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Electromagnetic Induction: a vertical path for conceptual learning

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I. THEORETICAL FRAMEWORK OF THE RESEARCH: CONTENT RELATED PHISICS EDUCATION RESEARCH

Scientific Educational Research is a field of research that was developed only in the last few decades, but its development was really fast and the set of the different approaches adopted is really wide. To describe the theoretical framework of this work and the corresponding assumptions done in this research, a briefly critical introduction on the main research approaches adopted in the previous years as concern scientific educational research is needed. This briefly description of the situations and the aspects that influence the development of the scientific educational research during its first steps during the second half of the Twentieth Century, does not aim to be exhaustive but aims to give an overview of which are the main aspects that had to be take into account in the developing of an educational research program.

I.1 Psychological, sociological and pedagogical aspects that lie on the ground of the assumption into the early educational research

The choice of a particular approach in scientific education found its roots in the researchers' ideas concerning the structure of knowledge in human minds. Looking for instance at John Dewey's pragmatic view of knowledge, individuals built up knowledge of the world as a result of experiences of acting in the world, and so the individual's knowledge was the product of experiencing the outcomes of previous actions, and acted as the basis for making decisions to guide future actions. This view implies that, as the world (the environment in which the learner acts) changes continuously, the knowledge could not be definitive; from an approach such this one, knowledge is not seen as a true representation of an external world, but as a set of tools for guiding actions. This

approach implies an idea of knowledge that lies on the assumption that different individuals develop different knowledge depending upon their past experience and that does not take into account the possibility that different (eventually incompatible) accounts of the world could be seen as equally valid descriptions of the universe (Taber, 2009). For this reason the Dewey's theory is often defined as 'qualified relativism'.
On the other hand, for instance, other thinkers, as Ernst von Glasersfeld uses a completely different approach called 'radical constructivism' that Glasersfeld (1988) define as 'a theory of active knowing, not a conventional epistemology that treats knowledge as an embodiment of Truth that reflects the world "in itself", independent of the knower'. So, in an approach like this one, knowledge is not passively received, but it is actively built up by the cognizing subject and the function of cognition is adaptive and serves the subject's organization of the experiential world, not to discover an objective ontological reality (Taber, 2009).

In addition to the idea of knowledge, an important role in the developing of the scientific education research is related to the psychological studies of learning. For instance Jean Piaget's Genetic Epistemology theory was one of the most influencing theories. In particular, in his work, Piaget argues that for all people cognitive development go through the same major stages in an invariant sequence and this ordering was fixed because each stage of development gave rise to structures that enabled more sophisticated actions providing the basis upon which the next stage could develop. Even if during the years Piaget's work was wildly analyzed and criticized (Donaldson, 1978; Pope & Gilbert, 1983; Sugarman, 1987; Sutherland, 1992), it is undoubted that it has a great influence and his work is still been the root of the 'cognitive acceleration' movement in science education (Taber, 2009).

In particular, also on the bases of the Vygotsky work, the Piaget's theory was criticized for its individual knower approach. In Vygotsky's (1978) theory he argues that from the two years old, the child's mind development is closely influenced by the

interactions with other minds (Crain, 1992) and so he considered any independent learning context, 'without the assistance of others, without demonstrations, and without leading questions' (Vygotsky, 1978), to be a contrived situation. In Vygotsky theory, analysis of the environment must also take into account people that interact with the learner (being those teachers or peers) and the influences that they may have on him and his mind development. And in particular, Vygotsky's research work, was focused on the study of how learning can be supported and facilitated by an adult or a more knowledgeable peer through the cultural tools (as for instance the language) that allow shared understandings to be negotiated (Taber, 2009). On the bases of these core considerations Vygotsky and his colleagues' founded with their works the 'socio-cultural' or 'socio-historical' view on conceptual development leading to the development of 'Activity theory' which has become widely influential in Education (Engeström, et al. 1999).
As George Kelly highlights, even if Piaget focused on the individual 'epistemic subject' and Vygosky on the individual's construction of the world towards common understandings, both assume that each individual has his own unique way to approach to the world (Taber, 2009). In this way Kelly (1963) developed his Personal Construct Theory arguing that in theoretical terms all constructs are personal. Even constructs drawn from say science or technology which have highly publicly specified relationships and implications and which have had their predictive validity tested and retested are still personal. They are personal in the sense that each person has to acquire them and integrate them into his total system of knowledge (Fransella & Bannister, 1977).

