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MAGNETIC FIELD FLUX IN UNDERSTANDING ELECTROMAGNETISM

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Electromagnetic phenomena offer an ideal theoretical framework in which students could address the investigation of the physical reality by means of the use of multivariable abstract elements of synthesis. The role played by the flux of the magnetic field in that description is pivotal but at the same time its interpretation represents an important learning knot that students had to face.
To explore this physical quantity, a Real Time Laboratorial activity was developed and proposed to Italian high school students in the framework of the development of vertical Inquired Based Learning path in which the formal nature of the magnetic field flux is constructed step by step from the observation of simple hands-on experimental activities and developed thought the use of the real time sensor to reach the interpretation of the electromagnetic induction. The core activities of the investigation of the magnetic field flux is described looking to the experimental explorations and discussions done with students concerning core concepts as the constancy of magnetic field flux along a flux tubes, the measure of the field along field lines and in each flux tubes individuating the relation between the magnetic field and the distance between the lines, the identification of the vector nature of the magnetic field distinguishing this entity from a the forces. In particular the visualization by means of a flux tubes representation of the magnetic field which is built from the field line representation in a framework in which the role of experiment founded the formal role of the entity and the formal representation and the critical analysis of them provide new more refined interpretative tools that could be applied in different, more general, contexts.
The experimental apparatus and its characteristics will be addressed and the analysis of the learning outcomes and reasoning that this learning activity promotes in students mind will be presented and discussed. Data presented from students referred to four different activities held with different groups of high school students: 1) 5th class of experimental scientific lyceum, 2) 5th class of scientific lyceum; 3) 5th class of a classic lyceum; 4) a selection of the Italian best student coming from all of the 4th and 5th classes of all the Italian high schools. From it, looking in particular to the role of the development of the angle of attach proposed, it represent a crucial step in which pupils recognize the presence of a constant of the system that is related to a multivariable abstract entity as the flux. In this way the role of the rigor and the inner coherence adopted in the learning path allow students to address the exploration of the phenomenology and its analysis in a systematic way constructing the formal representation of the physical entity involved.

Introduction

During the history of physics, the representations of formal entities are always interlaced with a clarifying role and, in the matching of several different interpretations, are related to the building of conceptual referents of synthesis that allows, as for instance in the case of the field lines of the magnetic field, the recognition of constant of the system as the constancy of flux. In particular, in the case of the magnetic field lines, they are able to give a phenomenological synthesis, detect and give new meaning to quantity able to formalized induction processes.

In the framework of Model of Educational Reconstruction – MER – (Duit et all, 2005) connection between different scientific topics and everyday knowledge is one of the main problem of learning (Pfundt & Duit, 1993). Students, in their everyday life, observe the world, and construct spontaneously their own mental models to interpreter the reality (Gilbert, 1998). These models are related to mental reasoning and they are built through a reworking of conceptual elements and reasoning on problematic situation that student encounter in their everyday life (Viennot, 2006). Students' mental models are narrow but coherent explanatory framework that has the form of a theory (Ioannides & Vosniadou, 2001) thus, although they differ from a scientific type of knowledge, they are structured with their own coherence (Carey, 1985). But, as highlighted in literature (Eshach & Schwartz, 2006), students have more coherence need at local level rather than on the global one; so it is necessary to design educational interventions aimed to promote a changing in the students' view allowing them bridging from a common sense to a scientific interpretation of the phenomena overcoming spontaneous model (Pfundt & Duit, 1993; Viennot 1996) through predictive conceptual models (Gilbert 1998; Hestenes 1987; Gentner 1983). The presence in student knowledge of persistent conceptions (Driver & Erickson, 1983; Duit, 1991; McDermott & Redish, 1999) may constitute difficult barriers to overcame (Clement & Brown, 2008). It is therefore necessary design informal hands-on and minds-on workshop activities to involve students in the process of building knowledge (McDermott, 2004) and promote a cognitive crisis and a re-structuring of students' concepts by means of dynamic mental models inextricably linked to the context and promoting so the conceptual change (Vosniadou, 2008; Michelini, 2005).
As topic, the study of the electromagnetic phenomena offer an ideal theoretical environment in which students could address the investigation of the physical reality by means of the use of multivariable abstract elements of synthesis. The role played by the flux of the magnetic field in that description is pivotal but at the same time its interpretation represents an important learning knot that students had to face.
Obviously this is not the only main conceptual knot as concern magnetism and electromagnetism. Research literature in physics education highlight the presence of several typical conceptual knots in the students' knowledge related to the concept of field: both in static and dynamic situation. In static field, students' difficulties are related to: the concepts of field as a superposition (Rainson & Viennot, 1992), the field representation (Guisasola et all, 1999) and the relation of the field lines with trajectory followed by bodies placed inside the magnetic field (Tornkwist et all, 1993). In dynamic field case, looking particular to electromagnetic induction, other important conceptual knots have been highlighted: relation between magnetic field and electric currents, the nature of the field itself – i.e. is it a state of space or a material entity? – (Thong & Gunstone, 2008), the sources of field and the role of relative motion (Maloney et all, 2001). In addition, related to the interpretation of Lorentz law, there are two main conceptual knots: students do not distinguish electrical and magnetic effect end they or do not recognize Lorentz force or they do not recognize that there are

