Sci & Educ (2012) 21:921–934
DOI 10.1007/s11191-010-9312-5

The Role of Historical-Philosophical Controversies in Teaching Sciences: The Debate Between Biot and Ampère

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Published online: 21 October 2010

Abstract This paper evaluates the viability of using controversies in teaching. An educational project has been elaborated in which some historical-philosophical clashes were introduced into the classical syllabus of physics. The historical-philosophical controversy dealt with here, took place between the French physicists Biot and Ampère in the 19th century and referred to distinct interpretations of the Oersted experiment. This controversy was inserted into the syllabus of the 12th grade of a Brazilian secondary school.

1 Introduction

The history of science is full of examples in which two or more scientists build totally distinct theories about the same experiment. The analysis of these historical controversies, motivated by philosophical questions, is fundamental to the understanding of the development of science and to scientific education (Niaz 2009, pp. 60–62).

However, if we investigate textbooks and syllabuses, we come to the conclusion that there have been practically no controversies in them. In the 19th century, Comte (1978) used to say that the best way to introduce a youth to the fundamentals of science is by making him/her think such knowledge had been elaborated by a single mind. Controversies could trigger doubt in the learning process and that was rejected by the philosopher. Several textbooks have followed this maxim since the 19th century (Braga et al. 2008, pp. 510–517).

Comte's defense has its merits when one expects to teach only concepts which are immediately applicable. However, this option hides in itself some fundamental elements of

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the process of building scientific knowledge. This option should be rejected if the aim is a broader education where concepts are introduced together with science being a human construction. Controversies tend to demolish beliefs that were built on top of discovered knowledge in the benefit of constructed knowledge. Discoveries are unquestionable truths. Constructions are temporal truths and can be changed throughout time.

Aiming at evaluating the viability of utilizing controversies in teaching and demolish the idea that science is built by discoveries, an educational project to teach electromagnetism, has been elaborated. Some historical-philosophical clashes were introduced into the classical syllabus of physics.

In 1820, physicist Hans Christian Oersted (1771–1858) carried out his famous compass needle experiment. Most physics textbooks published in Brazil present this experiment as a matter of chance. Oersted was supposedly teaching when he observed the deflection of a needle in the presence of an electric current. This approach gives the students an inductive view of the building of scientific knowledge. It also hides the fact that Oersted and other scientists were looking for experiments that would prove that an electric phenomenon could produce a magnetic effect (Martins 1986, pp. 91–97; Hottecke 2000, p. 347). Therefore, even before beginning the process of introducing controversy in the syllabus, it was known that there was a belief in the fortuity of the phenomenon.

These considerations led us to develop the pedagogical project which aimed to answer the following question: is the study of controversies a good way to deconstruct the inductive view of the knowledge building process and discuss with the students the role of experimentation in the construction of science?

The course structure hasn't been significantly modified. Some clashes were simply introduced at some specific moments of the course. The historical-philosophical controversy dealt with here, took place between the French physicists Biot and Ampère in the 19th century and referred to distinct interpretations of the Oersted experiment. This controversy was inserted into the syllabus of 12th grade of a Brazilian secondary school.

In order to have a concrete discussion about this controversy, after the first educational experience in 2003 (Guerra et al. 2004a), a 60-page book was written. This little book is considered to be what we call, in Brazil, didactic support, which means, texts to complement the didactic books. This book was written in colloquial language and presents science in a broader scope, showing the different relations of other cultures with the construction of the scientific knowledge. Some extra "boxes", were sometimes inserted in the main text of each book. When reading these "boxes", the student will reflect upon the studied theme relating it with movies, plays, songs, paintings, etc. It is an effort to show that some of the discontentment of the men of the past is the same as of modern man. This is used in order to make the learning process more dynamic and to update some of these discussions (Guerra et al. 2004a, b).

2 Methodology

The project was carried out in a 12th grade class of 25 students, 12 girls and 13 boys, aged 16 and 17. The project was carried out in a public high school in Rio de Janeiro, Brazil, which only receives students from other public schools for "diploma courses" (technical teaching). All students leave school prepared to work in the health field. It is a full time school in which students are taught subjects of the standard syllabus in the morning and specific technical subjects in the afternoon, when they also have laboratory classes. Most students belong to the lower middle class and live in several different districts of Rio de Janeiro.

There were 150-minute classes a week during 3 months and the class teacher became a researcher. The project group (researchers and the class teacher together) met every week. The first meeting happened 4 months before the actual beginning of the project.

