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# ADULTS' MISCONCEPTIONS IN ELECTRICITY

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## ABSTRACT

We present how unskilled workers and staff employees understand everyday situations where static electricity or electricity at home is involved. The method of data gathering was clinical interviews based on situations relative to static electricity in cars or in an electronic assembly workshop, to the functioning of a circuit-tester and a washing machine. Different cases were discussed (e.g.: electric shocks, short circuits, and so on). The analysis was made in the framework of mental models used to describe these situations. In spite of electricity lessons in their school time and/or in-service training in their companies, the subjects made no reference to formalized electricity. The models they used were built up from their own experience. Often electricity is considered as a substance or a fluid easily transferable from one place to another. Conceptions about grounding show that the earth is assimilated to a big reservoir into which electricity flows and then is lost. Human body is also considered as a reservoir of a limited amount of electricity.

## INTRODUCTION

Misconceptions in science have largely been studied in students from elementary school to college. On the contrary there are very few studies relative to adults' knowledge because the questions of adults' training have probably never been considered so important than students' learning. But a new era seems to be opening with studies relative to situated cognition (Brown et al., 1988) or to cognition in practice (Rogoff & Lave, 1984, Lave, 1988). In these studies, the

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emphasis is put on knowledge learnt outside of any schooling and deeply rooted with the acquired experience from real-world situations. The role of the context is crucial because this knowledge is situated and is built from action on the world (see *Cognitive Science*, 1993).

Electricity is very common in everyday situations, at home or at work. Anybody has already switched on and off lamps, used home appliances, fixed some faulty device or even has been got shocked when he/she comes into contact with the body of a car or a bare live wire. From these different experiences, how do people represent the electric phenomena? In the same way, many people use electric machines and apparatuses during their working activities. Does this use influence their conceptions of electricity? Nobody knows exactly! This paper will try to give a beginning of answer to the central issue of how everyday contexts shape the adults' conceptions in a domain which is usually well described by scientific knowledge.

## METHOD

### 1 - Subjects

All adults retained in this study had jobs related to the electric or electronics industry. Another characteristics is that all of them had a poor knowledge in formal and basic electricity. The subjects came from two companies:

(i) - 19 unskilled workers working in a factory which assembles parts for fabricating computers (Bull Company). The job places are typically workshops where several workers have to assemble different parts together on a system which at the end will be a computer. This job is always the same: wiring and soldering the same devices and is performed by unskilled workers.

The conditions of security against static electricity are particularly severe because any electrical discharge can destroy electronic chips. So all workshop benches are grounded, the floor is also grounded through large copper bars which cross all along the floor. The workers must also be protected against static electricity: they wear anti-static clothes and are also grounded by being linked by a chain and a metal bracelet to their benches.

For security reasons, all the workers were trained in basic electricity for one or two weeks in the factory when they took their jobs. But before this training session they just had attended regular science courses at elementary long time ago. Very few attended middle school. Thus we can consider that these people did not have a formal knowledge and all their knowledge about electricity is experiential.

(ii) - 14 people working at the French state electricity company (EDF). All were administrative employees who had been enrolled for a one-year-training program in order to get a higher position at EDF. When they have completed the training program, they will be able: (i) to welcome and to advise the customers who would like to make changes on the electrical power distribution in their apartment or to put in electricity in a new home; (ii) to manage the small team of technicians who will take charge the works. These people had a higher level of schooling as in general they had been able to attend middle school and even, for some of them, high school. So all were taught in basic electricity, but they had forgotten what they had previously learnt. At the time of interviews we made, they had not yet started their training, excepted they had to take a two-week training session in basic electricity for beginners to refresh their school knowledge. This session was designed so that basic electricity with its different entities such as current and voltage be presented. They did practical works and measurements with ammeters and voltmeters on electric circuits. Paper-and-pencil problems were given too.

In both cases, knowledge about electricity will not be school knowledge but rather knowledge acquired through working or everyday situations.

**2 - Interviews**

In order to have access and interpret the adults' ideas about electricity, we carried out clinical interviews following a method inspired from Piaget. The set of questions to ask during the interviews had been prepared beforehand, but the question order was dependent upon the previous answers. After a subject's answer, the interviewer built up a hypothesis on a possible model of electric phenomenon subject could have. The following question was for testing the hypothesis and getting more information on the mental model. Examples of interviews are given elsewhere (Caillot and Nguyen Xuan, 1993).

