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Selected Contributions

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INTRODUCTION

Electromagnetic interactions play a central role in explaining the natural world and they provide the foundations of most current technology. So, it is important for people to have a basic understanding of electromagnetic phenomena for two main reasons; firstly electricity and magnetism are seen as central topics in the science/physics curriculum at any teaching level and secondly, which is central to the arguments of this paper, the concepts and models involved in Electromagnetism (E&M) are particularly problematic. The concepts are highly abstract and their understanding is dependant on models.

Models and analogies are essential to teach electromagnetism, because in this content area most phenomena cannot be observed directly; only the consequences of these phenomena are evident. Moreover, scientific explanations are given on a microscopic level whereas observations are made at a macroscopic level. However, in the traditional E&M teaching sequences at High School (16-18 year old students) and Introductory Physics Courses at university, the usual approach involves rapid

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introduction of new concepts, models and ways of reasoning and most time is spent solving different types of exercises. Conventional teaching enhances abilities to complete only algorithmic problems. Students do not have sufficient time to think about the interaction model behind abstract concepts such as field, flux, potential difference, electromotive force or magnetic induction which only appear related to the formulas. Frequently, the maths which express the laws of E&M phenomena become fundamental tools and require students to apply them in an unfamiliar situation such as defining vectors on surfaces and paths which have been chosen ‘ad hoc’ or, calculating the path integral or surface integral.

From a constructivist perspective, knowledge about the way in which students’ reason is an essential element in the didactical reconstruction work in teaching objectives and contents. The extent of constructivist-oriented research in this content area is well illustrated by the 2007 edition of a widely cited and comprehensive bibliography on studies involving learners’ conceptions and conceptual change [1]. Physics Education Research results repeatedly show that students’ level of comprehension regarding basic concepts of electricity and magnetism is highly idiosyncratic and dependent on the terminology used in everyday life, for example, voltage or flux is often in conflict with the conceptions of physics. In addition, students who correctly solve complex algorithmic problems on electrostatics or electric circuits do not explain magnetic induction in scientific way or they do not distinguish between the model of action at a distance and the field model [2]. These learning difficulties are not surprising as the concepts involved are difficult, but it is more surprising that this lack of comprehension remains almost unaltered after receiving instruction. However, few studies have been done (or carried out, performed) on students’ difficulties in E&M at introductory physics courses level in comparison with studies in other areas of physics at secondary level, for example, linear movement or Newton’s laws of a particle. We assert that there is a lack of research studies on E&M about either a) the students’ forms of reasoning and alternative conceptions, or b) analysing the specific difficulties of traditional teaching sequences.

We situate the need for more information on students’ learning difficulties within a educational research model that emphasizes research based on practical problems. These problems become the focus of research projects generating results with practical use and contributions to developing educational physics. We claim that it is necessary more approaches focus on the improvement of classroom instruction, making explicit the design principles used [3].

In the workshop we presented, firstly, examples from our research projects showing teaching and learning difficulties in E&M. Secondly, how research based on practical problems might help to design and develop a teaching sequence. Thirdly, we will deal with relations between scholar context and informal context in Physics Education. A constant concern of school science education has been that science programmes need to be able to reach the world beyond the classroom and connect with society as a part of the general culture. Therefore, films and other ‘scientific cultural products’ offer the opportunity to work with science curriculum
and allow teachers to create science experiences which are appropriate for their students.

2 STUDENTS’ REASONING AND TEACHING DIFFICULTIES IN E&M AT INTRODUCTORY PHYSICS COURSES

Previous investigations into students’ difficulties indicate that students may have problems applying the concepts of electromagnetism [4,5,6]. The case of Ampere’s law includes situations defined by mathematical operators and several variables which raises well know difficulties [7,8,9]. However, few studies provide wider analysis that includes not only students’ difficulties with mathematical operators but also the students’ ideas about the sources of a magnetic field and its relations with field operators (path integral of field) and Ampere’s law, at first year University level.

In this study carried out by the Group of Physics Education at the University of the Basque Country, we shall get a deep insight into students’ procedural mistakes when applying Gauss’ and Ampere’s laws, and we shall analyse the forms of reasoning they use. Our aim is to answer the following questions: a) Which forms of reasoning do students use when applying Gauss’ and Ampere’s laws?; b) To what extent can the mistakes made by students in applying Gauss’ and Ampere’s laws be explained by means of spontaneous or ‘common sense’ forms of reasoning?

We will only consider situations involving stationary currents, so the magnetic fields are stationary. In this research we take into account the chapter in the curriculum that studies Ampere’s law for magnetostatics, which is an incomplete version of the Ampere-Maxwell law.

