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A teaching proposal on electrostatics based on the history of science through the reading of historical texts and argumentative discussions

Marina Castells(*), Aikaterini Konstantinidou and Josep M. Cerveró
GRIEC, Universitat de Barcelona - Barcelona, Spain

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Summary. — Researches on electrostatics' conceptions found that students have ideas and conceptions that disagree with the scientific models and that might explain students' learning difficulties. To favour the change of student's ideas and conceptions, a teaching sequence that relies on a historical study of electrostatics is proposed. It begins with an exploration of electrostatics phenomena that students would do with everyday materials. About these phenomena they must draw their own explanations that will be shared and discussed in the class. The teacher will collect and summarize the ideas and explanations which are nearer the history of science. A brief history of electrostatics is introduced then, and some texts from scientists are used in an activity role-play-debate type in which the "supporters of a single fluid" and "supporters of two fluids" have to present arguments for their model and/or against the other model to explain the phenomena observed in the exploration phase. In the following, students will read texts related to science applications, the main aim of this activity is to relate electrostatics phenomena with current electricity. The first text explains how Franklin understood the nature of the lightning and the lightning rod and the second is a chapter of a roman about one historical episode situated in the Barcelona of the XVIII Century. Students will use the historical models of one and of two fluids to explain these two phenomena, and will compare them with the scientific explanation of the "accepted" science of nowadays introduced by the teacher. With this type of teaching proposal, conceptual aspect of electrostatics will be learnt, but also the students will learn about the nature and history of science and culture, as well as about the practice of argumentation.

1. – Introduction

1·1. *History of science and science education.* – The History of Science (HS) has been fundamental for the development of Science Education to which it contributes in several aspects like:

(*) E-mail: marina.castells@ub.edu

- the theoretical bases of Science Education by its relationship with the New Philosophy of Science and the Sociology of Science (Bachelard 1938; Duschl 1990; Izquierdo and Arduiz 2003);
- the comprehension about the Nature of Science (NOS) (as it is built, legitimated, and communicated, actions that require argumentation and rhetoric in a central place) (Holton 1978; Gross 1990; Pera and Shea 1991);
- epistemologies of nowadays consider that the Science advances by solving problems and decision taking, activities carried on by humans (Laudan 1978; Giere 1992);
- the inspiration for new science teaching approaches of the curricula and for the design of specific Teaching Sequences (TS) with HS as a possible context, or a source for teaching approaches and learning activities in science classes (Mattews 1994a,b; Holton 1978, 1979; Heering *et al.* 2013, Mattews 2015);
- bringing a valuable information to help teachers in the comprehension of the science ideas and conceptions of students, and so, of the difficulties of some specific conceptual changes of students; as well information about common sense reasoning and arguments students may given (Bachelard 1938; Benseghir and Closset 1996; Viennot 1996; Seraglou *et al.* 1998; Castells and Konstantinidou 2008);
- specific approaches, ideas, and resources for the Teacher Training courses (Arons 1997; Furió and Guisasola 1998; Dawkins and Glatthorn 1998).

There is agreement among the experts about the NOS (McComas 1998; Millar and Osborne 1998) being part of the science scholar curricula, and this idea reinforces our hypothesis that a TS based on aspects of HS, and students' debates about historical or popularization texts related to specific topics of science may be a good proposal to teach science and about science, and also about history and culture.

1˙2. *Researches about students' conceptions in science*. – Researches about students' conceptions in science, that have been carried on for more than 30 years) (Driver *et al.* 1994; Pfund and Duit 1998; Duit 2009) confirms the difference between the science ideas and conceptions of students and the scientific knowledge agreed in the community of scientists. Quite often students' ideas are incompatible with physics views (Saltiel and Malgrange 1980; Duit *et al.* 2007). This also holds true for students "more general patterns of thinking and reasoning" (Arons 1983, 1984, 1997; Viennot 1996; Viennot 2014). Many researchers and experts on Science Education think that those differences may cause many of the difficulties students have in their learning about some topics. The need of conceptual change is accepted by experts but also there is agreement about how difficulty this change may be in some cases, as it had happened in the development of science (Bachelard 1938; McCloskey 1983).

