University students’ causal reasoning dealing with RC circuits

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Abstract. This study examines university students causal reasoning when tackling electric current in transitory situations. A questionnaire with emphasis on explanations was used to analyse students’ reasoning. The results obtained show that a significant percentage of students cannot correctly interpret simple transitory state current phenomena. Their explanations fall into two general categories: one based on potential difference and one that excludes current flow in processes of transitory state. We look at a number of aspects that have been little mentioned in previous research, for example, the reasoning university students use when establishing macro-micro relationships and some difficulties with complex reasoning.

1. Introduction

Despite the fact that there are many studies that identify which concepts and representations students learn well and with which of them students struggle within the context of DC circuits in the steady state, few studies have been made of students’ ideas on transient states of movement of charges in a conductor [1, 2]. In this research, we present two of the questions that have been used to investigate the representations of students about the movement of charges of transients in direct current, which focus on the transition between electrostatics and electrodynamics in first year at university. This study adds to prior research the examination of student reasoning on explanations of electric current in transitory situations in introductory physics courses for science and engineering. We are particularly interested in the causal models students use relating potential difference quantities and macroscopic-microscopic explanations. This study seeks to identify is the students’ main thinking patterns when interpreting contexts of current in transitory state.

2. Theoretical framework

Scientific reasoning is characterized by the use of models, which are in turn used as a representation of how systems behave and structure [3]. Partly, that’s the reason why the international community accepts as an essential part of education of science the educational value of models and modelling [4]. It has been probed that emphasizing students’ models results in a better comprehension on their behalf. The teaching of electric circuits is an example of scientific reasoning based in models, so it is important to question students’ causal reasoning.

The reason why students explanations are incorrect is that those explanations are interpreted as a consequence of a narrow range of causal models most of students become familiar with [5,6]. Most students are used to relatively simple causal models, however, most concepts and scientific theories depend on substantially much complex styles.

Science epistemology and cognitive psychology frameworks are suitable for the analysis of students’ explanations in electric circuits field and electric current in transitory situations. There are several theoretical frameworks that can be used to investigate students’ reasoning [5–8]. The international community
extensively accepts some reasoning types as scientific reasoning, although it is true that there is not a unique epistemological or cognitive theory. In this article, students’ answers are analyzed according to four types of causal reasoning that are widely accepted in scientific reasoning epistemological studies. The first type is the simple causal reasoning, which explains that an event A influences another B, although the effect A is not affected. It is a one-way reasoning. Often cause A is not analyzed correctly or correlation is confused with causality. This reasoning describes in a generalized way a regularity. For example, when a circuit is connected to a battery the bulb is illuminated. The bacterium produces light in the bulb [5,6].

A second type of reasoning is the so-called linear causal reasoning that explains that multiple phenomena that happen intentionally or not, become causes and effects successively. The behavior of the phenomenon is parallel to the result, there is no differentiation between phenomenon and result. Halbwachs [5] defines linear causal reasoning as a tendency to juxtapose a number of simple causal reasoning to form a new relation; a causal chain in which every cause is the result of other cause. Often, after establishing a few simple causal relationships (A, B, C), the reasoning operates in a causal chain A–B–C in which a process produces the next one in a successive way. One example of this type of reasoning would be the following: “the surface charge distribution of charge density in a wire generates an electric field in the wire. This electric field in turn produces a potential difference in each part of the circuit, depending on the resistance”. A simple causal reasoning chain has been constructed between the event A (the charge density distribution produces electric field) and the event B (the electric field produces potential difference).

A third type of reasoning is the relational reasoning or relational causality. It is used when the result is due to two variables or physical quantities of the system. Grotzer [6] affirms that this relations are not an explanation by themselves, but they have a predictive nature. One example of this type of reasoning is the following one: “the electric field is the result of the relation between the concentration of electrons and the width of the wire”. In this explanation the relationship between both variables predicts the value of the electric field. While in the case of the previous two reasoning the principal characteristic is the relation between two or more events, in relational reasoning a relation between two variables of the system is needed, which brings to a result. Last but not least, we find the fourth type of reasoning in scientific research called by Perkins and Grotzer [7] multivvel reasoning. In this case the description of the system is more refined and different models of description are interrelated. One example could be to use Ohms’ model or the model of gradient of surface charge distribution as the framework to explain the processes of an electric circuit. That is, two different descriptions of the same system are correlated at different levels of analysis. In this case the explicative power relays on the fact that the laws of the deepest model allow to deduce the laws of the initial model.