In an attempt to answer the research questions, we have produced a design involving tasks based on the previous bibliography review and our experience as teachers. The study is orientated towards first year University students. We have designed one paper-and-pencil questionnaire and we interviewed students about four of the questions of questionnaire. The questionnaire has seven questions similar to those in the textbooks used for teaching Introductory Physics in universities. The first three questions were about Gauss’ law, while the following four questions were about Ampere’s law. To devise the current questionnaire, a prior study was carried out to analyse the coherence between the way the questions were written and how the students answered. These studies confirmed that, in general, students had no problem understanding the meaning of the questions but they show serious difficulties in applying Gauss’s and Ampere’s law correctly.

The results obtained show that, after training, most students mechanically apply reasoning based exclusively in a particular strategy which considers that the field is constant in any situation in which Gauss and/or Ampere’s laws are applied, even when the pattern of field lines does not satisfy the symmetry conditions. For example, in questions 3 and 7 (Q3, Q7) it is necessary to take into account the field patterns to apply Gauss’ and Ampere’s laws. Students have to
reason that these laws are an easy path to obtain the field value (because direct integration is easy) when there are some symmetry conditions between field patterns and chosen surfaces and paths.

**Q3.** A student finds the electric field on the Gaussian surface that surrounds the charge \( q \) (see Fig. 1), using the following reasoning: According to Gauss’ law the total electric flux through the surface is:

\[
\oiint \mathbf{E} \cdot d\mathbf{S} = \frac{q}{\varepsilon_0}
\]

making direct integration:

\[
ES = \frac{q}{\varepsilon_0} \Rightarrow E = \frac{q}{S\varepsilon_0}.
\]

Do you agree with the student? Justify your answer.

![Figure 1](image)

**Q7.** Imagine a very long wire through which current \( I \) circulates (Fig. 2); this thread of current is perpendicular to the plane of paper and moves outward. A student, E1, applies Ampere’s law to calculate the magnetic field created by this current at \( A \), using the circular trajectory (1) which contains point \( A \) and through the centre of which passes the thread of current, and comes to the conclusion that the value of the field is:

\[
B_A = \frac{I}{\mu_0 l},
\]

where \( l \) is the length of the circumference corresponding to trajectory (1). Another student, E2, does the same thing but using a closed non-circular trajectory (2), which also contains the point \( A \), coming to the conclusion that the value of the magnetic field in \( A \) is:

\[
B_A = \frac{I}{\mu_0 L},
\]

where \( L \) is the length of the trajectory (2). Explain the reasons why you agree with student E1, or with E2, with both, or with neither of them.

**Note:** Trajectories (1) and (2) are situated on the plane of the paper.

![Figure 2](image)
In general, students’ answers do not take into account the pattern of field lines and so, they suppose that the field is constant along the surface or the path. Most students (58% in Q3 and 66% in Q7) do not take into account the symmetry conditions which the field must fulfil in the Gaussian surface or Amperian line to obtain a mathematically simple solution. Let’s look at a few examples:

**Example 1 (Q3)**

“In any closed surface (Gaussian surface) we can apply Gauss’ law:
\[ \oint \mathbf{E} \cdot d\mathbf{S} = \frac{q}{\varepsilon_0} \]
so the electric field will be
\[ \mathbf{E} = \frac{q}{S\varepsilon_0} . \]
I agree with student.”

**Example 2 (Q7)**

“Both students are correct as if we apply Ampere’s law we obtain:
\[ \oint \mathbf{B} \cdot d\mathbf{l} = \mu_0 I \Rightarrow B_A l = \mu_0 I \quad , \tag{1} \]
\[ \oint \mathbf{B} \cdot d\mathbf{l} = \mu_0 I \Rightarrow B_A L = \mu_0 I \quad . \tag{2} \]

We have also found that thinking based on the formula leads students to confuse field operators and the field itself. For example, in questions 1 and 6, students must differentiate between field operators (flux or circulation) and the field itself to justify their agreement or disagreement with the given explanation. In question 1, a situation is proposed in which the flux of the electrical field through a closed surface is zero, and the students must reason whether this implies that the field at each point on the surface is zero. For any closed surface, the net outflowing electrical flux is the product of the average of the normal component of the field according to the direction outwards and the area of the surface. Therefore, the condition \( \Phi = 0 \) does not necessarily imply that the field is null at each point on the surface. Question 6 is similar to question 1 but within the context of magnetic field and Ampere’s law.

**Q1.** If the flux of an electric field across a closed surface is zero, does it mean that the electric field on each point of the surface is zero?