The first meetings were about the historical-philosophical debate on the development of electromagnetism with the objective of familiarizing the class teacher with the theme. In the first months, texts and classroom activities were prepared and thoroughly discussed with the teacher, thus preparing him comfortable to carry out the project in his classroom.

In order to evaluate the project, one of the researchers watched the work of the teacher during 3 months. The researcher joined the classes 2 weeks before the beginning of the project itself. There were two objectives in this previous contact: the first, to get to know the reality in which the project would be carried out; the second, to ease the possible feeling of discomfort on part of the students in relation to the presence of someone new in the group. Data was collected through films, photos and notes made during the lessons. As the researcher was together with the group, it was possible to register the students' participation in and out of the classroom.

The researchers recorded only the activities in which students answered questions or developed some experimental activity. Those films were chosen because the students discussed in small groups and asked for the teacher's help. Before beginning the project, the researcher explained to the students that some activities would be filmed and what the purpose of the filming was, to make sure they wouldn't be distracted with the presence of the camera.

The films were analyzed by the research group and the teacher together. The notes made by the teacher and the researcher were discussed before the group watched the film. So they watch the film in order to observe the students that have not been mentioned in the teachers' notes. Their facial expression, as well as what they say is observed.

The teacher kept a diary where he registered his impressions of the class after each meeting. The teacher's records and the researcher's records on class observations were discussed with the project group weekly. This way of interacting resulted in a pedagogical proposal with an initial plan, but which was constantly reoriented.

Questionnaires or interviewees were not chosen to evaluate the viability of the proposal. Student's activities were developed during the course as part of the evaluation process. These activities will be described in the next section about the pedagogical purpose.

3 The Pedagogical Proposal

The class in which the project was developed had not studied electricity, magnetism or electromagnetism before. It was decided that the students would answer a questionnaire (individually and in writing) during the lesson before the beginning of the project. The questionnaire aimed to check if they recognized what an electric phenomenon was, if it was electric, magnetic or electromagnetic, and if they knew the basic principle of how a battery, an electric motor and an electrical generator work. Three of the questions were supposed to identify conceptions about the construction of science. Based on the analysis of the answers:

- 8 students didn't know what an electric phenomenon or electromagnetism was—they just associated the attraction and repulsion of magnets to magnetic phenomena.
- none of them knew the principles of how motors and electrical generators work.

– 7 students said that the construction of devices like batteries and electrical motors were the result of concrete material needs for the benefit of humankind. The other 18 students believed that technical and scientific knowledge was the result of observation of natural phenomena, thus observation being the way to construct science.

Student A—"Electricity and magnetism have always existed but recently man has observed them more thoroughly in order to use them in his everyday life."

Student B—"Someone curious enough must have asked how a certain magnet attracts the other and repels one of similar polarity. He must have studied the reasons why and how that certain property applies."

Student C—"As man became aware of factors around himself like electricity and magnetism, he improved his knowledge in order to make his life easier. But I don't know how he got to know those things. I just know that electricity rules our lives today."

Student D—"Man might have invented the battery based on observations of natural effects and experiments based on observations."

In the first lesson, questions were asked again and what the students said was brought for discussion. The records of the researcher showed that the students did not take the activity very seriously. They answered the questions quickly, showing that they didn't want to spend too much time on that. During the debate, they even said they didn't know why that kind of discussion was taking place. In spite of the students' points, based on the confrontation of the films and their written answers, it was possible to observe that they thought that scientific and technical production happened either because of unpretentious, casual observations or by mere technical need. To those students, scientific knowledge was built without any controversy. If scientists were always aware of nature, observing phenomena in a concrete way and carrying out adequate experiments, they would produce science.

This activity reinforced our initial consideration—the belief of inductivism as a means of constructing science—and oriented the future debates with the students about the role of experimentation in the process of constructing science.

The pedagogical proposal began by studying the concepts of electric charge and its conservation, of electric and magnetic force, difference of potential and electric current.

Although the focus of the proposal was the study of the Ampère-Biot controversy, it was thought that this preliminary study should be used to build the basis for the historical discussion that would result from the study of the controversy (Binnie 2001, pp. 379–385). So it was decided that the themes would be worked on from a historic-philosophical approach. The results of the preliminary activity led us to reinforce the role of experimentation in the construction of science in this initial approach.

The first activity was the construction of an apparatus similar to Gilbert's versorium (Hottecke 2000, pp. 344–346). The students were divided into groups and followed the guidelines written by the project group.