Research in Scientific education was also greatly influenced by the development done in the study of the Cognitive Science. This field of research was founded in the second half of the Nineteenth (Gardner, 1977). In particular the four main psychological traditions are: introspection and behaviorism, gestalt theory, learning through metaphor, information processing models (Taber, 2009).

Behaviorism in psychology attempt to employ only explanatory constructs that could be tightly defined and observed/measured in the analysis excluding such unobservable features as mental states. This idea, seen by some as necessary to establish a 'scientific' psychology (Watson, 1967), lead to do not admit explanatory constructs that could not be observed and measured (Glasersfeld, 1983), but explored how stimuli were linked to responses. Studies of this type were held with animals, but if from one and this approach produced detailed information about the types of reinforcement patterns that were useful to train behavior, from the other they were considered to have less immediate value to understanding conceptual learning in human learners (Aikenhead, 2006).

Gestalt Theorists is an alternative tradition founded on the ides that what is perceived from the world is interpreted at some pre-conscious level before we are aware of what we are experiencing (Koffka, 1967). Sensory information is highly processed before it is presented to consciousness. The term 'gestalt-switch' has entered into the language to describe how one can suddenly 'see' or understand the world in a different way. For instance there are well-known illustrations of how the brain can suddenly reorganize perception of the visual field (Gregory, 1966). The change is sudden at the level of conscious thought, but this may be understood as the output of 'processing' (thinking) that is not open to conscious examination; raw stimuli have to be perceived through active processes of organization, so that the same stimulus can give rise to very different perceptions in different individuals. In the educational environment, it means the teacher has no direct access to the learner's perceptions; student learns what the teacher intends will in part be contingent on the extent to which the student's organization of stimuli matches what the teacher hoped to communicate (Taber & García Franco, 2009).

As Vygotsky highlighted, the role of the dialogues is pivotal. Starting from the analysis of dyalaogues, Lakoff and Johnson (1980) argued that the human conceptual system largely functions through metaphor, containing metaphorical and non-metaphorical concepts – where non-metaphorical concepts are the ones that emerge directly from the experience and are defined in their own terms, and metaphorical concepts that are those which are understood and structured not merely on their own terms, but rather in terms of a different kind of object or experience (Lakoff and Johnson 1980).

Contemporary to these tendencies, the development of the computer science led to the comparison between the mind and the computer functioning (Young, 1978); this approach, not new in the human history (several example of descriptions of the human mind in terms of mechanical component may be found in the ancient literature), influenced the development of cognitive science moving from a mechanical representation of the "intelligence" to a computational view of the intelligence that was called 'artificial intelligence' (Taber, 2009). This approach, integrated with the development of the research in neuroscience propose a modeling of the cognition in terms of systems that processed information, and had identifiable components, but anyway, it argue that is not necessary to be able to identify the precise neural processes at work because they assume that cognition could be modeled at three distinct levels that could be studied independently (Dawson, 1998). It means that to analyze the cognition as a system is necessary to identifying the key functional stages that are involved (i.e. perception and the type of memory used – long or short term memory). Even if the models produced by this approach are useful in some situation, is hard to divide exactly which are functions of the brain and which are of the senses. Processing of data is done also at level of sense and the separation of the two processes is not clear and also the discussion concerning which are the modules of the brain that can work separately when one person is facing a particular situation is an open field. Being the information processing modeling is a new field of research, such debates are far from settled, but they are important for the foundation of the pedagogical theories because the models of learning should be consistent with what is understood about cognition and how minds may be ‘structured’ to enable learning processes (Taber, 2009). For instance in a representation of this type the Piaget’s development stage theory is described as an ‘horizontal’ structuring to the architecture of mind, where basic skills are assumed to be applicable to a wide range of domains (Fodor, 1983), but, as several situation shown that in some situation the application of the principle of horizontal décalage fails and it suggested that the learner’s Piagetian level represented the type of thinking possible in a familiar domain, but that may not be expressed in a context that was fairly new for the learner, so the Piaget’s model had to be improved. From the opposite side, another representation of the mind was highlighted by Fodor (1983): he argued that the mind is structured in specialized areas that deal with particular domains (vertical structure of the mind). Now both of these representations are not arguable separately, but the recent results show that human mind have vertical and horizontal structure and there is a still open considerable debate about the extent to which there might be modularization in terms of dealing with different domains of experience or knowledge (Fodor, 1983, Hirschfeld & Gelman, 1994).

