THE ELECTRIC CIRCUIT AS A SYSTEM

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1. The development of the "IPN Curriculum Physik"

Since the beginning of the curriculum work at the IPN in the late Sixties, the electric circuit has been one of the central topics. It has been treated within different projects and still is of interest in research and development.

In the first part of the curriculum, written for children aged 11 to 12 years, the objectives are centred on the topological structure of a simple electric circuit, where the two terminals of a battery and a resistor have to be connected (see Duit's paper an this topic in these proceedings).

In the second part of the curriculum (published in 1973), written for pupils aged 14 to 15 years, the terms voltage, current and resistance are introduced in a more systematic and rather conceptional way, using measurements as procedures to define terms.

In a third part (published in 1975), written for students aged 16 to 17 years, different models of the electric current were developed to treat in more detail the idea of model construction in physics and to reach deeper understanding of the basic terms in electricity.

2. Outcomes of the curriculum

When looking at the effects of these different parts of the curriculum, it was found that just for the first part the outcome was satisfying or could be tolerated. Pupils of that age like to play with batteries and bulbs, they quite easily grasp the idea, that a closed circuit is necessary and they are quite clever in building combined parallel and series circuits and making them function (see some more details in Duit's paper mentioned above). However, the teaching of physical terms like current and voltage turned out to be no more successful than the usual textbook teaching. The students did not understand the meaning of the measurements, they could not grasp the relation between the different terms, and Ohm's law still had to be learned by heart if it was learned at all.

3. Arguments for a new concept

The search for reasons to explain this failure and to give hints for new and better concept development brought three main results, which can be stated in a short and simplified manner as follows:

(a) The structure of the electric circuit with its elements and its associated terms, as it is found in normal textbooks, as it is represented in the minds of most teachers, and as it is presented and explained to students, cannot be really understood i. e. new and old knowledge cannot be integrated.

One can only get used to it by a lot of exercises and learning it by heart, hoping that real understanding will come later on. The definition and the presentation of a physical term as the result of a measurement like

Voltage = Energy / Charge

or

Resistance = Voltage / Intensity of current

is a method to demonstrate the elegance of the physical method, its exactness and clearness. Such a method is, however, a short-cut of the historical development of these terms within the development of science. It suppresses the qualitative relationships of these terms, thereby blocking or hindering real understanding.

(b) Students' preconceptions about the electric circuit, its elements and its functions determine their learning and understanding in a very dominant way.

Such preconceptions are described in more detail in other papers of these proceedings. Some important ones are:

- The battery is a source of current.
- The current is consumed while running through the

resistor.

- The events caused by the current are related to local interaction of the moving particles and the resistor, the lamp, the motor or the like.

The current is treated like a system, where single, unconnected particles are moving around. Even in modern textbooks this idea is supported by making an analogy to loaded and unloaded cars running around on a highway.

In such a system local interaction - an accident or a traffic jam - can block the incoming cars only. Those who have passed already can no longer be influenced by that event. So this local thinking leads to a sequence of events in only one direction.

For the electric circuit would follow that the moving particles could only influence those elements of the electric circuit which are in front of them.

It is not understood that the circuit is really closed and that it does not make any difference if a moving particle is in front or behind a resistor.

(c) These preconception cannot be changed by the simple demonstration of a so called crucial experiment, accompanied by the correct interpretation. These preconceptions are rather stable and in many cases they are blocking the possibility of making observations and of drawing conclusions in accordance with physical theory.

4. The system aspect of the electric circuit

One of the main reasons why the electric current is so hard to understand and so difficult to teach is seen in the fact that local or sequential thinking is so dominant in our everyday experiences.

It is even found in the explanations of physical phenomena and relationships in modern textbooks as the following model shows (from the US Curriculum "Probing the Natural World").

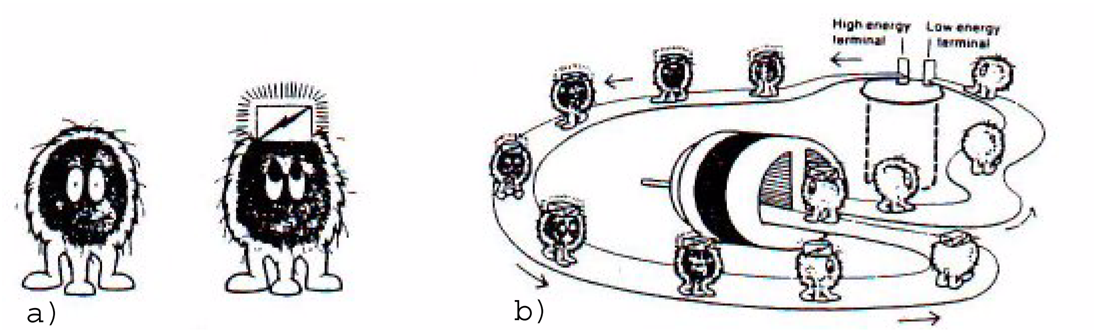

Figure 1: A misleading model

(a) Electroparticle without and with energy

(b) Model of an electric circuit

In this model the single particles are emphasized, while their interrelations are not visible. From this model, for instance, one has to draw the conclusion that the 'empty' particles which have passed the motor, cannot be influenced by any event behind them.