The researcher was together with the students while they carried out the experiment and answered the questions in the guidelines. The researcher noted that the students were involved in the construction of the model to relate data taken from the experiment. The experiment was not discussed by all members in two groups only. But the students' lack of attention was more evident during the class discussion. It was then decided that more guided experimental activities would be used and during the class discussions, quieter students would be explicitly asked questions.

After this activity, the development of electricity throughout the XVIII century was discussed. Some students volunteered to present the cultural, social and economic panorama of Western Europe before the French Revolution. This generated a historical discussion about the development of electricity in the XVIII century, which lasted longer than expected in the initial planning of the activity. Students got more involved when they put together what they had learned in the history classes with what the class teacher said about scientific development in the XVIII century. During the discussion, the teacher emphasized Newton's legacy as well as the search to expand the domain of mechanics into other areas of knowledge.

The teacher's observations during the activity were positive. He mentioned the history teacher's comment that some students had come to him to talk about the physics classes, which showed how deeply involved the students were. However, one student asked why the history class was being used to discuss physics. The teacher's arguments did not convince the student.

The films confirmed the teacher's impression: even those students who spoke less during the discussions were paying attention to their classmates' words as well as their teacher's. However, four students refused to take part in the lessons, slept during the teacher's presentations and refused to answer his questions.

To continue the study of the development of electricity in the XVIII century, students were asked to build a Leyden jar. First students read a historical text written by the project group. The text was about Gilbert's work, the social and cultural context in which modern science was born, the question of the universe-machine, mechanicism, the functioning of electrostatic machines and the two-fluid theory. The text aimed to systematize the classroom discussions but did not contain any comments on the development of the Leyden jar.

The procedures for carrying out this second activity were the same followed in the development of the versorium. Besides exploiting the functioning of the apparatus itself, students were asked questions about the process of constructing science.

This is the first activity used to construct the evaluation of the pedagogical purpose consisted of questions aiming at problematizing the students' ideas posed in the preliminary activity. We wanted to observe if the students had some change in their view after the first historical-philosophical studies. In order to reach this objective, the questions led the students to think about the reasons why two scientists in totally distinct places had tried to build an artefact to store "electric fluid". Students' answers showed that, in a way, they were deconstructing the impressions about science that had been reported in the preliminary research.

Group 1—"The person who built this jar was trying to store electricity because they already knew the theory of fluids and they also knew the electroscope, so they already knew about some possible results".

Group 2—"Because during that time, scientists were very much interested in knowing why sparks came out, in knowing what electricity was capable of, as well as its uses".

Group 3—"The experiment was not something that happened by chance. There was a moment of mechanicist euphoria in the XVIII century and scientists were dedicating time to unfolding the mysteries of electricity. The device was very sophisticated for that time".

The researcher's film showed that the groups discussed the questions collectively. The analysis of the film also showed that, during the discussion, some students manifested opposing opinions to those expressed in writing by their group. In these situations, sometimes students persuaded and convinced each other. But some other times, the one who had an opposing idea did not want to discuss the question, like one student in group 5—he accepted the contrary opinion just to finish the task quickly.

In the following meeting, the students presented their answers orally. The class teacher used the debate to present the context in which the Leyden jar had been developed, exploiting the fact that the theory of the electric fluids had made the initial project of the construction of the Leyden jar innocuous. But at the same time, this theory confirmed that there was a possibility of storing fluids, which helped the scientists involved in the project not to give up and search for help to find out what had made the artifact fail.

Another text given to the students presented the historical process of the construction of the Leyden jar and showed that its success stimulated research on electrical phenomena. Then it presented Franklin's work and Coulomb's quest elaborate mathematical relations that could systematize the results of the studies on electricity, presupposing gravitational attraction. The discussion about mechanics started again and the class teacher presented and systematized Coulomb's law. Using images, the teacher presented the Galvani and Volta debate and proposed the presentation of Kenneth Bragath's adaptation of Mary Shelley's *Frankenstein* (1994) to show how a work of art can be used to deepen the contextual approach.

The film was shown in parts. The class teacher, together with the project group, selected five moments when the film was interrupted in order to carry out a historical discussion. The students were really restless during the first part of the film and were surprised when the teacher stopped it for the first time. The teacher then explained that the main aim of that showing the film was to help them understand the historical context. He also explained who Mary Shelley was and talked about the time she lived in and the context in which she wrote the story. The students asked lots of questions about which experiments Mary Shelley knew and how she came about the possibility of constructing life. The discussion helped to call the student's attention to the film and highlight the fact that science is part of culture, makes scientific topics enchanting and frightening to people who do not work with science. When the film was resumed all students were involved, including the four girls who had refused to join in the activities before.

