

Children's Naive Ideas/Reasoning about some Logic Circuits Explored in an Informal Learning Environment

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Many studies have shown that operational paths developed as games and experiments in the framework of interactive exhibitions trigger informal learning procedures characterized by personal involvement in the analysis and interpretation of processes. Activities such as semi-structured interview-based cognitive laboratories can elicit children's reasoning schemas and naïve ideas. This is particularly true in learning situations in the framework of "islands" featuring simple apparatuses aimed at exploring ideas and phenomena. Recently, the hands-on exhibition GEI (Games, Experiments, Ideas) featured an updated version of the "island" of electric circuits that simulates the basic logic operators NOT, AND, OR, NAND, NOR. Cognitive laboratories held in the framework of "Marzo Scientifico 2005" (Scientific March 2005) at the University of Udine and the "Festival Internazionale dei Ragazzi 2005" (Children International Festival 2005) in Tricesimo (UD) provided opportunities for collecting data about the reasoning strategies of elementary schoolchildren (8-11 years). Analysis of these data (written answers, graphical representations, oral discussions) presented in this paper shows that pupils select essential elements for explaining the functioning of the circuit, use elementary models of the circuit to justify observations of phenomenology, and autonomously propose truth tables and correctly relate them with physical states of the circuit.

Introduction

Physics Education Research (PER) has often studied how learners build their knowledge nets [1]. Attention has also been devoted to reasoning strategies that address mental models used to build knowledge [2-8]. In this regard, some recent research studies have shown the importance of the learning context [9-12]. In this framework, the role of informal scientific education contexts such as "science centers", museum and exhibitions has been studied [13-16]. The learner's interaction with what is observed/studied is a key feature for fostering understanding, specially when it involves activities focused on exploring phenomena, expressing ones' own hypotheses, and comparing them with experimental results [17]. The interactive exhibition GEI (Games, Experiments, Ideas)⁴⁷, developed in 1994 as a collaboration amongst teachers and the PER group at Udine University, has been both an effective informal learning environment to foster young people's (4-15 years) qualitative/quantitative exploration of basic physics phenomena (mechanics, thermodynamics, electricity, magnetism) and a research tool for investigating naïve reasoning and mental models used to interpret the observed phenomenology [18]. The special focus of the exhibition is on electric circuits, through the "circuits' island" section. Studies on the nature of mental models used by students of various ages to describe the behaviour of electric circuits have been a central line of PER research since mid eighties [19-23] and have

⁴⁷ <http://www.fisica.uniud.it/GEI/GEIweb/index.htm>

lately attracted renewed interest [24-29]. Recently, the GEI “circuits’ island” has been updated with basic logic circuits (in a. o. AND, NAND, NOR, NOT, OR); the aim is to introduce pupils to basic components of everyday electronic devices such as mobile phones, PCs, etc.... So the exhibition addresses a content area that is rarely addressed in PER because logic circuits are not a basic physics content⁴⁸; moreover, the introduction of elements of logic in Mathematics syllabi has also raised words of caution. Nevertheless, we think that the introduction of this topic may increase students’ motivation. Here some preliminary results on GEI circuits activities are reported.

Context and data collection

The lab work activities took place during the Children’s International Festival 2005 held in Tricesimo, a small town near Udine in north-eastern Italy. Five elementary school classes were involved (2 fourth grade and 3 fifth grade classes), with a total of **87** pupils (8-11 years). Activities lasted about 90 minutes; **5** logic circuits were investigated (in sequence NOT, AND, OR, NAND, NOR). All the circuits were constructed with everyday materials such as batteries, wires, paper clips and hairpins (as switches representing binary inputs of the circuits), and light bulbs (representing the output variable). The activities allowed the introduction of a two-symbol system of numeration, given the two possible states of the switch (open/closed) and of the light bulb (on/off). The activities were carried out according to the following sequence: - open/free approach to the “context” (i.e. pupils, in small groups, explore and manipulate the circuits); - questions/problem posing about the role/function of circuit’s elements; - small group semi-structured interviews [30]. The protocol actually featured some interaction amongst the first author, the pupils and their teachers; it was as minimal as possible, being neither a guide for solving problems posed nor a support for looking at/correcting possible errors/learning problems. The pupils’ answers to questions and interview responses produced data of three types: graphical, written, oral.

