.

Op-amp Circuit Builder. I made this product, in order to reveal op-amp circuit evolution. In this interactive multimedia circuit "theatre" different electronic components played one and the same role on the circuit stage [4]. Applying one and the same 4-step procedure over 40 popular analog electronic circuits were built by converting the passive versions into active ones.

Strange Things Can be put into Feedback Loop. I created this funny story after Tom Hayes's Student Manual for the Art of Electronics [5]. The interactive multimedia tutorial reveals the unique feature of negative feedback systems to overcome all kinds of disturbances. It also shows how to build over a dozen op-amp circuits with a disturbance put into the feedback.

5. CONCLUSIONS.

The heuristic approach proposed is most appropriate for developing student and teacher's abilities for creative thinking. It stimulates the way of reasoning needed to create, synthesize and even invent new circuits. This approach may be successfully applied in other areas of engineering education.

6. REFERENCES.

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