Some experts agree that it is very difficult that students will discover the scientific knowledge to interpret the world on their own, and so, the school has to bring this scientific way to see the world to them (Guidoni 1985; Leach and Scott 2002; Ogborn *et al.* 1996) and the teaching has to be sensitive to the need to guide these changes and to engage students in the process of learning science. One way to help students in this process is to bring the scientific knowledge through the reading of fragments of historical texts about science or from popularization books about which debates may be carried on in the science classes (Lochhead and Dufresne 1989); but also by other ways, as through historical reconstructions; study of historical cases (Conant and Nash 1957; Holton 1978); historical narratives; or performing historical experiments, or activities based on historical controversies (Holton 1978; Heering 2013; Mattews 2015). The reading and work on biographies can be also very useful and engaging for the students and, so on. In fact, the use of HS is not new in SE although perhaps not enough research have been done about the students' learning based on HS.

1·3. *Students' misconceptions related to electrostatics.* – Researches on students' conceptions on electrostatics found that students have ideas and concepts very different from the ones of the scientific models to interpret these phenomena (Benseghir and Closet 1996; Furió *et al.* 2004). Among other, students consider electrostatics phenomena without any relation with the phenomena linked to current electricity and so, for them is very difficult to understand electric current based on the model of charges (Arons 1997; Seroglou *et al.* 1998; Criado and Garcia-Carmona 2009). Some researchers and teachers (Arons 1997; Harrington 1999; Knight 2004) found students familiar with the terminology used in electricity and magnetism but that the familiarity with the terms does not mean that they have a physics understanding associated to these terms. Researches on students' misconceptions consider that those in electricity and magnetism are at least as widespread and significant, perhaps more, than in mechanics.

We collect here some alternative ideas on Electrostatics, mainly from Knight (2004); that many researchers agree to attribute to students and which we summarize in the following:

- Students do not distinguish clearly the electric attractions from the magnetic ones. Some of them neither from the gravitatory ones. Some students say that the north magnetic pole repulses the positive electric charges. That means they may have a big confusion between attractions and repulsions that have to them a very different nature.

- Many students think that the insulated materials cannot be charged. Part of this difficulty is that students do not differentiate between *charge* and *motion of charge* (current). Because the current will not flow through an insulator (no *motion* of charge) students erroneously conclude that the insulator cannot be charged and they do not distinguish between an object (insulator/conductor) and its state of charge (charged or neutral).

- Some students think about the charge as an object more than a property of the matter. Or some may think a charge is a substance that can be painted on a matter.

- Relating everyday phenomena some students think that the lightning rod are useful to collect the lightings and because of this, they do not enter the houses.

- Some students think that "neutral" is a third type of charge.

- Students, in general, do not recognize the charge conservation.

- They think there is a fundamental reason which make the electrons negative.

- Some students think that an object positively charged has received an excess of protons and that the protons can move as the electrons do inside many materials.

- Students do not have a good comprehension of the structure and of the atomical properties of the solid materials. They do not know what does neutral, non-neutral or charged mean at an atomic level.

1˙4. *Our research about students' conceptions on electrostatics.* – Some pre-service primary education teachers at the University of Barcelona have answered some questions about electricity phenomena, some of these about electrostatics. These students did not have any specific scientific or technologic background. The results of the analysis of their answers mainly agree with the findings of other researches edited in journals. We will not comment here about theses answers' students because the extension of this paper and that coincidence with other findings.