In the case of the NOT circuit (see Fig. 1) the activity sequence was: interactively, the pupils described the circuit’s functioning in terms of the hairpin’s position (touching/not touching the paperclip). Then the “state” of the hairpin was formalized with 0 and 1 (0 = not touching, 1 = touching); the same was done for the “state” of the lamp (0 = off, 1 = on).

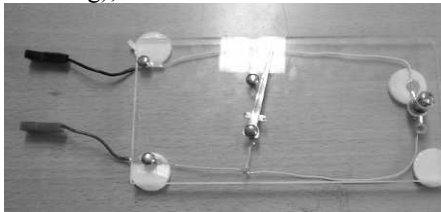


Fig. 1: NOT Circuit

Finally, the pupils autonomously built a truth table (shown below):

Hairpin	Light Bulb
Touching (1)	Off (0)
Not touching (0)	On (1)

Data Analysis and Research Questions

The questions asked during the activities were: “*What happens?*”, “*When is the lamp on?*”, “*Why?*”. Data analysis focused on: - identifying whether the observation description includes some justification and which variables (if any) are named; - analyzing possible/plausible models through which pupils could interpret physical processes; - studying pupils’ ability to relate physical processes to logical organizers (i.e. truth tables).

⁴⁸ In Italy, electronics is a subject usually taught in vocational schools for 16-18 aged students

More specifically, the research questions are:

- 1.1) How frequently is the analysis a mere description of the circuit? 1.2) How frequently is there also a justification of the observed behaviour? 1.3) Is there any difference between the NOT and AND circuits?
- 2) Is it possible to distinguish between descriptions and justifications?
- 3) Which variable(s) are used in the circuit description?
- 4) Which viewpoints are used in the circuit description?
- 5) Which interpretations are used to justify what has been observed?
- 6) How frequently do pupils' descriptions of circuit functioning correctly employ truth tables?

Preliminary results

Analysis was made of 87 answer sheets, of which 61% derived from the fifth-grade pupils (10-11 years). The analysis follows a schema already used in the GEI research framework [17].

As far as *RQs 1.1* and *1.2* are concerned, description and justification are quite often confused. Two categories of response were identified: **A**) focus on the physics/topologic elements of the circuit; **B**) focus on circuit behaviour and a physics variable justifying it. The following are typical excerpts: **A**: “*The bulb is on when the hairpin is not touching [the paper-clip], it is off when the hairpin is touching [the paper-clip]*”. (**NOT**), **B**: “*The hairpins play the role of a bridge carrying the current needed to switch on the bulb*” (**AND**). Global results are shown in the following tables:

N=87	NOT (number of answers)	AND (number of answers)
Type A	59	47
Type B	27	30
No answer	1	10

N=87	NOT (number of answers)		AND (number of answers)	
	5th grade (N=53)	4th grade (N=34)	5th grade (N=53)	4th grade (N=34)
Type A	31	28	19	28
Type B	22	5	28	2
No answer	0	1	6	4

Type **A** is the most common response (globally 69% for the NOT circuit and 61% for the AND circuit): it is plausible to assume that the pupils found it easier to focus on circuit elements. No significant differences appear between the 4th and 5th grade classes. Amongst the pupils who adopted Type **A** answer for the NOT circuit, 53% belong to the 5th grade and 47% to the 4th grade; slightly different percentages can be found for the AND circuit with 40% belonging to the 5th grade and 60% the 4th grade. Type **B** is much less common (~ 31% for the NOT circuit, 39% for the AND circuit). The pupils who have given this type of answer mainly belong to the 5th grade (81% for the NOT circuit, 93% for the AND one). It may be plausible to assume that the abstraction level is higher in the 5th grade pupils than in the 4th grade. The **A** and **B** answer correlation for NOT and AND circuits regarding *RQ 1.3* is shown in the following table.

	<i>AND</i>	Type A (%)	Type B (%)	No answer (%)
<i>NOT</i>				
Type A		69	21	10
Type B		26	63	11
No answer		0	0	100

The data suggest that:

- since a vast majority (~ 69%) described both NOT and AND circuits from a functional viewpoint, it is plausible to assume that this viewpoint is a “natural” one for most pupils. One fifth switched from type **A** to type **B** (21%), adding some kind of justification to their answers.