- yes ..........  no ..........  I don’t know ..........

Justify your answer.

**Q6.** Through each of the two “infinite” threads an intensity of current of \( I \) amps flows (Fig. 3). These threads are perpendicular to the plane of the paper and in one
the current is outward whereas in the other it is moving inward. Trajectory (1) is circular, it moves anti-clockwise and it contains two threads.

A student, using trajectory (1), applies Ampere's law and concludes that the circulation of the fields is nil, therefore field $\mathbf{B}$ is also nil at all points of the trajectory (1). Do you agree with this student? Justify your answers.

![Figure 3](image)

In questions 1 and 6 most students reason following two lines of reasoning. One of them includes answers (35% in Q1, 33% in Q6) which explain that, because the flux or circulation is null, the total charge or current enclosed is zero and therefore the field will be zero. This explanation is coherent with the idea that only internal charges on the Gaussian surface or internal intensities on the Amperian path produce an electrical field on the points of the surface or a magnetic field in the points of path. Let's look at an example of an answer from one of the interviews:

Interviewer: Why do you say that the field on the Gaussian surface is zero? (Q1)
Student: If the flux is zero, that means that there is no charge, doesn't it? Well, in Gauss' law, flux is proportional to charge, and if the charge is zero, this indicates that there is no field. In other words, if we use Gauss' law in this case, then if the flow is zero, the charge is zero and there is no field.

Other standard examples are the following:

**Example 1 (Q6)**
"If we apply Ampere's law:
\[ 0 = \oint \mathbf{B} \cdot d\mathbf{l}, \]
there is no current to create $\mathbf{B}$, and so $\mathbf{B} = 0.$"

**Example 2 (Q6)**
"If we apply Ampere's law:
\[ 0 = \oint \mathbf{B} \cdot d\mathbf{l}, \]
in the second part of the equation, $\mathbf{B}$ must be zero because $d\mathbf{l}$ is not, so I believe the student is right."
Thinking through the formula, students establish a link of causality between the charges or current enclosed by any surface and the field at the points on that surface. They wrongly conclude that the field’s only sources are enclosed by the Gaussian surface or the Amperian path.

The second erroneous variant of students’ reasoning (26% in Q1, 24% in Q6) correspond to a strategy which is commonly used in class but which has a very specific field of validity (symmetry conditions) for \( E \) or \( B \) to be constant in the Gaussian surface or Amperian path. This result is convergent with the results obtained in questions Q3 and Q7. One standard answer including this kind of reasoning is as follows:

**Example (Q6)**

“If we apply Ampere’s law:

\[
0 = \oint B \cdot dl = B \oint dl \Rightarrow B = 0
\]

so I believe the student is right.”

In the interview for question 1, most students do not establish the need for the field \( E \) to be constant in modulation throughout the Gaussian surface and for the angle formed with each differential element of the area to also be constant, in such a way that it can be taken out of the integral. The students do not analyze the field of validity for Gauss’ law and use it in a non-critical manner, as we can see in part of the following interview:

- **Interviewer:** Why do you say that the field on the Gaussian surface is zero? (Q1)
- **Student:** If we look at Gauss’ law, it is clear. If the flow is zero, the following equation is fulfilled:

\[
0 = \oiint \vec{E} \cdot d\vec{S} = \vec{E} \oiint dS \Rightarrow E = 0
\]

and therefore the field on the Gaussian surface is zero.

In the students’ reasoning, they do not establish the need for the field \( E \). This way of reasoning is convergent with example 5 in question 6. However, the students apply it generally, leading to functional fixedness on one strategy.

The above results are in coherence with results from the other parts of the questionnaire. For example, Questions 2 and 4 were designed with the intention of investigating the reasoning used by students in a situation where it is explicitly necessary to take into account which field is involved in Gauss’s law (question 2) or Ampere’s law (questions 4).

**Q2.** Consider an infinite sheet, with a surface charge density: \( \sigma \). Is the electric field you determine from Gauss’ Law:

a) the field produced by all the elements of charge in the sheet?

   yes .......... no .......... I don’t know ..........

b) the field produced by the charge within the Gaussian surface? (the Gaussian surface we refer to is the cylindrical one used in textbooks, see Fig. 4)
yes .......... no .......... I don’t know ..........
Justify your answer.

Q4. We consider a long solenoid, where we assume that as long as we are far from the ends, the magnetic field inside the solenoid is fairly uniform and the magnetic field outside is very small. As you know, in these conditions we can calculate the field inside the solenoid by applying Ampere’s law. The Amperian line of integration will be the line shown in the diagram below. From this we can conclude that:

A. The calculated magnetic field is caused by all the loops of the solenoid.
B. The calculated magnetic field is caused only by the loops inside the Amperian line.
C. Another answer.