2. – The teaching sequence

2˙1. *The framework.* – Our perspective is near to the *Didaktik* tradition in Germany, to the "Didactique Transposition" in French (Chevallard 1990) and Didactic Approach in some southern European countries, as Italy (Arca *et al.* 1990). I think the meaning we give in Catalonia to the word *Didàctica* is not very far from these German and French traditions. The meaning of *Didaktik* concerns the analytical process of transposition (of transformation) of human knowledge like domain-specific knowledge into knowledge for schooling. In this process, the *content structure* of a certain domain (*e.g.*, Physics) has to be transformed into a *content structure for instruction.* The two structures are substantially different. In fig. 1 adapted from Duit *et al.* 2007, of the process of *construction of the content structure and key ideas for instruction.*

In this TS we will use some historical texts or popularization texts because they can be instructive and illuminating of the actual historical ups and downs and controversies in the development of Electricity.

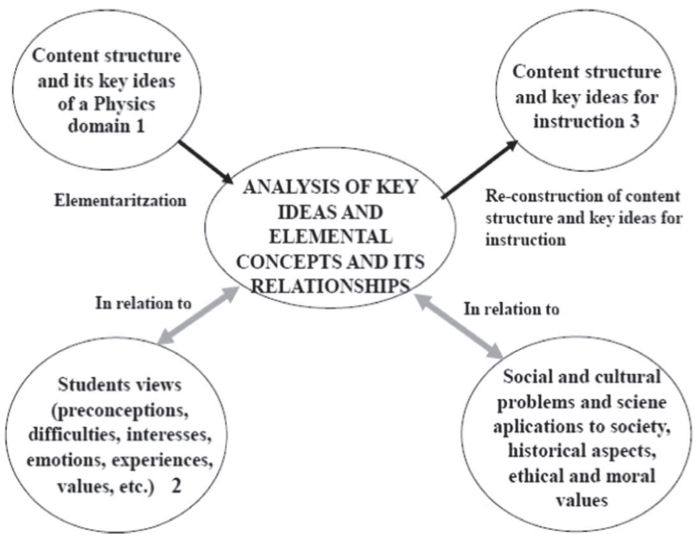

Fig. 1. – Didactical Reconstruction (adapted from Duit *et al.* 2007).

Many textbooks, after forming the concept of "charge" and examining electrostatics phenomena in the context of frictional electricity, make a discontinuous jump to current electricity by simple asserting that electric circuits containing batteries involve "charge in motion" and begin to talk of electric current. To most students, however, it is far from obvious that the current and the "charge" that has been "caused" by friction are of the same nature. And this is a big problem in the Electricity comprehension (Arons 1997). This is not a trivial matter, and had been a serious debate about it in the scientific community late on the 1830s (Castells 2000). Faraday gave many attention on this problem. In the *Electrical Researches* (Faraday 1965), there is a paper, dated on 1833 and titled "Identity of Electricities Derived from Different Sources," in which Faraday describes several experiments related to "different electricities". These "electricities" were referred by him as voltaic, common (frictional), magneto (from electromagnetic induction), thermo (from thermocouple), and animal electricity from some fishes. Through their experiments Faraday demonstrated that each of these types produces identical effects, and arrive to the following conclusion that electricity, whatever may be its source, is identical in its nature (Faraday 1830s).

2˙2. *The aims of the teaching sequence*. – Our proposal focuses on the teaching-learning the topic of electrostatics for a secondary school, which is mainly inspired by or is fitting with the history of this part of the Electricity, but also taking account of the results of researches made on students' science conceptions related to this topics other experts have done (Seroglou *et al.* 1998). Our *aim* is not giving to students a detailed history of the Electrostatics, but some aspects of the historical development of this topic with the support of some texts (historical or of popularization ones) about which the students may argue. The main idea that we want students to understand is that there are opposite theories or conceptualizations and interpretations of the same facts in a period of time. In our proposal we try also to relate the history of electrostatics with the students' interpretations of some qualititative experiments carried on by them in the classes or at home.