3. Context and methodology

3.1. Academic context and Sample

The current research involved about 200 students at the University of the Basque Country (UPV/EHU) in the first year Introductory Physics course for engineers. All of them had taken at least two years of physics in high school and had passed the national exams in Spain for admission to University to study science or engineering. Those students received 3.5 hours of lectures and 2 hours of laboratory per week during 14 weeks (second semester) on electromagnetism. Electrostatics and electric circuits were taught for 5 or 6 weeks of this course. In all cases, lectures were given by experienced teachers of the Physics Department, and the Electricity curriculum in both universities is similar to those given in textbooks like Tipler and Mosca (2004).

The data were collected in written questions. All the questions were answered as post-test after receiving instruction. The students’ answers to the questions were subjected to rigorous analysis [9]. The analysis does not focus on correct or incorrect answers but on identifying students’ understanding and reasoning. We are aiming at a nuanced understanding of what aspects of explanatory model on currents transient state students understand reasonably well and what aspects are problematic for them. One member of the research team derived a draft set of categories of description for each question based on a reading of the students’
answers, and tentatively allocated each answer to one of the draft categories. Three weeks later, the same researcher again read the students’ answers and repeated the process. The other members of the research team carried out that task independently, and once the answers had been classified all the results were compared. Disagreements about answer allocation were resolved referring to the answers as the only evidence of students’ understanding. It was reached a significant degree of agreement with a Cohen’s kappa reliability coefficient average of 0.85.

3.2. Experimental design
Two questions were given to students over the course to investigate their understanding on the mechanism of how current works in transitory movement of charges. The questions were administered in different formats, but all of them were done post-test after receiving instruction. The question Q1 is a multiple-choice question, which also asked for a reasoned explanation of the answer. Question Q1 presents an RC circuit made up with two capacitors in series connected to the battery and two bulbs located in the wires that connect each pole of the battery with each capacitor. Several alternative responses are presented for the transient state until the capacitors are charged: a) when closing the circuit none of the bulbs will bright; b) when closing the circuit only the bulb connected between the positive pole of the battery and the capacitor brights; c) when closing the circuit only the bulb connected between the positive pole of the battery and the capacitor brights; d) when closing the circuit the two bulbs will bright.

The question Q2 shows an RC open circuit, made up of a battery, a bulb, a capacitor and a switch, which is very familiar to students in the academic context. Students have to describe what happens in the transitory between the circuit is close and the capacitor is charged.

**Q2.** In the circuit shown below, after the switch is closed, describe:

- a) What happens to the brightness of bulb
- b) What is the potential difference between plates of capacitor?

![Figure 1](image_url) A battery, bulb, capacitor and wires make up the circuit. The resistance of the wires is considered zero.

4. Results
In question Q1 around a third of the students indicate the correct option (d), although only half of them adequately explain their choice. This minority of students shows a lineal causal reasoning when connecting to the process of charge of the capacitors with the current circulation due to a potential difference in the different sections of the circuit. This reasoning associates the current to the potential difference in different parts of the circuit and, it is able to relate the current throughout all the circuit. Almost half of the students reason explaining that only the light bulb connected to the positive pole shines because from where the electric current begins to circulate (option b). This simple causal reasoning that attributes the effect of the brightness of the bulb to a single cause, the current begins to
circulate from the positive pole, does not take into account the role of the negative pole of the battery and does not explain what happens in that part of the circuit.

In question Q2, the 38% of students answered correctly that there is a transitory movement of charges through the switch until the potential between the plates of capacitor becomes the same as the potential difference of the battery. Another 12% of students explained that, after very a small period of time, the potential difference capacitor will be the same as that of the battery, but they did not reason about the current and the brightness of the bulb.