- the majority (63%) of the pupils giving **B** type answers for the NOT circuit confirmed their choice in the AND case. Almost one fourth switched to a type **A** answer. It may be possible that the circuit’s structure influence the abstraction level at play.

These results might have been influenced by two factors in the activities: - the pupils’ interaction with their teachers and the researcher; - at the end of the NOT activity, the collaboratively-built functional viewpoint (truth table, conditions for lamp on/off) was summarised: it might have been partially acquired as an “automatic” approach; in this case, some potentialities of other interpretations might have been lost.

RQ 2) Five types of answer have been identified; 1 and 2 correspond to Type **A**, while 3, 4, and 5 correspond to Type **B** in RQ 1a, b. The data are shown in the following table.

Type of answer (N = 87)	NOT (number of answers)	AND (number of answers)
1) description only	50	42
2) description mixed with tautological justification	9	5
3) description mixed with justification	9	13
4) description and justification apart	13	2
5) only justification	5	15
6) no answer	1	10

The number of pupils who chose a descriptive viewpoint is about the same for both circuits. Typical examples of Type 1 answers are: “*We connected a battery to two wires. If you put the two hairpins next to two paper-clips, a bulb comes on, while if you take them away, the bulb goes off (AND)*”

The Type 2 answers mix a description with a tautological justification: “... *if the hairpin is in the “0” position, i.e. it is not touching, the bulb is on... if the hairpin is in the “1” position, i.e., it is touching the paper-clip, the bulb is not on.. (NOT)*”. It is plausible to assume that there is some confusion between a simple formalization (0/1 vs. touching/not touching or on/off) and an interpretation of how the circuit functions (see below).

In Type 3 answers the description is mixed with a justification: “...*(connecting) the circuit on one side to a battery, and the other side to a light bulb, makes it switch on. But, if the electricity path is blocked, the light bulb turns off since it is not fed... (NOT)*”.

In Type 4, description and justification are separate, much more so for the NOT than for the AND circuit. Answers with only a justification (Type 5) are more frequent (by about a factor of 3) for the AND circuit.

RQ 3) The results of the analysis are shown in the following table.

Variable	NOT (number of answers)	AND (number of answers)
Current or electric current	5	8
Electricity	11	3
Energy or electric energy	12	13
Total	28	24

Energy is the variable most widely quoted both in the descriptions and the justifications. This fact may be plausibly related to the common-sense idea about a battery as a source of energy, whatever the meaning given to energy.

Some pupils intended the named variable as something flowing through the circuit; moreover, the variables are used without distinguish them: “...*The circuit allows the electricity to pass through the wires, moving the hairpin toward the paper-clip, the light is blocked.. (AND)*”. The identification of a variable is more frequent amongst the 5th grade pupils; only six out of 34 pupils from the 4th grade name a variable.

RQ 4) Here we analyze those answers referring to categories 1-4 of RQ2 in which a description is present. Three main categories were identified:

D1: some elements (hairpin, paper clip) are acknowledged as components responsible for how the circuit works: “... *if you move the hairpin and put it close to the paper-clip the bulb goes off (NOT)*”.

D2: the circuit is looked at as a whole, it makes the lamp go on/off; it is plausible to assume an implicit model focused on some entity flowing through the circuit: “*The circuit is made up of electric wires connected to a battery which transmits energy and makes the bulb go on. Pushing the hairpin close to the paper-clip blocks the current ... (NOT)*”

D3: an explicit reference to how the circuit works is present. The answers to the question “When is the lamp on?” identify the correct configuration of the hairpins, therefore this group includes those answers where words such as “only” or similar clearly indicate the “on” condition: “*The circuit functions only if the hairpins are aligned... (AND)*”

Nine pupils out of 87 for the NOT circuit and 26 for the AND circuit either do not clearly identify any meaningful circuit element in their descriptions/justifications or do not write any description at all. The data are shown in the following table:

Description Type	NOT (number of answers)	AND (number of answers)
D1	62	41
D2	12	3
D3	4	18
Total	78	62

RQ 5) For both NOT and AND circuits, three models have been identified:

M1 or “compensation” model: the energy stored in one of the battery’s poles is lost as soon as a wire or a hairpin touches it, so the lamp is off. It is plausible to assume a kind of compensation of the battery’s energy (what is lost at one pole is regained at the other): “... *touching the negative pole with the hairpin all the positive energy goes to the negative pole and the positive disappears.. hence without the positive pole the bulb is not on...*” (NOT). M1 is never used to justify the lamp on.