moving charges inside the conductor (Maloney et all, 2001). Indeed, for what concern the application of Lentz law, students have difficulties in the determination of the versus of the induced magnetic field (Bagno Eylon, 1997).
To address all those learning knots, in the framework of a Design Based Research, an enquired based learning path concerning electromagnetism was developed in accordance with the MER grounding it on the cultural dimension of physics (considered both on the methodological and the contents planes) and aimed to construct a conceptual knowledge in terms of students' competencies that can be (re)used in several different contexts. As core elements of this learning path, the construction of the representative formal entity of the magnetic field is posing in strictly relation with its punctual and not punctual representation (i.e. vector and pattern of field lines).

Rational of the proposed learning path

The cultural aspects of the proposed learning path lies on three main levels: 1) the cultural background that found its roots in the literature of physics education of the MRE; 2) the historical interpretative problems related to the topic, that have the role of the detection of the possible learning problems with two additional gain: the reinforcement of the mastery of the concepts with their physical meaning and the pre-identification of the alternative interpretative models for the argumentation in phenomena explanation; 3) the conceptual knots highlighted in literature.
As methodological choice in the foundation of the teaching proposal we adopted the actual way of thinking of phenomena avoiding reductionism and an historical development of the learning path, without following the historical development of the theories that often proposed alternative models that may reinforce the commonsense ideas in contradiction with those adopted by the today physics. So no obsolete interpretations of the phenomena were addressed in the learning path even if they do not emerge spontaneously from the class/student discussion and argumentation. The learning path is so built on nuclei concepts related to crucial aspects in the interpretation of phenomenology in a framework of experimental investigation in which the assumed approach is aimed to integrate the exploration and the analysis of the phenomenology.
The students' personal role so become pivotal and the learning path itself is not thought as a fixed learning trajectory, but a path that had to grow with the gradual evolution of the conceptual formal models developed by means of students' reasoning following the ideas of the group/class.
On the methodological plane, the integration of the experimental and the interpretative aspects is crucial. So, the learning path is aimed to promote students' investigation of the 'which' and the 'how' the explanation of the phenomenology and the experimental activity are related and comparable addressing the power and the limit of each interpretation provided by the students considered in a critical analysis of alternative explanations.
In the learning path, the development of the mathematical formalization of the magnetic field and its representation is pivotal. The core part of the learning path is aimed to construct the formal representation of it both as a formal mathematical entity (vector) and as graphical representation (path of field lines).
From the analysis of the interactions of a magnet approaching objects made of different materials, students individuate the types of interactions and the idea of a magnetic property

into the space around a magnet. Then the compass is individuated as a magnet itself and an explorer of the magnetic properties of the space.

The used of the compass as an explorer of the magnetic properties allows students providing the first spontaneous representation of the magnetic field that usual is in terms of graphical representation of the needle or arrows of fixed length that, in the view of the mathematical formalization, are versor.

Field lines representation is so introduced by the teacher as an alternative way of representation of this propierty of the space and is asked to student to compare the two type of representation (field lines and versor) and say if they are equivalent in the sense that they had to check if both are able to describe the explored properties of this spatial entity.

Once students recognized the correspondence between these two representations, the focus of the investigation moves on analysis of the properties of the field lines representation in which students recognize for instance the presence of not intersecting point between the lines and the no-constancies of the distance between the lines. Then, from the comparison of different pattern obtained by different students, the analysis of the deformation of the different pattern will suggest the presence of an influence of the magnetic field of the Earth among with the magnetic properties of the magnet. This, if from one side denote the identity between the two types of magnetic properties, from the other it highlight the limitation of the formal representation of the magnetic field as a versor. So students had to implement their earlier versor representation moving to a vector representation [####Figura###]

Developed a vector representation for the magnetic propriety in one point, now the issue is to check if the field lines representation is still enough to represents those vector property of the space. So now the problem is to look if the field lines representation we used able also to represent the intensity of the magnetic property in each point. First of all, students, using a real time field sensor, explore the intensity of the magnetic field along the lines discovering that it is not constant along a line and so the representation of the intensity of the field in a field line representation is not direct and it could be problematic.