Starting from these approaches, an important work was the one developed by Annette Karmiloff-Smith (1994; 1996) concerning the representational redescription during the cognitive development. She saw that cognitive development involves two parallel processes: modularization and the representational redescription. The process of modularization was took from the one coming from the modular encapsulation of Fedor (1983) but involves in the process of information either at different stages in processing (at different ‘horizontal’ levels), or relating to different areas of experience (in different ‘vertical’ slices, as in the distinction between life world and scientific knowledge). The representational redescription instead involves a process whereby the information represented in the cognitive system becomes increasingly more explicit and available to that system (Taber, 2009).

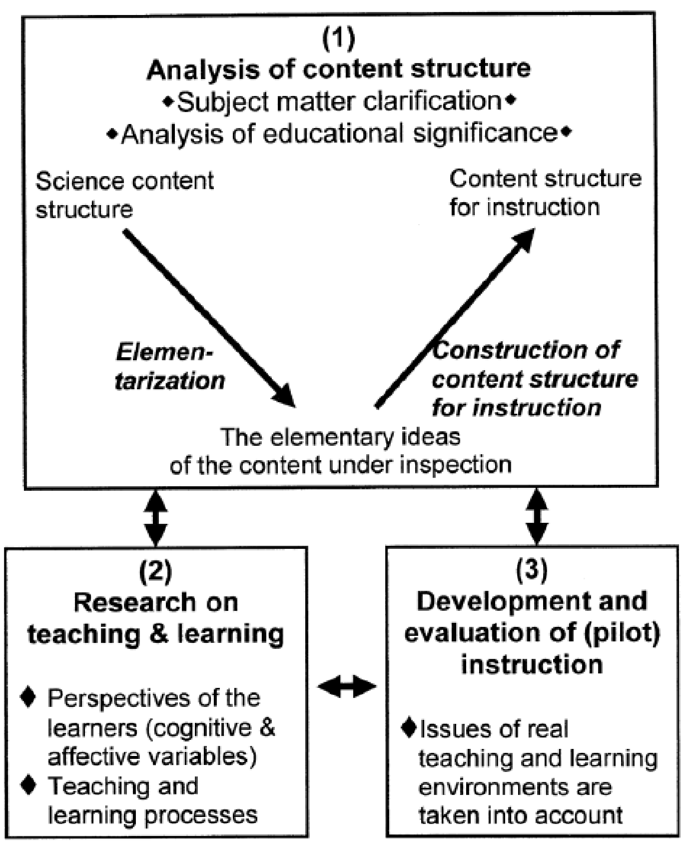
This approach still opened the problem of the mental models and the representation of knowledge, in particular the notion of mental models is used to describe the way people form mental representations that can be used to make sense of their experiences (Norman, 1983) and Williams et al. (1983) highlight the ideas that seem fundamental to the conception of mental models are that they are composed of autonomous objects with an associated topology, that they are 'runnable' by means of local qualitative inferences, and that they can be decomposed and mental models can be understood as comprising identifiable components organized into a scheme, and allowing certain 'outputs' to be predicted by simulating scenarios with particular 'inputs'. Last but not list, there is development of the idea and the roles of metacognition. Metacognition, can be paraphrased as 'thinking about thinking' (Taber, 2009) and has a pivotal roles in the analysis of complex and/or ill structured situations and the individual needs to plan a strategy for solving the proposed problems (Phang, 2006).