In this way, our approach fits with a teaching sequence that incorporates some of the nowadays agreements in science education, among other which consider in science classes we should try to answer questions as: What the scientists know? Which ideas, concepts, and models we select to learn in our science classes? Why? Which are the most relevant facts which interpretation has lead to the specific ideas or models? Or, how the scientists arrived to a specific explanatory model? Why we accept or belief these (.....)? How does an idea, concept, . . . , is related to other ones? The TS agrees with the nowadays Science Education recommendation of contextualization of the scientific knowledge for the instruction (Gilbert *et al.* 2010). We participate of the Socioconstructivism (Vygotsky 1978) perspective, and we are also interested to help the development of the Critical Thinking of our students in the meaning of Arons (1997) and considering also aspects of values. (See fig. 2.)

2˙3. *The sketch of the teaching sequence about electrostatics*. – From the results of our research about students' conceptions on electrostatics, from our study of the historical development of electricity (Castells 2000), from the reading of proposals that Science Education and HC experts have done (among others, Arons 1997; Furió *et al.* 2004; Heering 2000; Seroglou *et al.* 1998) and the agreements nowadays exists between experts in science teaching we will sketch a proposal of a Electrostatics' TS and contextualized on the HS of this part of the electricity and also on a periode of history in a specific place and cultural context.

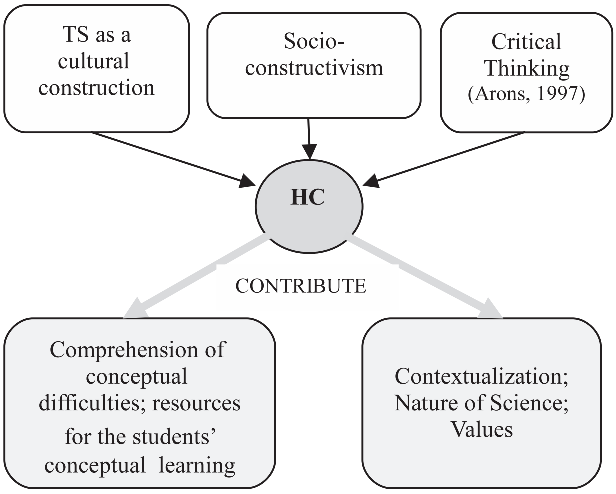

Fig. 2. – Teaching sequence.

1. Exploration of electrostatic phenomena in peer-groups.
2. Brief history of electrostatics is introduced, and some *readings from or related to the HC are proposed* to students.
3. Debates and arguments in the class using ancient models (of one or two fluids) to interpret the electrostatics phenomena.
4. New phenomena and instruments are introduced to be explored and interpreted with the same models.
5. Reading texts about applications of electrostatics and related to HS (the discovery of the Lightning rod by Franklin) and HS related to our country, in particular to Barcelona and an ancient Academy from 1764.
6. Introduction of the accepted explanatory model of electrostatics by the teacher and by students.
7. Students in peer-group compare one of the historical models with the nowadays model and argue in favour or against each one.
8. A more modern application using the Van der Graaf generator to produce electrostatics effects is experimented.

2.4. *Detail of the main relevant parts of the proposed TS.*

1. `Exploration of electrostatics' phenomena`

a) Exploration of electrostatic phenomena of attraction and repulsion with everyday materials in peer-group is performed:

> *Attraction and repulsion of bodies of small weight* (water, pendulum, small pieces of paper, of ....) by electrified objects *by friction* (pen, globes, bar of glass ...) with several different materials (silk, cotton, hear, wool...)
>
> ASKING THE STUDENTS
>
> What happens?

Why do you think that it happens?

How can you explain this?

With which other phenomena do you relate these facts?

If students have not been aware of the repulsion with the same objects once they are put in contact with the small bodies, the teacher has to ask the students to pay attention to this phenomenon of repulsion.

b) Exploration about conductors and insulators

Exploration with conductors (metal bars, ...) and *with insulator materials* (plastic bar, ...) to see if there are differences.

ASKING THE STUDENTS

What happens?

Why do you think that it happens?