The questions were about situations that the subjects can have already met in their ordinary life or at work. Here we will present only three situations: the first was relative to static electricity and the two others to home electricity. In this latter case, the subjects were invited to describe (i) the functioning and the use of a circuit-tester and (ii) what happens when a washing machine is faulty.

The interviews relative to static electricity were made preferentially with the people of Bull Co., place where the security measures against static electricity are so important. On the other hand, people coming from EDF were interviewed mostly on the situations where home electricity is involved since they will have to face problems with it when their training is completed.

We are going to describe more precisely the situations on which the interviews were made. With static electricity, it was easy to find working or everyday experiences where it is present. In the assembly workshops, the workers are in an environment such as static electricity is always present in their mind since each time they start their job they must get into their anti-static clothes, chain themselves to the bench with the metal bracelet. At the end of their working day, they have to take off their special clothes and to chain off. Static electricity is also very present in the everyday life: the body of a car can be charged and when one touches it, one receives a shock; clothes in synthetics can also be charged and hairs after a blow drying too. All these situations are well known and during the interviews, people can spontaneously evoke them in their discourse as a reference to justify what they are saying. If interviewees do not evoke them spontaneously, we question them on these situations.

In the case of electricity at home, we presented a circuit-tester to the subjects and sometimes we ask them to show us how it works. A circuit-tester looks like a small screwdriver with a tiny neon bulb inside its handle. When the blade is plugged into a hole of a socket, the tiny bulb brightens up if the hole is connected with the power line; if there is no voltage at any socket terminal, then the bulb does not light up. A circuit-tester is relatively common at home because it helps to locate breakdowns and short circuits. The circuit-tester was chosen because it makes possible to reveal misconceptions about electric current at home. Usually it is a three-phased alternating current, so that at one of the socket terminal - called the neutral- there is no voltage at all and the circuit-tester bulb does not light up. The subjects, when they were experimenting with the circuit-tester, were generally surprised to see what happens when they had plugged the blade into each socket terminal: the bulbs lights up when it is connected with the main line whereas it keeps off when it is plugged into the other terminal, the so-called neutral. The existing usual symmetry of the terminals with direct current or one-phased alternating current has then disappeared.

The other situation relative to alternating current is about a faulty washing machine. Of course we could not have a real one with a short circuit, so we replace it by asking the interviewees to produce drawings simultaneously with their explanations of what happens to the washer.

**3 - Analysis framework**

The answers to the questions, supplemented with the tests made with the circuit-tester and the drawings, have given access to the conceptualizations made by the interviewees. The construct of “mental model” has appeared to us as a good candidate to explain the subjects’ discourse. Norman (1983) gave some properties of mental models which were relevant to what we observed: mental models are incomplete, unstable and “unscientific”. Norman added:

> “People maintain “superstitious” behavior patterns even when they know they are unneeded because they cost little in physical effort and save mental effort.”

The fact that mental models are “unscientific” has lead many people to consider the conceptualizations made, for example, by students as “misconceptions”. If we use this term here, it is more out of habit, but we are well conscious that it can be misleading. The prefix “Mis-” introduces the idea of bad or wrong which is always a value judgement with respect to a certain norm. Here the norm would be scientific knowledge.

We consider that the mental models developed by people about electric phenomena have a sufficient predictive and explanatory power for acting in the world, in the everyday life and at work.

We are going to describe different models we observed. Often as we will see they are local; that means they are adapted to such or such situations and that they do not consist of a whole and well organized system of explanations. The different models will here be presented as organized into a hierarchy, from the crudest where "superstition" can be present to the most elaborated which, in some cases, can announce scientific models. Of course this hierarchy is "the scientist's conceptualization" of mental models, as Norman said.

## MENTAL MODELS RELATIVE TO STATIC ELECTRICITY

Static electricity is a phenomenon relatively common in everyday life and also in factories like the Bull factory. The questions focused on its origin and how electric charges move. One of paradoxes of static electricity is that beyond its visible effects like hair-raising after a drying with a blowing dryer, static electricity appears only when one gets an electric shock (e.g. after touching a car body initially charged), that is when electric charges move from one place to another, otherwise when electricity is no longer "static"!