This model therefore will support local or sequential thinking and will lead to serious difficulties if students take this model as background and start asking questions. There is another example where explanations in physics support sequential thinking: the long and tiresome discussion about the direction of the current flow. When a teacher is pointing out that the current is flowing from plus to minus (or from minus to plus) he or she inevitably supports local or sequential thinking.

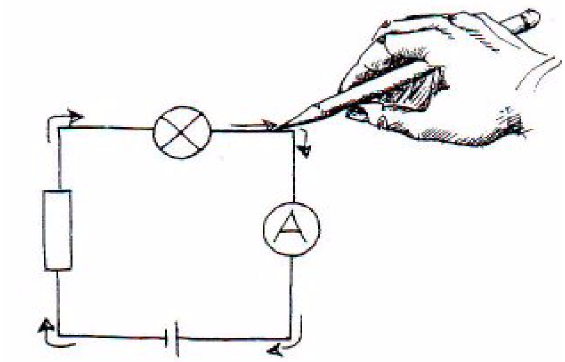

Figure 2: Demonstration of current flow unintentionally supporting sequential thinking

In daily life there is not much experiences with systems with very strong relationships between all the elements and where these relationships are visible or will be observed. The electric circuit, however, is a system where every point depends on all the others and influences all the others. The formal expression of this fact is Kirchhoff's 2nd law.

$$\Sigma V_i = 0$$

Thus it is understandable that many students who never could built up an idea of a system will not be capable even of reaching a starting point for understanding.

It seems necessary to activate first a new schema as a background for understanding by explicitly treating the system aspect for adequate mechanical or hydro mechanical systems as a bicycle chain, a stiff ring or a water circuit.

The discussion of such systems in comparison with the preconceptions based an local thinking should be helpful supporting understanding and ones own thinking.

Moreover the treatment of an electric circuit as a complete system - similar to a stiff ring - is most adequate to explain and to describe all the different phenomena. In the process of teaching, this structure has to be developed further. It has to be shown that the bicycle chain is only a model to start with. It is a rather limited model because it needs a frame to function and there is only a pull on one side of the chain.

The stiff ring is a bit better, because there can be a push on one side and a pull an the other. But again a common frame (ground of the earth) is necessary for this system to transport energy.

Inevitably there is a moment when the analogy with mechanical objects leads to contradictions. Field forces acting on a distance are different from short range contact forces between mechanical particles. But the fact, that every point is influencing all the others and is influenced by all the others remains true and has always to be considered.

Based an these consideration a teaching unit was developed (Stromstärke, Spannung, Widerstand, 1981). This teaching unit was described in the European Journal of Science Education (Härtel 1982). For further details the reader is referred to these publications.

5. Supposed results of the new concept

Until now there has not been a systematic evaluation of long lasting effects of this new approach. From observations during the trials and from discussions with teachers using this approach, there are three points worth mentioning.

(a) The changing of preconceptions of daily life experiences and the building up of new concepts is a tedious process which requires much time and much effort. The possibilities of falling back are numerous and it needs a lot of understanding and patience on the side of the teacher to give constant and fruitful support during this process.

(b) The system approach, the accentuation of the interrelation of all parts of the circuit and the constant search for the closed circuit which moves as a "stiff ring" is a good tool to give this required support. It helps to convince the students to change their own ideas and to start their own thinking about the various objects, processes and outcomes.

(c) It is not very likely that even with this teaching concept there will be many long lasting effects on students knowledge.Probably these effects will be small when just tested by questionnaires or other similar evaluation instruments some time after instruction.

There are two reasons for this presumption.

First, the preconceptions about electricity and the electric circuit are permanently supported by experiences in daily life. These preconceptions are reinforced all the time, because they do not lead to apparent contradiction. So it is not astonishing that these conceptions are the dominant ones, which are found again in follow-up tests.

Secondly, the electric circuit as a topic for tedious study is just not very attractive for a large part of students aged 14 to 16. There is no real connection to their life, the terms and rules to be learned are abstract and without any meaning to them. Only for those who are involved in electronics can the knowledge about electric terms be relevant for directly improving their actions and products.

So it seems to be quite natural that most of the objectives which are reached during instruction and which can be tested in the final examination will soon be forgotten.

A better way of evaluation than just applying a follow-up test would be to measure the time of instruction, necessary to brush up the knowledge to a satisfactory level.

It is hoped that teaching the system approach will lead to rather short refresher courses necessary to remind the students of the "stiff ring" and all the consequences for current flow, parallel circuits, etc.

However, the evaluation to prove these assumptions have still to be done.