Table 1. Answers to question Q2 at University of the Basque Country. Categories of explanation for students’ answers.

| Type of reasoning                                                                 | UPV/EHU (N=200) |
|----------------------------------------------------------------------------------|-----------------|
| A.1.*Lineal causal (the transitory movement of charges is due to a potential difference, the final potential of capacitor is calculated and the bulb brights is mentioned) | 38%             |
| A.2.*Relational causal (the transitory movement of charges is not mentioned, but the final potential of points A and B is calculated) | 12%             |
| B. Dichotomic simple causal (Ohm’s law. They do not become charged. It is not a closed circuit) | 20%             |
| C. Answers based on incoherently justified or not justified statements            | 22%             |
| D. Not answered                                                                  | 8%              |

In category A.1 (about 40%) are grouped those responses that account for the movement of charges based on a potential difference between the ends of the conductor. This type of response can be interpreted as an explanation based on the Drude model. The vast majority of answers follow a linear causal reasoning [5] that has a chain of cause and effect: a) There is current because there is a potential difference between two points of the conductor, b) at the end of the process the potential in the two ends will be the same, as the current ceases. Standard examples of this category of response are:

“There will be current until the potential difference will be equal between the points and the poles of the battery. The final potential is equal in both points, but they have opposite signs.”

“There will be current until points’ potential became: \( V_+ = 12 \text{ V} \) and \( V_- = 0 \text{ V} \).”

Category A.2 emerged with 12% of answers (16%). In this category the students’ reasoning is related only with the relation between the variable charge and potential. To reason in this way they propose the equation of the capacitance: \( C = \frac{q}{V} \) without reference to transitory current that happens before arriving to equilibrium situation. One standard example of this category is:
“Both plates will have the same final potential, but with opposite signs. The plate positive will have 6 V and the plate negative will have -6 V. Applying the definition capacitance: \( C = \frac{q}{V} \), and then solving for the charge, we obtain the final charge of the capacitor.”

About 20% of the answers explain that the points do not become charged because the circuit is open (category B). Most of them mention Kirchhoff’s Law to justify the answer. The responses follow a simple causal reasoning [5] based in a dichotomy that relates one cause with one effect: a) the circuit is open (cause); b) there is no flow of charges (effect). It is clear that these students do not recognize the transient current in this context; they only imagine closed circuit in steady state current. One example of this kind of answer is the following: “The + and – sides of the battery are not connected, so the circuit is not complete. The sum of the potential differences in the circuit is zero.”

In category C we included answers without internal logic or that apply physics concepts in a wrong way. Some of the answers do not use a physics model to answer the question. Other answers use physics concepts but without meaning form the theoretical framework. Those type of answers show that in this category there is not an explicative model to interpret the phenomenon given in question Q2.

5. Conclusions
The results obtained show that a significant percentage of students cannot properly interpret simple transitory state current phenomena. Moreover, the percentages of correct answer are similar in both questions Q1 and Q2, which indicates the consistency of the types of responses. We found that there are two major explanatory tendencies of current in transitory states. One category explains the movement of charges qualitatively according to the potential difference. Explanations of students in this category are usually accompanied by a linear causal reasoning that associates electric current between two points with the potential difference between them. This explanatory model can be regarded as an application of the Drude model, which is explained in most textbooks.

The second explanatory category does not take into account the transient motion of charges in circuits. The explanation is associated with a simple causal reasoning which links the “open circuit” to the fact that there cannot be an electric current in steady states. This line of reasoning is related to a supposed dichotomy, that is, there are only two options: a) open circuit, no current; b) closed circuit, steady-state current. It seems that students in this category have only one explanatory model for a steady-state current.

According to our findings and the explanatory model of current in a wire, the key idea that will be necessary to emphasize would be the microscopic mechanism of production of potential difference between two points within the circuit wire, in both transitory current and steady situations. In particular, this involves the relationship between the concept of electric potential studied in Electrostatics (capacitors, charging bodies …) with those analysed in DC circuits. The results show that omitting an explanation of a microscopic mechanism of charge movement makes it harder for students to interpret transitory states in DC circuits.

6. References
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