In question 2, the students were given a problem about identifying the sources that produce the field that they deal with when applying Gauss’ law. The law establishes that flux through a closed surface depends only on the charge enclosed within the surface. It is well-known that this proportionality between the resulting flux and the enclosed charge is not generally valid for the relationship between the resulting electrical field on the surface and the enclosed charge, because the resulting field $\vec{E}$ at one point on the surface is due to both the internal and external charges of the Gaussian surface.

In question 4, we present a very similar question to question 2 but concerning magnetic fields and Ampere’s law. The students were given a problem on identifying the sources of field that they considered when applying Ampere’s law.
Ampere’s law establishes that the circulation through a closed line only depends on the intensity of currents enclosed within the path. The proportionality between the resulting circulation and the enclosed intensity-current is not valid in general for the relationship between the resulting magnetic field on the path and the enclosed intensity, because the resulting field $\mathbf{B}$ at one point on the path is due to both the internal and external current-intensity for the Amperian path. In this question, it is the presence of all the loops which determines the existence of special symmetry for the magnetic field which permits simple mathematical treatment. If we consider the field which is only produced by the internal loops of the path, it is not calculated using Ampere’s law because the variations in modulation and direction of $\mathbf{B}$ at each point will make it impossible to find an adequate integration path for a simple calculation.

The majority of the students’ reasoning is based on the formula (57% in Q2 and 60% in Q4). Students establish a causal link between the charge (Q2) or current intensity (Q4) enclosed by any closed surface/path and the field at the points on that surface/path. They wrongly infer that the only sources of the field are those enclosed by the Gaussian surface or Amperian path. We can observe this form of reasoning in the following examples:

**Example (Q2)**
“According to Gauss’ law ($\Phi = \frac{Q_{\text{in}}}{\varepsilon_0}$), it is the internal charges that create the field.” (Q2)

**Example (Q4)**
“According to Ampere’s law, I applied the field circulation for that line, and as we have already seen in class. In the vertical segment and in the external part there is no circulation of $B$. Therefore, you would get field $B$ from there, because we know the intensity that circulates through the loops:

$$\mu_0 \sum I_{\text{internal}} = \oint \mathbf{B} \cdot d\mathbf{l} = Bd \cdot dl = Bd .$$

**Example (Q4)**
“Since there are 10 loops within the integration curve, I multiplied the intensity by 10 and ‘$d$’ is the length of the rectangle of integration. I use the formula and it is for the intensities inside the Amperian line, so these are the intensities that create the magnetic field.”

According to the students’ reasoning, it seems there is a functional fixedness with respect to a solving strategy based on the mathematical expression of Gauss’ law or Ampere’s law. It seems that, by using the formula, they establish a causality link between the charge or current enclosed by any surface and the field at the points on that surface.

In question 2, there is another type of reasoning, which is less common, but which we must take note of. One example is as follows:
Example (Q2)
“The electrical field that is calculated by Gauss’ law is the field produced by the internal charge, as the formula indicates. However, because the distribution of charge is uniform throughout the conductor, the field that is calculated is that of the entire conductor.”

This type of ‘ad hoc’ explanation would be associated, according to the bibliography, with a “common sense methodology” that is frequently characterized by an absence of doubt, by sure, fast answers based on “common sense evidence” and a lack of consistency when analysing the situation.

In question 4 and 5, some answers, although to a lesser extent, show forms of reasoning which confuse the field with the field circulation operator. See example:

Example (Q5)
“It is true because the Amperian line does not enclosed any current and the equation
\[ \oint \mathbf{B} \cdot d\mathbf{l} = \mu_0 \sum I \]
tells us that we only have take into account enclosed intensities.”

A minority of answers indicates correctly that the electric or magnetic field calculated by Gauss’s law or Ampere’s law is due to all charges/currents in the universe (all plane charges in Q2, all currents-loops in Q4, the three currents in Q5). Examples of answers included in Category A are as follows:

Example (Q2)
“The field is what is formed by both the internal and external charges of the Gaussian surface.”

Example (Q2)
“The field that is applied in Gauss’ law is formed by the charges inside and outside the Gaussian, although in the formula it is the one inside the Gaussian.”

Example (Q4)
“The magnetic field is created for all current-loops of the solenoid because we analyze all solenoids.”