After the film, the students, under the teacher's orientation, read the foreword to Mary Shelley's Frankenstein. These two activities were followed by a debate with the physics, history and literature teachers of the class. The debate explored the contextual approach, emphasizing the cultural context of Europe at the end of the 18th century and beginning of the 19th century, the fundamentals of "Naturphilosophie" and its criticism of the mechanistic view of nature. The debate and the reproduction of Oersted's experiment were the second activity used to evaluate the pedagogical proposals. The attention of the researcher was directed to the ideas manifested by the students about the role of Galvani's experiments in the debate about animal electricity.

The film caught the students' attention and motivated them to participate in the debate. In the following lesson, they reproduced Oersted's experiment, using a modern battery and compass (Leon 1983, p. 28). A written text was given to the students. Not only did the text explain the experiment, but it also included the historical context in which it occurred. The highlight was the randomness of the magnetic needle experiment. The text also described Oersted's trajectory calling attention to the fact that during his visit to Germany, Holland and France, he became friends with exponents of "Naturphilosophie" like Schelling and Ritter. It was also mentioned that Oersted developed his scientific activities based on the idea that nature was a harmonic organic whole with an active soul that generated natural forces.

Oersted and some of his contemporary like Ritter, argued that there was a relationship between electricity and magnetism. For them there was a unity in the disconnected phenomena of the Universe. In this way there was not distinguish between matter and force, matter was been a result of the balance of the two opposite forces that compound the Universe. The action a distance observed in some phenomena was the result of propagation of disturbance or balance of these two forces. So they denied the idea of the fluids acting a distance (Darrigol 2003, p. 2).

Due to his theoretical conceptions about the forces of nature, Oersted was considered an important character in the development of those studies. He was always informed about experiments and theoretical analyses and that made him search for the relationship between electricity and magnetism through the electric current, not through electrostatic action. Another highlighted point was the fact that this choice was not unpretentious. Experiments had shown that heating and light emission were caused by the passing of electric current through a thin conductor not by any electrostatic action. Together with the fact that the galvanic current transported electric non-material fluids in opposite ways in the same wire, positive and negative, made him construct a particular thesis in which the magnetic effect would irradiate from the wire in the same way he thought it happened with light and heat (Caneva 1997, pp. 48–53).

The text also mentioned some of Oersted's works prior to 1820 and that these texts circulated in France. For example, in 1806, Oersted published an article about the electric nature of chemical force in the "Journal de Physique". In 1813, an edition of the 1812 work on the identity of the chemical and electric forces was found in France ("Ansichten der chemischen Maturgesetze") In this work, Oersted tried to establish a theory of general chemistry in accordance with the philosophical principle that says that all natural phenomena were produced by the same original power (Caneva 1980, pp. 128–129).

At this point in the course, the students did not question the teacher about the reasons why the classes were different. Perhaps they were silenced by the fact that in their formal evaluations (tests) there were questions about the history of science that had been discussed during the lessons.

The discussions held so far, as well as the results of the analysis of the texts written by the students, showed that this first historical approach problematized their initial position that a simple and unassuming observation may bring scientific knowledge. This question was very much exploited during the analysis of the Oersted experiment. The reproduction of the experiment showed them that the deflection of the needle was not something simple to observe. Apart from that, the activity allowed for discussion on the experiment having made evident something unprecedented in scientific development: a force manifesting an action perpendicular to it. Considering this, the study of the controversy was carried out in order to deepen the questioning of induction in science, highlighting that philosophical questions also guide the work of scientists and are fundamental to the development of science. But one cannot conclude that theories always determine the results of experiments or those experiments determine theories (Galison 1987, pp. 6–13).

4 The Study of the Controversy Biot × Ampère

This second stage began with a debate on the repercussion of Oersted's experiment. In 1820, a French scientist, Arago (1786–1853) gave a lecture about the experiment. Two French physicists, Jean Baptiste Biot (1774–1852) and André-Marie Ampère (1775–1836) were in the audience. They had different views of nature and of the world (Caneva 1980, pp. 124–128).