At the same time these consideration coming from psychological studies are inextricably interlaced with some important traditions that have focused more directly on informing teaching (Taber, 2009). For instance Robert Cagné (1970) explore the forms and conditions that supported human learning and recognize that, whilst somewhat influenced by the stimulus, a full understanding of human learning had to consider both external and internal context, i.e. 'one must look, first, at the capabilities internal to the learner, and second, at the stimulus situation outside the learner'. These consideration concerning the internal representations that learners have are inferred and non-observables aspects and, even if this approach were refused by behaviorists, it become a key focus of research into learning science (Taber, 2009). Gagné (1970) described the internal conditions for learning in terms of learning hierarchies which 'represents what is expected to be a general pattern to be followed for all the students in the group' and he argued that 'identifying these capabilities and assuring their availability are matters of critical importance for instruction'.

In the main time, also Ausubel introduced the notion that learning needed to be meaningful, and this depended on the learner's cognitive structure, and the nature of the material to be learned (Ausubel, 1961: 18; Ausubel & Robinson, 1971: 50–51). And him with Robinson (1971) suggest three conditions for meaningful learning to occur: 1) the material itself must be relatable to some hypothetical cognitive structure in a non-arbitrary and substantive fashion; 2) the learner must possess relevant ideas to which to relate the material 3) The learner must possess the intent to relate these ideas to cognitive structure in a non-arbitrary and substantive fashion. The notion of cognitive structure is important, conceptual knowledge is represented in minds, it is not an arbitrary arrangement, but rather the representation is structured (Vygotsky, 1934) and this structure reflects how the individual understands the concepts to be related.

I.2 The framework of research strategy: MRE

As highlighted in the previous paragraph, being the educational research a multidisciplinary subject, several aspects had influenced the first studies in the education research. The need to take into account all this aspect without focusing only on some of them (as for instance the pedagogical ones or the one related to the subjects threated), Duit et al. (2005) developed the Model of Educational Reconstruction (MRE). This model represent the way that the authors propose to be followed by the researcher in the developing of their works overcoming the problems related to the too much focused previous approaches that were (usually) focused only on the content or on the pedagogical aspects. The key ideas of the MRE are: 1) the science content is not given but has to be (re)constructed by taking the aims of instruction and students perspectives into account and 2) the Science Content Structure and Science Content Structure for Instruction have to be clearly differentiated. This model, that founds its roots in the



constructivist approach (Duit e Treagust, 1998, 2003), is characterized by three main phases that are represented in the figure below: 1) the analysis of the content structure, 2) the research on teaching and learning, 3) development and evaluation of (pilot) instructions.

The main goals of the first phase are the clarification of the subject matter and the analysis of its educational significance. In this phase the researcher had to study the contents starting from high level textbooks (maybe university level) and/or publications for experts concerning the selected topic and, starting from the study of the science content structure, do a process of elementarization that allow to extract the elementary ideas that are at the ground of the selected topic. Then, after a deep analysis of these elementary ideas and their educational relevance, the researcher reconstructs the disciplinary content in a new structure that is more educative oriented and centered on the level of the students that he wants to involve in his research.

The second phase, that represents the part of empirical research, is characterized by the investigation of the perspective of the learners (both as concern cognitive and affective variables) and the teaching and learning processes. An analysis of relevant research literature in physics education is needed or, if it is not available or if it is not sufficient, it is recommended to do a pilot study to have almost an overview of which will be the learning knots and the educational problems that had to be addressed.

At last, during the third phase, on the basis of the previous phases there is the development, the experimentation and the evaluation of the educational materials and activities proposed. Guidelines and preliminary version of the materials are implemented in a real context, then, basing on the data collected, the evaluation of the experimental activity will include the evaluation of the analysis of materials end the educational relevance of the proposal. Then, on the bases of the analysis of the obtained results, the proposed material will be optimized and (eventually) reformulated.