### 1 - Origin of static electricity

Static electricity, in spite of its pervasive effects, can still have a mysterious origin for some people. In the crudest model, static electricity is seen as being present everywhere in the ambient environment. Firstly it can be found in air as by thundery weather or when it is hot, weather which favours the electric shocks when one touches a car body. It can be present also in the factory workshops. People believe that static electricity is then on all artefacts found there: on carts, on the floor (in spite it is grounded) or on the different electronic devices and parts workers have to assemble together. The model is built up from the electric shocks that these people have already experienced. This model is rather primitive because it seems based on a sort of magic belief where superstition is not very far: static electricity is mysterious and can produce shocks without warning, since any part of the environment can be source of these shocks.

The second model is more precise on what is source of static electricity. People were able to categorize objects in two sets: those which are carriers of static electricity and the others which are said "anti-static". Some objects are "natural" sources of static electricity, such as clothes made of Nylon or other synthetics, car seats, artefacts made of plastics. The analysis of subjects' answers showed that these three examples refer to precise everyday life situations where static electricity effects happen: women's underclothes, such as slips made of Nylon when they cling to the skirts; car seats seen as the source of electric shocks when one comes into contact with a car body, or the experiment made by children with a comb made of plastic attracting small pieces of paper. On the contrary other materials and objects are considered either as "neutral" or as "anti-static" such as those made of wood, or the fabric softener used in a washing machine. For the people who developed such a model, the criterion to decide whether a material or an artefact is "static" or "anti-static" is to know if they get a bad shock when they touch it. In this model, static electricity is localized whereas in the first model it is completely spread into the ambient environment.

In the two first models static electricity is considered as a physical state characteristic of either environment or materials and objects. On the contrary, in the two last models static electricity is rather seen as the result of a process. People who have the third model think that static electricity is produced by something moving. So a worker from Bull factory said in his interview:

> "It's by moving *[boxes]*. … The more we move them, the more they get electricity".

His job was to go to the warehouse for the parts what he will have to assemble later. These parts were prepared beforehand and displayed in plastic boxes. He experienced that he got more electric shocks if he had moved the boxes a great deal. In the same way, a woman was able to relate the origin of static electricity when she took her underclothes off:

> "*[Static electricity]* happens when I take off my underwear. This gives static electricity".

Friction appears in the fourth model. Static electricity is produced when two objects move with friction. Thus an interviewee, when he was asked about the origin of static electricity on a car body, said:

> "May be it's friction between the body and the air … which produces … charges".

A woman evoked also friction to explain static electricity appearing with the clothes made of synthetic fibers. This last model can be related to the physicist's model where static electricity is produced by friction between two insulate materials: surface charges on one of the two materials are removed by friction and transferred to the other, so that one of both is positive charged and the other negative charged. Of course, these scientific notions did not appear in the interviews we made, but we consider that this fourth model can be a good base if a training in electricity is planned.

**2 - Models of static electricity discharges**

As we told beforehand, static electricity is made visible by its effects during transfers and discharges. The most common discharges are those which give bad shocks and so they are well felt in the whole body. The question is then: "Where does static electricity go at the time of the shock in the body?". Two models of what happens to static electricity in a discharge come out. The difference between these two models is the place where charges go.

Subjects who have the first model think that when they get electric shock, static electricity goes to their body and then stops. As a worker from Bull factory said:

> "… touching the cart with our overalls, it *[static electricity]* goes through us. It stops like this".

The human body is viewed as a reservoir in which flows electricity. For some of the subjects, this reservoir has a limited amount of charge[3]. When we asked questions about the role of the anti-static bracelet, we got answers in which the bracelet and the chain of conductors linking the worker to the ground are described as draining a too big flow of charges: the chain of metal conductors is thought as an overflow pipe which drains an excess of water. If there is a too big discharge, the human body can not withstand and the charge in excess is then removed outside it. The subjects used unconsciously a metaphor of water or fluid flow to model what happens with this charge in excess. A similar metaphor has already be found by Johsua and Dupin (1984) when they studied the students' misconceptions on DC circuits. They called this metaphor "the metaphor of the fluid in motion".

The second model supposes that electricity carriers go directly to the ground, even if there is no grounding at all. So a subject explained that if he touches a charged cart of the workshop he got an electric shock and that:

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[3] Here we use the term "charges" for convenience. It is not necessarily the term that a subject would employ.

“I am discharging myself … and the electric charges are lost into the earth”.