Looking at the increasing of the density of lines near the poles of the magnet, students spontaneously proposed to relate the density of the line with the intensity of the magnetic field. Doing measurement and realized that the field lines represents only a 2-dimensional section of a 3-dimensional property, students explore the relationship between the intensity of the magnetic field and the surface described by the lines (or the square of the distance between the line) highlighting so the presence of a constant that relate this two quantity. This constant, that mathematically is the flux of the magnetic field vector along one flux tubes, is constant in each tube, but the value of the constant differs from tubes to tubes. To perform a really effective representation in terms of field lines the students had so to perform a renormalization of the field line pattern selecting from all the possible field line the one who describe tubes with the same flux. In this way, the representation done by means renormalized field lines, that we labeled as 'flux tubes representation', allow to represents in a univocal way the value of the intensity of the magnetic field in each point of the pattern.

Experimentation of the learning path; data and data analysis

The proposed learning path was tested in several different context, in particular the data presented referred to four different activities held with different groups of high school students: 1) 5th class of experimental scientific lyceum, 2) 5th class of scientific lyceum; 3) 5th

class of a classic lyceum; 4) a selection of the best Italian students coming from all of the 4th and 5th classes of all the Italian high schools.
Data presented will refer only on the main core steps of the construction of the formal entity and their representation. Data were collected during the activity using IBL based personal worksheet in which each student had to write his/her prevision and argumentations replying to open questions and/or task. Students' answers were analyzed and collected in categories in accordance with a phenomenographic analysis of the data.
Here will be described in detail the situation proposed and the distribution of the students' answers. The first situation we addressed here will be the consideration that the students did as concern the comparison between the different draws that they did of the field lines around a magnet. For this task, a magnet, a sheet of paper and a compass was provided to each students that, pasted the sheet on the table an fixing the magnet in its center had to draw the field lines around the magnet. No further instructions were given as concern the direction and the displacement of the magnet on the sheet. After that everybody drew his own pattern, were asked to students to compare their draws with the ones of the other schoolmates: 71% highlight no relevant differences, while the remaining 29% highlight some differences and, in particular, 2/3 of those 29%, propose as justification of this change an influence due to the magnetic field of the Earth; the remaining third instead gave a description of the changing in shape.
This not-vision of the differences into the patterns comparison could be related to two factor: the effective similarities of the draws done by the students due to the common tendencies to put all of the magnet in square with respect the side of the table that implies that the deformation effect due to the magnetic field of the Earth is similar among several of the pattern drawn and an effective difficulty in the understand the modification of the perimeter area of the drawing as an important factor instead of be localized in one point.
In fact, in the next activity proposed, in which students had to work on the property of one point and not on the whole sheet, the effect due to the superposition of different field is strongly detected.
The situation proposed is the one reported in Figure 1.

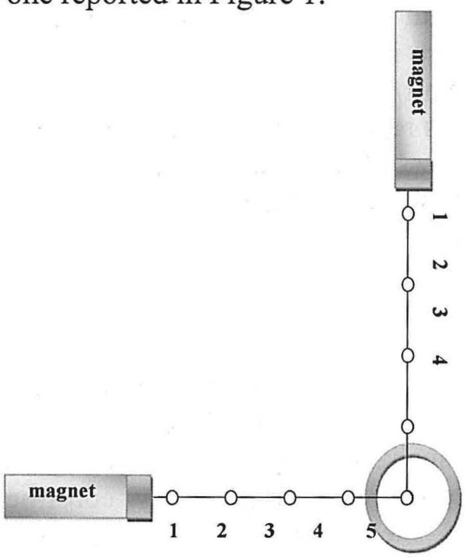

Figure 1. Superposition of field in one point

One compass (the blue circle) and two magnets are placed as in the figure above. Students were asked to observe the direction assumed by the needle of the compass justifying, in their opinion, why it assume that position.