Example (Q5)
“The answer is not correct, because acting on any point of the line is the magnetic field produced by the current from within and the magnetic field generated by the other current cable. I believe that ..., we have two magnetic fields to put inside the integral. I do not believe that it is easy to do this kind of exercise. I believe that the integral is complex.”
However, in Q2, no answer includes a justification, such as only the presence of all the charges allows for the existence of a *special symmetry* for the electric field, which in turn allows the type of simple mathematical treatment which we are familiar with for Gauss’s law. In the same way, in Q4 and Q5 students do not justify why it is necessary to take into account all currents-loop (in Q4) or two currents (in Q5).

In the two questions presented, it seems that there is a style of reasoning characterized by a functional fixedness on the formula of the law that is used in a non-critical manner, in which the erroneous inference is made that the only field sources are those enclosed by the Gaussian or Amperian path. Furthermore, to a lesser extent in this part of the questionnaire, this functional fixedness on the formula leads students to confuse the field with the field operator.

In summary, most of the students do not consider the sources of the field and its lines to analyze the situation. This lack of meaning for the field itself leads to students finding it difficult to distinguish a clear understanding between the field operators and the field itself. They show a lack of meaning for the flux and field circulation operators. We have seen this erroneous reasoning in the areas of both electricity and magnetism.

In addition, the results show us which strategies are used in the classroom, and which cognitive skills are favoured when learning these laws. Teachers should keep in mind that students already have ways of approaching questions and problems, and these are prototypical of a common sense methodology (i.e., repeating a strategy mechanically, thinking through the formula, etc.); therefore teaching should be planned more according to scientific epistemology. Thus, to avoid the common tendency towards fixedness in a strategy (i.e., field always constant in the application of Gauss’ and Ampere’ laws), it may be very useful to propose a different task in a teaching sequence that encourages students to draw up the field patterns and to establish a ‘criteria of acceptability’ for different forms of Gaussian surfaces and Ampere pathways. In this way, students must use different strategies for the field sources and their pattern of symmetry. For example, discussion about the feasibility of the strategy based on the field model (Gauss’s and Ampere’s laws) or on the model of action at a distance (Coulomb’s law), in relation to the symmetry of the patterns of field lines.

The teaching sequences which are usually proposed in text books consider that the pattern of field lines is obvious and start discussing the convenience of Gauss’s or Ampere’s laws for a proposed surface or path. However, as we have shown, it will be necessary to design teaching sequences that stimulate students to analyze the field lines patterns for different charges or current configurations. This analysis should encourage students to take into account all field sources and to avoid functional reduction based on the formula. These activities will encourage students to search for all the sources making up the field pattern and discuss what the pattern would be if only the charges or currents enclosed by the surface or path were taken into account.
3 PROSPECTIVE PRIMARY TEACHERS AND ELECTROMAGNETIC PHENOMENA: A TEACHING/LEARNING RESEARCH

Research literature on teachers training underlines that a great part of learning difficulties of students are in common to the teachers and then become professional problems in approaches and strategies. In prospective primary science teachers’ courses, one of the principal problems is to build the didactic competence in science education combining pedagogical and content knowledge to guarantee them as prerequisite. In this perspective, and regarding the area of electromagnetism, we carried out an empirical research aimed to Teaching/Learning (T/L) proposals for prospective primary teachers.

The research program developed by Unit in Physics Education of the University of Udine developed a study focus on electromagnetic interactions to built the concept of Lorentz’ force, which represents a conceptual gap as for the analysis of the simple effects related to the properties characterizing the electric and magnetic nature of those phenomena. The participants in this study were students at the second year of primary science teachers at the University of Udine. The research was developed within the theoretical frame of Model of Educational Reconstruction (MRE) [10] and the research questions are the following:

- Which are the conceptual referents to describe electromagnetic interactions?
- Is knowledge about magnetic interaction effective to activate the identification of the currents’ system having the same behaviour? (magnet/solenoid)
- Which angles of attach are effective for the reasoning in terms of field in the conceptual reconstruction of the phenomenology?
- Which is the role of project tasks to induce explorative behaviour to overcome description in a common language and to reach explicative and interpretative competences?

The sample consisted of 105 students of the 2nd year of Scienze della Formazione Primaria (21 years). We worked for two sessions of three ours each of cognitive laboratory Conceptual Lab for Operative Exploration (CLOE) [11] in which prospective teachers worked in small group of 6-7. Prospective teachers worked to an explorative hands-on path with stimuli sheet [12,13,14] based on SPPEA cycles (Situation, Prevision, Planning, Experiment, Analysis) and rogersian interview followed the activities to clarify ideas and type of reasoning.