M2 or “flux” model: something, named current or electricity, flows through the circuit. The focus is on the topology of wires and hairpins; how the circuit works is expressed in terms of interruptions/blocks: “... *If you move the two hairpins and they do not touch the paper-clips,*

the flow of current is interrupted”(AND). Moving the hairpins does not interrupt the flow in the NOT circuit, while it does in the AND case.

M3 or “short circuit” model: in a very simple way the concept of mesh is acknowledged as the only part of the circuit where something (i.e. current) can flow. The idea of how the circuit works is linked to that of “turning off the lamp”: “*..Because [the current] enters and goes through the bulb, if the hairpin is touching the paper-clip, the current turns back (NOT)*”

Only one pupil used a model different from those cited above: “*... when a hairpin falls onto the paper-clip [the energy] is transmitted to the other hairpin and in this way the bulb is on (AND)*”. The following table summarises the data:

Model	NOT (number of answers)	AND (number of answers)
M1	5	0
M2	16	23
M3	6	0
Total	27	23

The vast majority of pupils used the “flux” model; in the AND case no other model is present. In the NOT case about a dozen pupils used the other two models, distributed almost equally. It seems plausible to infer that the circuit structure suggests the type of model used: - the “flux” one is rather “natural” for the AND circuit because the two hairpins are in close proximity; - the NOT circuit, which has 2 meshes when the hairpin is closed, also suggested the other two more complex models.

RQ 6) The results of the analysis are reported in the following table.

Truth Table Type (N=87)	NOT (correct tables)	AND (correct tables)
0-1	58	35
0-1 and words	11	12
words	0	28
Total	69	75

About 80% (NOT) and 86% (AND) of the pupils are able to use truth tables autonomously to describe observed phenomenology coherently. The 0-1 description is most common for the NOT circuit (84%). For the AND circuit the 0-1 and the phrasal description (“*touching/not touching, on/off*”) are about equally frequent (47% vs. 37%). Mixed descriptions are used with almost the same frequency for both circuits (16%). The absence of phrasal descriptions in the NOT case is a feature to be further investigated. The data plausibly suggest a capability to correlate physical states with truth tables that here play the role of logical descriptors.

Conclusions and future work

The informal context of the GEI exhibition has again given hints for studying some reasoning strategies of elementary school pupils (9-11 years). This preliminary data analysis shows how possible “theoretical worlds” [31] are built on the basis of observations and experiments. In summary:

1. the circuit descriptions are focused mainly on the role of specific elements rather than on the circuit as a whole. It is plausible to infer that local viewpoints prevail over the global one. The capacity to use both viewpoints is usually a high level skill. On the other hand, the pupils’ tendency to select aspects of the circuits that help

- interpret what happens and to neglect those that do not may resemble a common attitude in the physicist's work, i.e. to analyse phenomena by focusing mainly on aspects functional to their interpretation;
2. this study seems to support the hypothesis that the acquisition of a content/concept is favored by the construction of mental models [24]. The pupils' models of what they had observed focus on those features perceived as most meaningful. It is plausible to infer that the spontaneous construction of models may be strongly influenced by the adoption of interpretation viewpoints if they are proposed by "trustworthy" teachers. If this influence is confirmed, it has to be taken seriously into account when designing/implementing activities aimed at eliciting pupils' reasoning strategies;
 3. in the pupils' explanations of how the circuits work, three models have been identified, all focused on the lamp on/off process. The most frequent model, for both the NOT and AND circuits, is a "flux" model, where some physics variable flows through the circuit;
 4. the capacity to correctly use simple logical organizers such as truth tables (and relate them to physical states) may plausibly set up anchors for functional "micro-rules" (e.g. "*hairpin touches*->*lamp on*") that help in interpreting the process.

Future data analysis will be aimed at correlating the phrasing and drawings used for the NOT and AND circuits, and categorising the answers for the OR, NAND and NOR circuits by focusing on features that foster comprehension of how the circuits function, their possible correlations and possible favouring/hindering factors.

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