Biot, was a member of the Arcueil Society which followed a very clear line based on the Laplacian programme. Together with a group of natural philosophers, Laplace developed a project that aimed to give to all sciences the same prestige as that of Newtonian mechanics. In this programme that sought to account for all phenomena, in the molecular and celestial scales, in terms of central forces between particles. These central forces that were conceived as being exerted by imponderable fluids as well as ordinary ponderable matter varied with the inverse of the distance (Gillispie 1997, pp. 209–215).

The unity was presented in the theories constructed by Laplace's group, but this unity was in a different way that defended by Oersted. For Laplace, the physics could gain the perfection like the gravitational theorie gained. In 1783, Laplace declared his conviction that the refraction, the capilarity, the coesion, the cristalines proprieties and the chemistry reactions could be explained using forces identical to the gravitation ones. The doutrine of reduction to distance forces was the definition of laplacian's physics (Heilbron 1993, pp. 141–146).

Biot is a laplacian, he utilized the theorie of the forces to explain the double refraction and the chemistry affinity. But he declared in a didactical text about the laplacian physics, that the ideas of the imponderables were only good hipotheses, and it was necessary that the physics didn't put any idea of reality in those hiphoteses (Heilbron 1993, pp. 141–146).

Supported by his view of science, Biot rejected the idea of unity in nature as Oersted defended. He argued that the link between the phenomena was the fact that better explanations could be built starting from attraction and repulsion forces between distinct particles or fluid materials. Biot was one of the scientists who immediately accepted the results of Coulomb's experiment, becoming a follower in the use of the torsion balance. Based on this view of the world, he developed a very peculiar theory to explain why a compass was deflected in the presence of an electric current. Considering that Coulomb had proved that electricity and magnetism were independent phenomena, or better, that electric effects would be exclusively provoked by electric fluids and magnetism by electric magnetic particles, he concluded that the electric current had magnetised the wire. To him, the electric current transformed the wire particles into small magnets while it flowed through the conductor. Thus, he concluded that deflection was provoked by those objects, not by the electric current. Considering Coulomb's work, Biot and Felix Savart (1791–1841) proposed that the force between the electric needle and the conductive wire varied according to the square of the distance and also established the angular dependence through controlled and precise measurements (Purrington 1997, p. 38).

The debate about that episode was the third activity used to evaluate the viability of the study of controversies in the process of deconstruction of the idea that science was made by inductively. That was a very rich moment.

Many were puzzled by the fact that Biot believed that his theory eliminated the relationship between electricity and magnetism. Others were surprised by the fact that a scientist didn't accept an experimental result. To those, it was said that Biot didn't deny the fact that a compass was deflected in the presence of an electric current. The problem was that his view of the world led him to accept that electric and magnetic phenomena were only provoked by electric or magnetic fluids that acted from a distance, without any interference of the space between them.

Classroom work continued with the presentation of Biot and Savart's mathematical systematization of that specific phenomenon. Theories and experiments weren't enough for him. It was highlighted that in that context, good science should be based on experimentation and mathematics. The teacher referred back to the discussion about Biot's position in relation to Oersted's experiment. Thinking back about the debate between Galvani and Volta, one of the students asked if Biot hadn't followed the same path as Volta. The Italian scientist recognized the frog's spasms but worked to disprove Galvani's interpretation of animal electricity. To the student, Biot, as he himself, did not deny the experimental results, but tried to explain the new phenomenon according to the theory he accepted. The teacher reinforced what the student had said, adding that Biot recognized the new phenomenon. That was evident in Biot's efforts to perform precise experimental measurements aiming at developing an expression that determined the intensity of the magnetic force on a magnetic needle.

Biot's position was confronted with Ampère's experiment. The first contact of the students with Ampère was by means of a short presentation of his biography and his professional path before 1820. Showing "Frankenstein" to the students proved to be positive. They were involved in the discussion about Mary Shelley's biography and what they said about the film showed how important this kind of activity can be to place them in the time of the discussed characters. The biographic discussion was also important to the understanding of the French scientist's work since his work should be seen as a result of a complex interaction between his experimental results, his worldvew, his scientific philosophy, his mathematical ability and his frustrations due to the rejection of his electromagnetic theory.

The students dealt with the following topics: Ampère's involvement with chemistry, the results of the studies and the way he distanced himself from the Laplacian group in his country. The teachers were concerned with presenting Ampère as someone who took part in an intensive philosophical and scientific debate (Caneva 1980, pp. 122–123).

Ampère's scientific path can be divided into three phases: the first, which lasted until 1808, when he dedicated himself exclusively to mathematics; the second, when his chemistry works won him prominence and the third, which started in 1820, when he worked with electromagnetism only (Williams 1989, pp. 72–76).