The tackled knots in the sequence are the following: exploration of interactions between a magnet and an other magnet, ferromagnetic objects, objects done by other materials, compasses; reciprocity of the action being not in contact; the compass is a magnet; magnet ordinary suspension; the space around a magnet: magnetic field and their representation through field lines; superposition of fields; magnetic effects of a current: field lines of a current, a coil, a solenoid; interaction between a magnet and a solenoid; a current into a magnetic field: Lorentz’ Force.

Data analysis was done with the following methodology: classifications of answers in a priori classes, statistical analysis of standard answers, qualitative case
study for special interpretative models, comparison with quantitative and qualitative data, cross analysis with group discussion, control using rogersian interviews.

From data analysis emerges that:

- The main conceptual referent for the descriptions of magnetic interactions is the attraction. It is a generic criteria (for magnetic, electrical, gravitational interactions) so it is necessary to build the specificity of these different types of interactions for prospective teachers to give clarity to students that in this way do not remain on a descriptive phenomenological level. Interaction is described in terms of behaviour of systems and rarely in terms of physics quantities/entities (force, field, torque). The identification of the behaviour of systems is (in 32% of cases) local and contingent and often without explanations. It raises up that it is the need on one side to build the subject prerequisites and, on the other side, to make teachers responsible in their concepts’ organization to be able to reframe the main elements of an interpretation of phenomena. We find evidence that planning tasks turn out effective to overcome the common diffuse attitude to be reductive and reproductive.

- The familiarity with magnetic interactions produces effective analogy to the identifications of systems of currents with same behaviours. The need to learn the specificity of magnetic interaction before of that electromagnetic rises up from 3 elements: 1. the need to recognize the characteristics of magnetic interactions (rotation and attraction); 2. the awareness of the need of an explorer of space properties; 3. the recognition of reciprocity of interactions. Introductive work is effective for the right use of explorers and students immediately recognize a magnetic field around a current.

- The representation in terms of field lines is an useful angle of attach to overcome local and animistic interpretations of magnetic interactions, to build reasoning in terms of field and to conceptual reconstruction of phenomenology and is effective when has a role in superposition of field and interactions between magnet and current.

- Project tasks active explicative needs and make students awareness of processes not analyzed before. Through the responsibility of explanation, students overcome descriptions of a local type and in common language: they start to use specific terms of physics entities, even if sometimes in a not so correct way, instead of common sense ideas. It is necessary to recall often theoretic frame to avoid that teachers precipitate in local vision of single phenomenon or underestimate the exploration of simple phenomena and give a sequence of non related descriptions and that, often, are only their previsions.
4 CHARGING BODIES WITH ELECTRICITY: A PROCESS TO UNDERSTAND FOR PRIMARY SCHOOL TEACHERS

The interest in electrostatics has always been high given its central role as a fundamental context in the concepts of charge, field and potential. Interest has also increased as it has emerged that learning difficulties about electric circuits find their origin in the absence of links with the concepts developed in electrostatics [15,16]. The investigation of learning in electrostatics highlighted difficulties in the management of the process of charge transfer [17,18] and in the interpretation of phenomena both in terms of field and using the principle of superposition [6, 19]. In particular, interpretative difficulties emerge in elementary phenomena including induction: investigations aimed at the modalities of interpretation of electrostatics by students [20] brought to highlight that these utilize spontaneous interpretative models, which recall historical scientific models; in particular, students utilize a vision of Coulombian force rather than a Maxwellian vision of field.

With regard to teaching, it is necessary to produce training for teaching that integrates disciplinary and pedagogical aspects, according to the model Pedagogical Content Knowledge [21] which is fundamental to structuring teaching professionalism of a disciplinary character. An empirical study has been carried out by the Unit in Physics Education of the University of Udine, aimed at Teaching/Learning (T/L) proposals for prospective teachers. In the theoretic frame of the Model of Educational Reconstruction (MRE) [10], this study is focused on the macroscopic properties of electric interactions, to construct the first level of interpretation of the electrostatic phenomena.

Within the informal context of the exhibition Games-Experiments-Ideas (GEI)) this study focuses on the identification of the properties of electric charge starting from macroscopic interactions, as a first step towards the building of the concept of charge as microscopic property of particles. We explore simple electrical phenomena to recognize that there are modes that change the state of systems: they charge/activate. This property has a dual nature: the systems interact in a mode of attraction or repulsion according to the concordance or discordance between these properties, when we consider interactions between pairs of systems. We explore modes of charging to recognize that the charging process is an activation, it is due to something that is already in the material, that preserves itself and is mobile. The main research questions are:

- R1. What is the role of experimental exploration in the construction of an interpretative model which is coherent with phenomenology?
- R2. How is the multiplicity of experimental variables managed?
- R3. Is it possible to construct a formative proposal which is based on the macroscopic properties evident in electrostatics?