For the subjects who think according to this model, the series of contacts floor/human body/cart (or any charged object) are enough for discharging takes place and that electric charges go to the ground where the charges are then “lost”. Thus during discharging and its corresponding shock ,static electricity goes right through the body to the ground. This model could be right if a grounding (continuous chain of conducting materials) would exist. For all other cases, this model is very far from the scientific model.

The scientific model is, of course, more elaborated so that it can not be inferred directly from sensible experience but only learnt. When a charged body is touched and there is no grounding, so that the charged body and the person who is in contact with it are both insulated, some amount of the electric charge is transferred from the charged body to the person. Thus when a discharging is completed, both are finally charged, what means static electricity does not go right through the human body to the ground as the subjects suppose it.

## MENTAL MODELS OF ALTERNATING CURRENT

We were able to infer mental models in which alternating current is involved through several situations, but here we will discuss only two: the functioning of a circuit-tester and a short-circuited washer. The interviewed subjects came mostly from EDF.

### 1 - Circuit-tester situation

The subjects answered to our questions on the functioning of a circuit-tester and made some tests with it by plugging the blade into the holes of a socket. We asked them to predict and explain why in some cases the tiny bulb lights up and in other cases it remains off. The answers showed how people modelled current in situations very far from the situations where DC current flow into circuits as those studied in class with their battery, bulbs or resistors and wires. We were able to find four different models whose the main characteristics is to consider open circuits. It is sure that it is quite impossible to represent how circuits are closed at home. and only people who had learnt it at school could know. In fact AC current which goes back and forth along the wires, arrives for half period by the main line and goes back through the neutral which is related to the power plant by grounding in each building. The circuit is indeed closed by this grounding which is obviously never visible. As the mental models are often built up from sensible experience, they can not take into account what is invisible and it is practically impossible to infer hidden features.

The first model is very limited: current flows through the circuit-tester, puts the neon bulb on and stops into the user's hand or body. This model is directly built from experience since when a test is made the user should touch the metal part located at the handle end with a finger tip. So an interviewee said:

> "If we put a finger at the end, we will receive current. Then it is stopping and producing heat. The hand makes contact".

The second model is slightly more elaborated because it tries to take the circuit closing into account. This model was called the U-turn model because as a subject said:

> "The current makes a looped circuit".

He meant that the current goes into the circuit-tester and makes a U-turn inside his finger or in his body. In fact this model tries to fit to two requirements: the first is about the need to have a closed circuit and the second is about the current which is alternating. The subjects knew from their own experience that only the live wire enables to light up the bulb in the circuit-tester whereas the neutral does not, so by building up the U-turn model, they believed that the input and output are made through a unique wire. Thus the circuit is closed by looping. Moreover with this model, people imagine that during a first half period, the current flows from the live line to the circuit-tester whereas during the second half period, the current comes back from the circuit-tester to the same line. These ideas are strengthened by the way of using the circuit-tester: it works by touching the metal end by one's finger tip. As a subject said:

> "The finger forces the current to turn back"

Another also said:

> "*[Touching the metal end]* enables the current to go through the person in order to come back to the live wire".

The third and fourth models suppose that grounding is needed to close the circuit. When the subjects see that the bulb lights up when the blade is plugged into the hole socket connected to the live wire, they know that the circuit must be closed. This knowledge comes either from the time of schooling or from a most recent adults' training. For closing the whole circuit with a current going out from the power plant, flowing through the circuit-tester and through the user and then coming back to the power plant, the circuit should be continuous. The models elaborated by the subjects try to take this unbroken chain of conductors into account.

In these two models, the first elements of the conducting chain is correct: the current coming from the live wire goes through the circuit-tester, then through the user's body and finally to the floor and the building. The difference between both models is about what happens to the current after the building. The third model supposes that current is spread out into the earth, it fades and disappears as this is shown through a quotation drawn from an interview :

> "*[Current]* is lost".

so that the subjects having built up this model were not able to predict how the circuit could be closed. The last model is the scientific model indeed. the circuit is closed by grounding so that current flowing in the earth can go to the power plant. In fact only one employee over fourteen interviewees owned this model which obviously comes from a formal education. Moreover when this model had been built, he also was able to explain correctly why the light does not light up when the blade is plugged into the neutral hole. He justified his explanation by saying :

> "There is no light because the person who serves as a way back *[for the current]* is grounded".

This is right since the neutral is grounded too. In this case, the whole circuit made of the neutral line, the circuit-tester, the user, the floor and the building is grounded.