Ampère's change of focus was very much debated with the students. Fox (1974) arguments that between 1815 and 1825, there were two rival research lines in the country: one represented by established Laplacians such as Poisson and Biot and the other by a less organized group whose members were Fresnel, Dulong, Petit and Fourier. The main protagonists of such clash were Biot and Arago. The nature of light was a question of dispute between these two groups.

The chemistry works of Ampère, although prior to 1820, together with the ones that came after Oesrted's experiment, form a solid block with an explicit view of science. While Ampère was working with chemistry, the Englishman Humphry Davy (1778–1829) was stirring up the orthodox basis of French chemistry, which was dominated by Lavoisier's theories. Ampère's growing interest in chemistry was connected with Davy's questioning. During the time when Ampère constructed relevant works in chemistry, he was not very interested in electricity or magnetism (Williams 1983; Ampère 1811, p. 82; Ampère 1814, p. 85).

Up to 1820, Ampère lived in a context in which Arago and Fresnel's group were presenting theories about the nature of light different from the corpuscular particle theory of light, defended by the Laplacian group. Ampère and Fresnel were in close intense contact and between 1814 and 1820, they discussed several matters and carried out experiments together (Caneva 1980, pp. 126–127).

In a letter to Ballanche, written in 1815, Ampère presented the wave theory of light as something real, which made him abandon the corpuscular particle theory of light (Ampère 1816, p. 92).

Ampère's contacts with scientific works that were out of the Laplacian structure were not restricted to those developed in French territory. Even before 1820, he had come across articles where Oersted defended the thesis that all natural phenomena were directly related and that, starting from electricity; one could understand chemical affinity, thermal, optical and magnetic phenomena (Caneva 1980, p. 129).

Arago’s introduction to the Académie des Sciences made Ampère believe that Oersted’s work was incomplete. Thus, he dedicated himself to the investigation of that experiment. He did not intend to reveal new facts. He wanted to understand the essence of the phenomenon (Williams 1983, pp. 496–498).

Because of this peculiarity in Ampere’s path and also because the students responded so well to the experimental activities of the first part of the project, it was decided that the debates would continue and the students would carry out experiments based on those developed by Ampère in the years of 1820 and 1821.

Ampère’s first experiment with electromagnetism was presented to the students, showing them it was just a reproduction of Oersted’s experiment. They didn’t observe anything different from what they had analyzed in Oersted’s experiment. This was confronted with the fact that Ampère had realized that the results of the experiment were caused by a combination of the action of the electric current and the action of the Earth’s magnetic forces. Thus, in order to investigate the real magnetic power of the conductive wire, it was necessary to eliminate the action of the terrestrial magnetism. He wanted to establish the characteristics of the force that emanated from the wire itself, without any external influence. This episode was used to show the students that Ampère’s mind worked in one direction and that his experiments aimed at producing evidence to his theory (Darrigol 2003, pp. 6–8).

Between 4th and 18th of September 1820, Ampère carried out several experiments that showed that when the conductor was fixed, the compass needle was always 90° from the direction through which the electric current circulated. Based on this he built an instrument, the galvanometer, whose function was to detect the electric current through the movement of a compass needle (Williams 1983, pp. 498–499).

The students reproduced a galvanometer and read a text about why Ampère had developed such an instrument. After reading, the students answered some questions proposed by the researcher group.

It was also highlighted that the galvanometer made it possible to map the electric current in a voltaic circuit without any great external influence. Before the galvanometer the electric current was investigated by imposing something on its own circuit, like a fluid or animal tissue, which influenced it very much.

Ampère’s definition of electric current was also in the text. His definition was in total disagreement with the theory that had Biot as one of its great defenders, and was accepted by most scientists in France. They argued that the “electricity” produced by a battery was the result of the separation of the electric fluids inside it, triggered by the contact between different metals. To them, this separation occurred by means of electrostatic tension in each pole that produced a charged conductive wire due to the discharge of that tension. Electrolysis was explained from the idea that the observed decomposition was provoked by opposite electrostatic tensions that were immersed in liquid that attracted different particles over the distance. Ampère opposed this group and built arguments based on experimental data (Williams 1983, p. 499).