6. Computer-Simulation to support understanding

In his book "Mindstorm, children, computer and new learning", Seymour Papert has demonstrated the use of the computer as a microworld, where only one single idea is demonstrated without any side-effect or complex surrounding.

It seems to be possible to adapt this idea to the electric circuit, particularly in respect to the system approach. At the IPN a program in machine language was developed to simulate the movements of a dotted circle with different velocity according to the applied "voltage".

Figure 3: A simple electric circuit

Five resistors of equal size can be applied in series or can be removed and each time the velocity of the moving ring is changed according to Ohm's law. One resistor - the sixth - can be placed in parallel, so that even a combined circuit can be demonstrated.

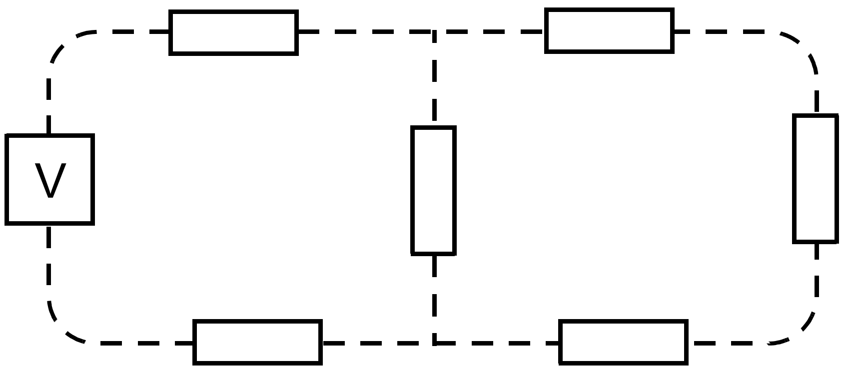

Figure 4: A combined electric circuit

A second program has been developed to simulate the properties of flowing matter at a branching point. It has been found out that students do not normally see the relation between incoming and outgoing currents and that the application of the continuity condition is not at all simple.

To help and support teachers while explaining these relationships, a simulation program was developed. It shows the flowing matter symbolized by a drift of vibrating points at variable density and velocity passing through the branching point.

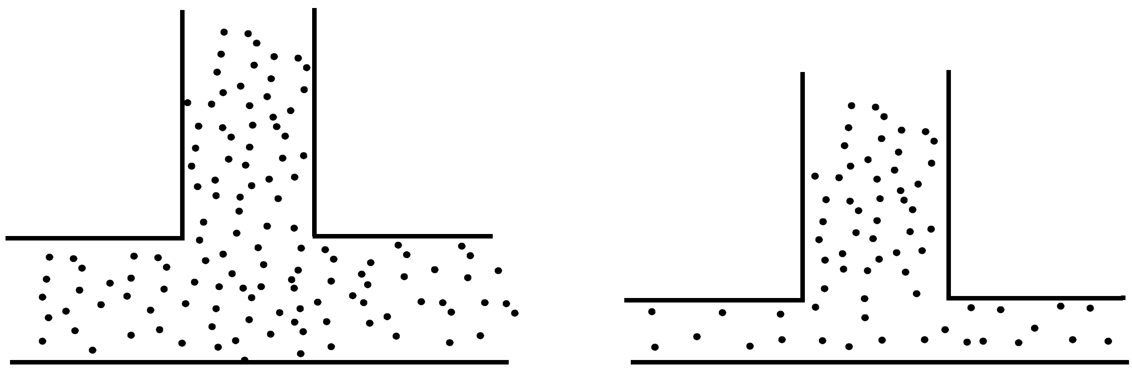

Figure 5: Vibrating points drifting through a branching point

The diameter of the outgoing tubes can be changed and as a result the drift velocity of the points is changing in accordance with the continuity condition.

For stimulation of thinking and reflection the program can be altered in a sense that the gas is highly compressible. In addition a program loop is included where the continuity condition is no longer valid. New points are created or a fraction of these disappears at the branching point. All these programs are proposed as a medium to support teaching by using less words and yet leading to better concentration on the central points of concern. The message for a student could be something like:

"This is a way in which you are allowed to think and you will come up with good and reasonable results. Later you will have to develop this structure in different aspects but for the first beginning it is a good starting point."

The message should never be something like:

"This is a true and final picture of what happens within the circuit. If you have understood this, you will find any explanation you want without further problems."

These programs of course should not replace experiments with real objects and they cannot replace the own model building and reflection.

References

- IPN Curriculum Physik. "Stromstärke, Spannung, Widerstand".

Klett, Stuttgart 1981.

- H. Härtel: "The electric circuit as a System". European Journal of Science Education 1982, Vol. 4 Nr. 1, 45 - 55.

- Seymour Papert: "Mindstorm, Children Computer and New Learning".

The Simulation programs are written for an Apple II computer. They can be ordered from the IPN by sending an empty discette together with a return envelope.