How can you explain this?

With which other phenomena do you relate these facts?

c) Explicitation and argumentation about the interpretative models

Every group presents their interpretations of the phenomena and a whole group class discussion about the different interpretations is then performed. The teacher guides the whole class debate and she/he will try to find some interpretations similar to the historical interpretative models of the XVIII century, in fact, the *theory of one fluid* (Franklin; Aepinus and others) or the one *of two fluids* (Symmer; Coulomb and others).

2. Brief history of electrostatics and some readings from or related to the HS

The teachers elaborate the summary of the history of electrostatics using relevant bibliography (books and papers they can found at the University of Barcelona or in other libraries, as in the library of the "Real Acadèmia de Ciències i Arts" in Barcelona). Some references are included in this paper (Whittaker 1951; Priestley 1966; Taton 1973; Heilborn 1979; 2002; Holton 1979; Rosmerduc 1987). Then, students have to read two texts about two ancient interpretative models:

Text 1: One fragment of *Experiments and observation on electricity made at Philadelphia in America, by M. Benjamin Franklin, L.L.D. and F.R.S*([1]), in which Franklin defends the theory of one fluid to interpret the electrostatic phenomena (see fig. 3).

Text 2: A fragment of the Chapter 2 of the book from Einstein A. and Infeld L. (1939) *The Evolution of the Physics*, in which the theory of the two fluids is summarized by Einstein and Infeld([2]).

([1]) M. Benjamin Franklin, L.L.D. and F.R.S, *Experiments and observation on electricity made at Philadelphia in America* (D. Henry and F. Newbery, London) 1749.

([2]) We do not copy here this text 2 because there is not enough space in this paper and because the book is very easy to download from the Internet.

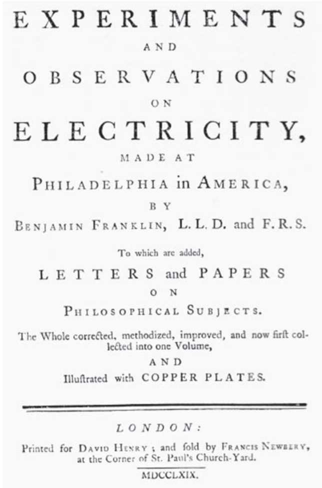
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Fig. 3. – The cover of the book of Franklin 1749.

To elaborate the Text 1 we have used a French translation from 1749. In concrete, our copy is from a book which belonged to Francesc Salvà Campillo, a Catalan scientist in the XVIII century (about which we will comment below) that we have translated to Catalan language for our students in Barcelona. As the title says in this volume, there are also some letters and papers on other philosophical issues. We choose the LETTERS ON ELECTRICITY from M. Benjamin Franklin of Philadelphia (America) to Peter Collinson, from the Royal Society of London.

The Letter I is from 1749, and it is the one we have used in our Teaching Unit.

OPINIONS AND CONJECTURES

Concerning the Properties and Effects of the Electrical Matter, and the Means of preserving Buildings, Ships, 8fc. from Lightning, arising from Experiments and Observations made at Philadelphia, 1749. — Golden-Fish — Extraction of Effluvial Virtues by Electricity impracticable.

1. The electrical matter consists of particles extremely subtile, since it can permeate common matter, even the densest metals, with such ease and freedom as not to receive any perceptible resistance.
2. If any one should doubt whether the electrical matter passes through the substance of bodies, or only over and along their surfaces, a shock from an electrified large glass jar, taken through his own body, will probably convince him.
3. Electrical matter differs from common matter in this, that the parts of the latter mutually attract, those of the former mutually repel each other. Hence the appearing divergence in a stream of electrified effluvia.
4. But, though the particles of electrical matter do repel each other, they are strongly attracted by all other matter([3])*: this has to be understood from which are susceptible of this.

([3]) In the original text, the asterisk (*) links to a note that says: See the ingenious *Essays on Electricity*, in the Transactions Phil, by Mr. Elliot.