The text emphasized that Ampère had mapped electric current in two different situations using the galvanometer. In the first situation, the wires of a voltaic circuit were put into pure water. In this case, he didn’t notice either decomposition in the water or deflection of the needle of the galvanometer. Keeping the original circuit, he explored the second situation and added some nitric acid. Significant deflection of the needle as well as water decomposition was observed. Both varied according to the amount of acid added. As neither the battery nor the original circuit had suffered any modification, Ampère argued that the tension of the battery couldn’t have been altered. He thus defended that the effects observed were provoked exclusively by the increase in conductivity of liquid in which the conductive wires had been submersed.

When debating with the students, Ampère's (1820) conclusions were highlighted: whenever deflection of a compass needle was observed, the existence of circular electric currents was certain.

The intense dialogue between Arago and Ampère was another highlight. Arago asked Ampère theoretical and experimental questions that were fundamental to the development of his work (Wiliams 1989, pp. 77–78).

The researcher's notes related to the activity with the galvanometer showed that when the students discussed the answers to the questions, they referred to Biot as a naïve scientist, someone who believed in a theory that made no sense. This was discussed in the meetings of the project group and it was decided that the classroom texts and activities would emphasize the fact that not all conclusions reached by Ampère derived from direct observation of the experiments. Ampère had gone to the laboratory to maximize Oersted's experimental results, but his conclusions presupposed analysis that had not been reached by the laboratory. Thus, like Biot, he was immersed in a conception of nature of which he would not disperse with when analyzing his experiments.

At this stage in the course, the students reproduced experiments, carried out by Ampère, to investigate the cause and effect relationship between magnetic force and electric current. The same procedures were used as in the previous activity. So the students answered some questions put by the research group. The analyse of this activity was the fourth moment used to evaluate the pedagogical proposal. Questions were elaborated to evaluate the position of the students about the role of experiment in the development of science. We wanted to verify if the students had deconstructed their first opinion, that science was built on top of discoveries.

Students were separated into groups and given guidelines to be followed during the experiments as well as questions to be answered. The purpose of this activity was to put the students in contact with an experiment that antagonized the theory but in which the scientist, who believed in the theory, did not abandon his project. He continued his work looking for the solution of the problem. The text and the questions compared this situation with Biot's position about Oersted's experiment. In this episode, the major theory was not abandoned.

In one of the experiments, two coils (each connected to a battery), were put close together. The script of the experiment explained that Ampère hoped to observe great attractions when the currents circulated in opposite directions and great repulsions when the directions of the currents were the same. According to him, this would happen because same direction currents would create "magnets" with equal poles and opposing currents would create "magnets" with different poles. However, it was impossible to verify that in the way Ampère conducted the experiment (reproduced by the students), the coil was not constructed in such a way to eliminated the longitudinal effect.

The failure of the experiment was uncomfortable for the students who couldn't observe anything. They argued that they had spent too much time with something that didn't work. The teacher then asked them to leave their groups and resume the class discussion but three out of the seven groups did not obey him. They kept on trying to make the connections and alter the polarity of the battery in order to succeed with the experiment.

The teacher discussed with the students that the apparent failure of an experiment is not capable of refuting a theory, so Ampère continued his work. The contact with other scientists like Arago allowed Ampère to modify the original experiment and finally observe the attraction and repulsion he was looking for. Without telling the students what should be done to modify the experiment, the teacher asked them to try the experiment more one time. No student was able to observe the attraction and repulsion between the coils without the teacher's guidance. Just when the teacher indicated that they should alter the original coil in order to get a flat coil was the expected effect observed.

Then the teacher showed the students two experiments. In the first one, he magnetized iron filings and a sewing needle inside a coil connected to a battery and confronted this situation with the one faced by Ampère and Arago.

At this moment, except for four students, the others were really active during the lessons. They were always asking questions and asking the teacher to repeat points he had explained before. During the discussions, they also mentioned observations the teacher had made before. This behaviour was also registered by the researcher while watching each group discussion. Students very often referred to class discussions to support their points of view when disagreeing with other students. They always referred back to the film, Frankenstein.

Another group activity was the building of an apparatus that allowed them to see the attraction and repulsion of straight conductors. Based on this experiment Ampere's conclusion was presented: straight wires through which an electric current circulates may attract or repel each other according to the direction of the circulating current. At this point, attention was called to the fact that this conclusion had not been foreseen by Ampère's theory, based on circular currents. That was a very important moment because it showed the students that Ampère's conclusions were not the result of unpretentious observation. Although he was searching for something more concrete in his experiments, unexpected facts were presented to him in the laboratory. It was also shown to the students that Ampère used this unexpected observation to explain why his experiment with coiled wire had failed.