### 2 - The washing machine situation

The interviewees should answer questions about a situation in which a washer would be faulty: a bare live wire would be in contact with the washer body. Moreover they could make drawings to explain the path followed by the current. So in this fictitious situation, if the washing machine is not grounded then it will be at the same voltage than the bare live wire, that is 220 V. If somebody comes into contact with it, (s)he will be electrocuted and current will flow to the ground through his/her body. This dangerous situation, even it is rather uncommon, was well known by the interviewed adults and often they knew that the washer must be grounded by regulation.

When it is ungrounded, we were able to infer that the subjects use only two models to explain what happens. In the first model, some subjects believe that, as the washer is at 220 V, electricity is accumulating on its surface, or even leaves the washer to go into the ambient air. The surface carries electric charges like a body charged by static electricity (see the above discussion). If one comes into contact, electricity flows into the person's body and is stored inside it, until one gets electrocuted. In this model, electricity arrives to the faulty washer only by the bare live wire carrying electricity. Of course there is no idea of closed circuit. The main idea in this model is to represent electricity as a "fluid in motion". This substance can pile up, be stored, be poured like water.

The second model is slightly more elaborated. The subjects think that when the live wire touches the washer surface, electricity goes on the washer surface - as in the first model- , and comes back to the neutral. These subjects incorporate the necessity of a closed circuit in their mental representation. But their description of how one gets electrocuted is the same as in the previous model. A worker said:

> "the person who comes into contact with the washer will be incorporated into the circuit".

This statement means that electricity goes through the person's body, before going back to the power plant through the neutral. Although the electricity goes back to the neutral, death is caused by the storage of electricity inside the human body. The idea of death caused by a certain amount of electricity is supported by this utterance:

> "If you come into contact with the washer surface, you get a shock. If you react quickly by moving your hand away, you are not killed. Your body has not yet been filled up with electricity".

When the washer is grounded, practically all the subjects answered that electricity flows directly to the ground where it is completely dispersed and lost.

Again the idea of a closed circuit is absent as the third model used to explain the circuit-tester situation.

**DISCUSSION**

Beyond the specific differences between the three situations on which interviews were partly made, we are able to see some common ideas or beliefs which apply to the static electricity and to the alternating current as well.

First electricity is considered as a substance. As the dictionary says: "a substance is a particular kind of matter". Bachelard, as soon as 1938, showed that the substantialisation, otherwise the sustantialist explanations, based on empirical experience is an epistemological obstacle to knowledge (Bachelard, 1977). He wrote:

> "The need of substantializing properties is so big than metaphorical qualities may be considered as essential[4]" (Bachelard, *op.cit.,* p 109).

Whatever the situations we studied, electricity is modelled as a material stuff which can flow, pile up and be stored. All these properties are those of a fluid which can move, but which also can stop as in static electricity situations or when electricity is stored inside the human body or on the surface of a faulty washer.

Secondly, through static electricity and AC situations, the adults consider the role of earth as crucial because, in the models they have developed, it is the place where electricity (electric charges or current) goes and fades when there is a discharge or an overload.

## CONCLUSION

In conclusion, the models developed by adults about static electricity phenomena and alternating current appear to be strongly based on well known everyday or professional experience: they are experiential models indeed. Their function is to help the subject make useful predictions in everyday situations. Moreover, these models present two more characteristics. The first one is that

[4] Translation made by one of the authors.

they are usually local models based on constructs that are not always coherent. For example, in the interviews about the alternating current, some of the subjects think that when the washer is ungrounded and there is a short-circuit, the electricity flows through the person who comes into contact with the washer surface and then goes back to the generator along the neutral wire. So this mental model for a short-circuit situation implies the concept of a closed circuit with two different wires: the live line and the neutral. However these same subjects think that the electricity makes a U-turn inside the circuit tester, or inside the body of the person who holds the tester, so if in their mind the circuit is closed, in fact it does not because it comes back by the same wire.

The second characteristic is that the models vary more or less between different individuals, although three strong beliefs are shared by all but one subjects as we have discussed previously.

All these models are built up from everyday life or professional experience and are deeply rooted in the adult's mind. When adult training in electricity is planned by a company management, instructional designers and trainers should be aware of the existence of these models and should take them into account as a starting point for their teaching. This will be one of the conditions of a successful training.

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