5. From these three things, the extreme subtility of the electrical matter, the mutual repulsion of its parts and the strong attraction between them and other matter, arises this effect, that, when a quantity of electrical matter is applied to a mass of common matter, of any bigness or length, within our observation (which hat not already got its quantity), it is immediately and equally diffused through the whole.

6. Thus, common matter is a kind of sponge to the electrical fluid. And as a sponge would receive no water, if the parts of water were not smaller than the pores of the sponge; and even then but slowly, if there were not a mutual attraction between those parts and the parts of the sponge; and would still imbibe it faster, if the mutual attraction among the parts of the water did not impede, some force being required to separate them; and fastest, if, instead of attraction, there were a mutual repulsion among those parts, which would act in conjunction with the attraction of the sponge; so is the case between the electrical and common matter.

7. But in common matter there is (generally) as much of the electrical, as it will contain within its substance. If more is added, it lies without upon the surface, and forms what we call an electrical atmosphere; and then the body is said to be electrified.

. . . .

18. These explanations of the power and operation of points, when they first occurred to me, and while they first floated in my mind, appeared perfectly satisfactory; but now I have written them, and considered them more closely, I must own I have some doubts about them; yet, as I have at present nothing better to offer in their stead, I do not cross them out; for, even a bad solution read, and its faults discovered, has often given rise to a good one, in the mind of an ingenious reader.

19. Nor is it of much importance to us to know the manner in which nature executes her laws; it is enough if we know the laws themselves. It is of real use to know that China left in the air unsupported will fall and break; but *how* it comes to fall, and *why* it breaks, are matters of speculation. It is a pleasure indeed to know them, but we can preserve our China without it.

3. Debates and arguments in the class

Students are divided into two groups: "supporters of a single electric fluid" and "supporters of two electric fluids" and a *roll play activity* is performed. Both groups have to give arguments to defend their model and to refute the other group's model. It is important not only to take a position but also to give arguments that other students may refute.

4. New experiments and instruments in electrostatics

a) Using the electrofor and the electroscope.

Basically the process is the same as have been done with the other explorations and interpretations. The activity focuses on the *storage up of electricity* with the *electrofor* and on the detection of the electricity with the *electroscope*. The instruments will be also useful to differentiate between the concepts of *electrization by contact* and *electrization by influence* (see fig. 4).

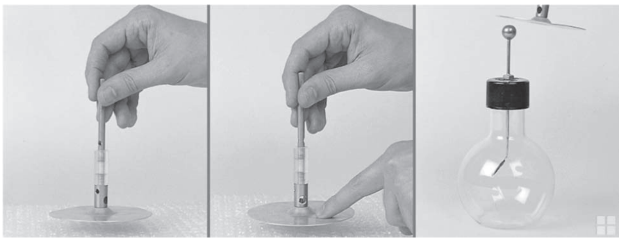

Fig. 4. – Electroscope and Electrofor.

b) Exploration and interpretation with the Leyden jar

It is convenient to build a *Leyden jar* in the class or at home and it may be used as another instrument that can store up "electric fluid" or electrical charge in the modern language and that had been a very important instrument in the historical development of electrostatics. Students could read some fragments of any ancient book about the Leyden jar or, particularly, in the book of Franklin in which there is a summary of de history of Electricity in which the Leyden jar is deeply commented. The instrument may be presented at the first level as an instrument that can store up "electric fluid", if the concept of *condenser* is not introduced yet to students. The experiments performed will be described and interpreted by students using both models of one or of two fluids following the same methodology of the other explorations and interpretations but now interchanging their models.

c) Exploration of conduction of electricity to big distances.

Exploration and interpretation of phenomena of *electricity conduction* through conductors is carried on. The electrofor may be used as storage of electricy, and better if the Leyden jar is used because its great historical relevance.

5. Reading texts about applications of Electrostatics and exploring ideas about phenomena

a) Exploration of students' conceptions about the Lightning and the Lightning rod.