The study about the works of Biot and Ampère showed that philosophical questioning can, in a certain way, guide theories showing that some scientific conclusions could result from logical and theoretical analysis. To exploit this situation and to conclude the answer of the central question of this paper, the students read an excerpt of "Memoire sur les effets du courant eléctrique", 1820, p. 203, where Ampère presents arguments in favour of his thesis of electric currents around the equator belt. After reading, the students answered the following questions: How did Ampere interpret terrestrial magnetism? Can Ampere be seen as a member of Biot's group? The first question was intended to simply evaluate the students' understanding of the referred text. The second was aimed at evaluating whether the students had noticed there was controversy between Biot and Ampere.

Although some students showed some difficulty in answering the question, others showed that some of them had noticed the controversy between the two scientists. Those answers were used by the teacher to come back to the historical debate about Biot and Ampère's ideas on Oersted's experiment.

STUDENT 1—"As Oersted's experiment proved the link between these phenomena, it was difficult for Biot and his followers to explain how the electric current could alter the magnet, that is, how an electric fluid would cause an electromagnetic phenomenon. To Ampère, that was not a problem".

STUDENT 2—"No, because Oersted noticed a small deflection of the compass needle that was near the wire. Thus, it was proved that different natural phenomena were related to each other. From this point on, many other experiments, like Ampère's, were carried out (considered non-Laplacians). The experiments proved the connection between magnetism and electricity. According to Ampère, for example, every magnetic effect was generated by a circular electric current. Biot denied that".

STUDENT 3—"No. To Ampère, electric and magnetic forces have a very strong relationship; one can generate the other or interfere with the other, thus opposing the idea that electrical phenomena could only generate other electrical phenomena".

During the debate about the answers, it was shown that Ampère, besides experimental investigations, had also undertaken quantitative analyses that helped him build a mathematical expression to calculate the intensity of the magnetic force between two infinitesimal electric currents.

Ampère's expression is similar to the one elaborated by Biot and Savart. One can be reduced to the other. Nevertheless, there are significant differences in the way the analyzed object is treated.[1]

5 Conclusion

After studying the Biot Ampère controversy, induction laws and the concept of electromagnetism were undertaken. Due to time restrictions, there was no worry about a systematic historical study during the second stage.

The work about the Biot Ampère controversy was very important. Although the debates had a strong experimental base, they led to the fact that science is not constructed by means of induction. The studies showed that Ampère chose the laboratory to enlarge the knowledge of the phenomena that had intrigued him. But his theoretical and philosophical conception guided his experimental works. From a different point of view, the chosen experiments would have been different and he wouldn't have insisted on some tests.

Apart from that, the students studied the Biot-Savart law, recognizing that Biot hadn't tried to enlarge his knowledge about the phenomena made evident by Oersted. On the contrary, he developed an explanation that would eliminate the problems caused by that experiment in his concepts of nature and science.

The participation of the students in the project classes was intensive in time. The historical-philosophical clashes were thoroughly discussed. The classes, the experiments and the texts put the students in conflict with their first vision of science. But the research could not conclude that their inductive vision was changed. To evaluate this kind of thing, another research project should be developed. We concluded that the study of controversies is a good way to deconstruct the inductive view of the knowledge building process. We came to this conclusion because the study of the controversies placed questions to those students, made them reflect about science and in particular about the role of the experiment in the building of science.

So we could conclude that when exploring these issues in the classroom, the teacher questioned a view of science present in many Brazilian textbooks. The teacher did not present inductivism formally but told a story where there were not only discoveries, but theoretical and experimental constructions that guided the development of science.

Even though it was not the main aim of this work to evaluate if the students learned more physics with the described approach, it is important to say that the implemented course did not abandon the study of scientific concepts. Parallel to the debates of historical-

[1] In "Theorie mathématique des phénomènes électro-dynamiques uniquement déduite de l'experience", 1826, Ampère made statements that show him connected with the Laplacian programme. This panorama made some science historians, John W. Herivel, R. A. R. Tricker, defend the fact that Ampère was a representative of the Newton-Laplacian system, having also enlarged the structural body of this system. But if we look at works previous to the written letters, we see Ampère putting himself explicitly against the Laplacian programme.

philosophical issues, the scientific contents were focused on either by means of theoretical analysis or by means of experiments. In this way, a teaching method of applying mathematical theories and laws was abandoned. The students learned about the history of the science they were studying. This brought them closer to physics since the acknowledgement of controversy gave those contents a significance that was fundamental to its understanding (Matthews 1994, pp. 49–50).

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