The sample consisted of teachers from elementary schools both in training and in service (2 groups, 23 and 11 persons, G1 and G4); students of the Teaching Secondary Specialization School (33 students, G3) and students in the degree course for teaching in primary school (30 students, G2). The last group worked in
two sessions, for a total of 3 hours, carrying out the whole course. The other groups worked for 1 hour.

We proposed an explorative hands-on proposal in 10 points on Table 1 in the field of a conceptual laboratory Conceptual Lab for Operative Exploration (CLOE), utilizing explorative stimulus-worksheets [12,13] and a strategy based up SPEA cycles (Situation, Prevision, Experiment, Analysis).

### Table 1

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<td>Interactions of sticky tapes separated after being stuck together with different objects that have been rubbed, even with each other</td>
<td>4.2 different nature of the change in state of two objects that interact by rubbing;</td>
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<tr>
<td></td>
<td>4.3 dual and non-multiple nature of change of state</td>
</tr>
<tr>
<td>5. Repulsion of straws brought together after one is rubbed</td>
<td>5. contact between charged and uncharged objects as a modality of change of state of the same type.</td>
</tr>
<tr>
<td>6. Repulsion of aluminium strips from the bottom of a can to which a charged object is brought near</td>
<td>6.1 presence of “something” in the can even when interaction is not visible</td>
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<tr>
<td></td>
<td>6.2 effect of distancing as an indication of action between internal components.</td>
</tr>
</tbody>
</table>

For multiple choice or written answers relative to the identification of beings, we analyzed the frequency of choices made. For all the other questions, individual responses to open questions were classified on the basis of typical replies defined a priori based upon expectation and then organized in classes.

Analysing the answers we found that results of the first 3 groups are homogenous at the beginning. To the question of what happened to cause repulsion between pieces of sticky tape, in the first three groups students make major reference (48%) to a state, expressed as charging or electrifying, or polarity; from 20 to 39% refer to a change as something which is transferred, in terms of modifying, acquisition, movement, distribution. The fourth group mainly attributes what is observed to friction (55%).

Ninety-five per cent of students (102/107) recognize after repeating the experience from different surfaces a change of the state of sticky tape after being pulled, but many of them (up to 39%) did not recognize that it dealt with the same change, indicating the difficulty of connecting the same method of operating with the same state. An expression of the same type of modification in all the answers
about the behaviour of the sticky tape appears in 53/107 (50%) students, but only 9/107 (8%) cite (without developing the idea) that the same action done on two equal objects produces an equal change in those. The condition of equality seems to assume a lesser significance than action or change.

When, after repeating the experience with two sticky tapes on top of one another, we asked if both tapes are in the same condition, as in experience 1, 23/107 (21%) students maintained that the two pieces of tape stuck on top of one another are in the same condition.

After having observed the interactions between elements of two pairs of sticking tape separated after being stuck on top of one another, we ask if the pull is relevant for the phenomenon, and if it explains everything in it. In the first two groups the pull was thought to be relevant for almost all students, and 30% maintained that it was the key element. These students were concentrated on a single characteristic of the phenomena and the experiences seen were not sufficient to give an articulation to their view. On the contrary group G3 fully understood (97%) the articulation, but seemed to underestimate the role of the pull, relevant only for 67%.

When we looked at the answers that should have connected pull and characteristics of behaviour of the tape the differences that emerged reflect the difficulty in finding connections between systems and experimental conditions upon which an interpretation might be based.

Group G4 seems to have concentrated on a more closed structuring of questions, which favoured a better addressing of the objective of the activity.

All students of group G3 (from here we consider only it) recognized rubbing as a modality of change of state and foresee and explain repulsion of two rubbed straws with equal typologies of charge/electrification; over 80% foresee attraction of cloth and straw rubbed together.

At the end of the trials carried out with many materials 28/30 (93%) students cite attraction and repulsion as types of behaviour and influence shown, and 47% as conditions of rubbed or pulled objects: only 3/30 (10%) single out the conditions of them. A distinction is thus present, but only at a level of interaction.

After having seen the experience of the straws in contact 12/30 (40%) of students recognize that in contact there is a passage of charge, 13/30 (43%) do not specify, 4/30 (17%) believe that they are in different conditions: already elsewhere we have seen that “different” could mean it charges only for one element, with interaction between charged and uncharged objects too, so the meaning of this affirmation is not clear.