This part of the TS could have be done in several ways. One could be coming from the reading of a book of popularization about Franklin and some of his experiments and ideas. At the end of the activity the teacher asks some questions to the students which they answer in peers and then they debate with the whole group-class. The book is *Vida de Benjamin Franklin*([4]). The proposed fragments to discuss in class are a) the fragment which is a description of the experiments that Franklin had performed to understand the electric nature of the lightning and b) the fragment explaining how to construct an instrument to protect the buildings from the lightning.

We suggest students may extend their readings at home about the *life and experiments of Franklin* with other parts of this book. The book is part of a collection named LIFE OF GREAT MEN edited in Barcelona many years ago. The book does not present only Franklin as a scientist, but also the man with his values and social actions he did,

([4]) Jorge Santelmo (1934) *Vida de Benjamin Franklin* (Seix Barral, Barcelona). Due to lack of space this text is not included here.

Fig. 5. – Cover of the book by S. Riera Tuèbols *The town of the change.*

and his life as politician too, acting very strongly in favour of the independence of his country from the UK. We think this book should be a recommendable reading for our students nowadays.

b) Exploring another application of Electrostatic in a specific cultural context and period of time. The electric telegraph (XVIII century).

The class methodology is individual reading, peer-group discussion and whole group discussion and synthesis.

The reading is a text about a new application of Electrostatics: the case of *the electric telegraph* by Salvà Campillo, from a novel from Riera (2005)(5) based on historical facts in Barcelona at the XVIII Century (see fig. 5). This roman can be an interesting resource to teach about science, nature of science, as well as about history and culture of a key episode in the development of science in a specific social and political context, the Catalan one, not many years after the Succession War (1714). The chapter 4 of this book is related to Electrostatics, in which it is presented the historical case of Salvà Campillo performing an exhibition in front of the King of Spain (Charles IV) and his family with the telegraph he had invented. In this telegraph several Leyden Jars with the electric fluid stored were connected to conductors and then the messages could be sending through theses conductors from one place to another (Iglésias, 1964, 1965).

The European context in which many Science Academies and other Scientific Societies were created could be a larger context of the TS. In fact, the plot of the novel is related to some academics of the "Real Academia de Ciencias y Artes" (1764). The two main characters are: Francesc Salvà Campillo (1751–1828) (who worked on topics of Physics

(5) Santiago Riera Tuèbols (2005) *La ciutat del canvi* (The town of the change) (chapter 5, pp. 53–67).

Fig. 6. – Spark from a Van der Graff.

and Medicine) (1751–1828) and Antoni Martí Franquès (1750–1832) (who worked on topics of Chemistry and Botanics).

There may be several other didactical strategies teachers can use to work in the classes with this text, as role-play, interviews, etc.

6. `Introduction of the scientific nowadays accepted explanatory model by the teacher and/or by students looking for information about electrostatics in books or Internet`

7. `Comparison between the historical models of the nowadays model about electrostatics`

Students in peer-group compare one of the historical models with the nowadays model. They look for the advantageous and the inconvenient of the models through argumentation. Perhaps they may do new observations and interpretations. Every peer-group writes a *summary* of these. These *summaries will be shared in the whole class* guided by the teacher trough debates or agreements among all the groups.

8. `A more modern application`

Conduction of electricity through conductors (exploration, interpretation, experimentation) and sparks production with the *Van der Graff* is performed in the laboratory.

These observations can help students to understand the lightning and to change their conception about the nature of electrostatics and of electricity of current, which is the same. With the Van der Graff it is possible to produce sparks very far from the generator, and so students can relate the electricity by friction and the electricity of current (see fig. 6).

3. – Final comment

To conclude we can say that with this type of teaching proposal, students will learn conceptual aspects of electrostatics as well about experiments' interpretation, but also they will learn about the nature and history of science and culture, as well as about argumentation.

* * *

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