All the answering students said that the compass needle had an inclination of 45° with respect the two lines and 61% of them justifying it referring to the sum of the reoresentative arrow of the magnetic property, while 25% justify this placement as due to the equal attraction provided by the two magnets.
But, during the next step of the activity, we asked them to approac one of the magnet to the compass moving it in the different positions 1,2,3,4... looking at the disposition of the compass needle and justifying its variation in direction. Almost all of the replying students (75%) interpret it as due to a variation of the intensity of the field (32%) or of the force (43%) of the approaching magnet and 29% of them also explicit the need of a change in the formal entity adopted to represent the magnetic property of the space we are exploring assuring that we need a vector instead of a versor-like representation.
Then, in the next question, when we asked them to say which type of formal entity you had to use to describe the magnetic properties of the space, 88% propose a vector because this property has direction and intensity.
At this point of the learning path, we arise the problem of the distinction between field and force. A magnet and a ferromagnetic balls are placed as in figure and we ask them to do a prevision as concern the starting direction of motion of the ball and in particular if this is coincident with the direction of the field lines in that point (i.e. if the field lines are also force lines). Almost one third of the students reply that the physical quantity under investigation is a force and in particular is interesting to noticed how they reach this conclusion starting from its formal representation (i.e. vector means force). Half of the students, instead, highlight (correctly) that field and force are different entity.
As concern instead the need of improving of the field lines, all of the students highlight the problem of the representation of the intensity of the magnetic property in a field lines representation and propose to relate: the intensity of the magnetic field and the distance between the lines (54%); the intensity of the magnetic field with the surface described by the lines (25%), the intensity of the magnetic field and the square of the distance from the nearest pole (11%) or assure that the flux is constant along the considered pipe (11%).
After the measure of the intensity of the magnetic field using a magnetic field sensor along a stripe and look at how to relate it with the characteristics of the pattern, 85% of the student define a correct way in which acquire information concerning the intensity of the magnetic field inside a flux tubes that, then, will be the ground on which to do the renormalization of the field lines, moving to a flux tubes representation. This provide a huge contribute both on the quantitative plane and to the process of formalization involved in the reinforcement of the concepts, while the vice versa, an approach based only on the formal entities, makes it difficult the conceptual interpretation.

Conclusions

The development of those type of learning path, allow defining key disciplinary aspects that had to be addressed and that characterize the field as: the divergence equal to 0, the constancy of flux, the recognition and the visualization by means of a representation which can be enriched with elements whose formal role is gradually constructed starting from the conceptualization of the field lines, the measure of the field along each flux tubes, the recognition of the constancy of the flux along a tube, the identification of vector nature of the magnetic field distinguishing it from the force, the (re)introduction of it in a cultural framework in which the magnetic field with its peculiar characteristics differs from the electric and gravitational fields.

With this work on the construction of formal entities, the field lines and the flux tubes representation became so a real interpretative/predictive for the students.
The phenomenological approach is reinforced at various points among the learning path, but it is always done interlacing the exploratory and experimental approach with the interpretative aspects arising role and meaning the physical quantity involved; in this way it represent one of the main methodological ground aspect in the foundation of the physics culture.
This continuous mutual enrichment between the experimental and the interpretative planes allows students going deeper on formal aspects understanding and analyzing the characteristics and the restriction of the theories and the models they proposed along the learning path.
With this aim we address directly the phenomenology using directly a field model (avoiding reductionist approaches) facing by means of experimental activities in which the measures acquire meaning and role addressing specific opened interpretative issues.
The validity of this approach is reinforced by the data that shown how the gradual construction of the property of the magnetic field by means experimental exploration relate to the problem of its graphical and formal representation highlights the presence of crucial situation/observation that constitute milestones in the development of the characterization of this entity: Early representation of the magnetic properties by means students' spontaneous representations (i.e. drawing of the needle, fixed length arrows, versor); Field lines representation and its relation to the students spontaneous representation; The superposition of field (move from versor to vector representation); Relation between field lines representation and magnetic field nature (i.e. is the field lines representation enough to represents the magnetic field?); 3-dimensional structure of the magnetic field; Improvement of the field lines representation moving to a flux tubes representation; The idea of tube of flux and its constant value for magnetic field.
But, overall, the development of the angle of attach used, (i.e. addressing to how to look for a way to represent the intensity of the magnetic field starting from the field lines interpretation) represent a crucial approach in which pupils recognize the presence of a constant of the system that is related to a multivariable abstract entity (the flux) that so assume the role of key elements for the explanation of the electromagnetic induction.
In this way the role of the rigor and the inner coherence adopted in the learning process allow students to address the exploration of the phenomenology and its analysis in a systematic way constructing the formal representation of the physical entity involved.

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