At the conclusion of the experiment with the aluminium can, 27/30 (90%) students maintain that there is something inside the can: in 4/30 (13%) cases it is in movement; suffering action at a distance with the object brought near: “it has something activated inside” in 6/30 (20%) cases. Two students speak of charge. In addition, 28/30 (93%) of students maintain that the influence of the rubbed object is upon the internal component and not upon the can.
Although the students spoke of charge throughout the experience, at this point they will discard the term and use a new one, as though what they used in the past no longer represents the image that they had formed of the phenomena.

Looking at the activity, students connected the experiences with electrical phenomenology with ease and used evocative terminology. This terminology is only a linguistic reference, constituting a point of arrival where it is not necessary to provide explanations: the insertion of the phenomena in the corresponding framework is sufficient to declare understanding. The beings that constitute this framework are however tools of interpretation: they are used in descriptions of processes, in connections between experimental variables and behaviour observed, and in the elaboration of models utilized in the predictions. On many occasions the experimental conditions, which should constitute the departure point of the investigation, are not grasped or they are not reutilized to analyze analogous experiences. Their transferability as information seems limited.

The identification of relevant variables constitutes a problem in any case, that may be reduced by looking at many phenomena rather than only one; however, the processes in choice seem to prefer a little number of variables, better only one, and to neglect the others, in a process of synthesis that is not always useful: it seems that the relations of equality are more difficult to grasp, less significant, than noting changes. The course experience, although it brought to light difficulties in management, succeeded nevertheless in producing the idea that in objects a “something” in motion interacts in the same manner as macroscopic objects: in this sense on the one hand it realizes the utilization of phenomenology previously missing; on the other it constitutes a possible link between the macroscopic and microscopic world.

5 CONCLUSION AND IMPLICATIONS FOR TEACHING

In the Workshop we have firstly discussed some problems involved in teaching/learning electromagnetism in Introductory Physics Courses. We have situated our research within a model that emphasised research based on practical problems which relate the problems of implementing physics education with its possible answers. We have pointed out some problems that arise from the need to understand students’ learning difficulties. We have showed the need for more research studies concerning students’ forms of reasoning in specific areas of electromagnetism at High School and first year University level. Designing teaching which aims for students to learn explanatory models of different physics phenomena such as electric interaction, magnetic induction etc. requires knowledge of the students’ reasoning on these specific topics of electromagnetism.

One of the questions which emerge is whether the new proposals of teaching sequences constitute a substantial improvement in learning compared with the ‘prevailing teaching praxis’. The answer is not clear and, in our opinion, it is answered through a series of designs which analyse the usual teaching through the analysis of the usual didactic materials (textbooks, topic teaching sequences etc.). For this reason, it is important to achieve consensuses on the explanatory models
and the teaching indicators which can justify the worth of the new proposals compared to the traditional proposals.

Another question related to the problem justifying the new teaching sequences based on the results of the research is the reproducibility. Reproducibility is an important prerequisite for making progress in science education. In this sense, we want to emphasise two aspects: The first deals with the real context in which the activities programme was developed. We were restricted by the programme set down in the University’s study plan and the challenge was to make changes to the teaching methodology within this real context. Due to these restrictions, it was necessary to produce a very detailed teaching plan for the time available and show that traditional conceptual contents would not be lost as a result of working with a different teaching methodology. On the contrary, the designed and implemented learning sequence gave rise to enhanced learning outcomes when compared with those from a parallel class of students. In any case, it seems that the issues of time required and the perceived loss of knowledge involved with innovative teaching approaches are very relevant for teachers in the usual context, and should at least be taken into consideration. The second aspect deals with the role played by the teacher in developing the teaching sequence. The teacher has a strong influence on what and how the topic is taught, however as researchers we should make the effort to prepare a detailed teacher’s guide, as well as discussion seminars on the new teaching proposal where teachers would have the opportunity to discuss it and share ideas. Moreover, the teacher’s role becomes highly important in our approach in terms of their own professional development, since they become an active researcher who will make their own critical reflection after the educational interactions and will therefore improve their educational action.

Sometimes, it has been noticed in the staffs that govern the University that the results of educational research do not reach the practicing teachers and contribute to improving physics teaching. Physics Departments require considerably more of the kind of research that is “close to practice” and particularly emphasizes the need for research into the didactics of subject matter. In view of this, the idea of developing and testing content-oriented teaching theories seems to be a step in the right direction (Heron & Meltzer 2005). These theories might also stimulate teachers to participate in research programmes with the aim of developing the aforementioned aspects of physics education. We believe that designing and testing those theories can be a way to strengthen physics education as an autonomous speciality in physics departments, which is in the interest of both teachers and researchers.

REFERENCES