The last step indeed is the modification of the content structure and systematization of the results and implications from the previous step of empirical research. This means that the approach propose by the MRE had to be figured as a recursive process that cycle after cycle tends, trough successive refinements, to improve the quality of the proposal.

I.3 Physics Education Research

As highlighted, education is an interdisciplinary field of research, and in particular, as concern the research in science education, the goal of the research is to better understand the cognitive and social progress that results in the most effective learning and use this knowledge to redesign classroom and other learning environments allowing people to learn more deeply and more effectively (Sawyer, 2006).

In the development of science education Sawyer (2006) highlights the presence of five main early influences: constructivism, cognitive science, educational technology, socio-cultural studies and studies of disciplinary knowledge.
Constructivism lies on the idea that knowledge could not be simply transmitted, but the learner has to construct them in its mind. As argued by Piaget, children's a mind contains different knowledge structures than the ones that there are in adult's mind. It means that researchers had to do a deep study of the children's cognitive development and the role of the naïve knowledge of the learners has a key role. In this prospective, cognitive scientists began to analyze the cognitive characteristics of the children and adults naïve interpretation of the different subjects, and in particular began to design an effective educational environment on the bases of the learner's naïve knowledge.
Cognitive science began to have a key role in science education during the nineties, in particular it contributed when concepts as representation, expertise, reflection and problem solving became central in the study of the learning science.
Educational technology instead was introduced with the development of software designed for educational purpose since the seventies and, in particular, in the following decades the use of the computers was widely promote in classroom even if this use of this technological materials did not was followed by an increasing of the students' performances since the years 2000 (Cuban, 2001). As several researches shown this was due to the general instructionist approach of the wide majority of the software (Sawyer,

2006). For this reason in the last decade, a series of research based software were developed and this allows using the computers and the simulations as cognitive facilitators that help students in their processes of construction of knowledge. Sociocultural studies are constructed on the assumption that all intelligent behaviors were realized in complex environment characterized by the presence of several objects and phenomena, but also several persons (Greeno, 2006; Salomon, 1993) and therefore the process of learning is hard could not be understood as a mental process occurring in the mind of an isolated learner. Some of the main studies in this field are related to the investigation of the learning in informal contexts (Cole, 1996; Saxe, 1991) and became the root for the study of the peer cooperation, collaborative discourse and the project teams (Sawyer, 2006).

In addition, in the last decades the necessities of address specific learning problems require to take into account the nature of the topic in which the learning knots is located. The analysis of the context and the learning environment is not enough. Some learning knots had to be studied as particular cases that are strictly content related. For instance, the use of the analogies is completely different in biology than in quantum mechanics. From this consideration, several strand of research were developed each one centered on the study of the education problems related to a specific topic and in particular, as concern physics education, several work on optics (Hirn & Viennot, 2000), thermal phenomena (Benciolini et al, 2000), quantum mechanics (Ghirardi, et al, 1995), electricity (Michelini & Mossenta, 2007) were developed.

I.4 CLR – Content Learning Research

As highlighted by the MRE approach (Duit 2005), pedagogical and content aspects had to be take into account in equal part to obtain an effectively reconstruction of the knowledge and make so it accessible to different school level students. In particular, as concern the need to face specific learning problems, typical of the considered subject (or in more detail, from the topic) considered. A strand of research was developed in the way of investigation physic education in content related framework. Using this approach, focused and narrow formative intervention may be design to address very particular learning problems, conceptual knots, which characterized specific aspect of the knowledge.

In the past two decades, research in physics education has emerged as a field of scholarly inquiry in which physicists are actively engaged. Systematic investigations contribute to a steadily growing of research base (McDermott & Redish, 1999).

Physics Education Research start so to study and analyze how the same students' approach could be successful (or not) depending by the context in which it was applied. For instance if the use of analogies in some framework of classical physic they may be misleading when students face quantum mechanics problems.

The primary goal of physics education research is to develop pedagogical techniques and strategies that will help students learn physics in a more effectively way. The first steps to developed the Content Learning Research, being them working on a specific topic, is the individuation of the main learning problems, called, learning knots, that characterize the specific topic. The increasing number of study done on several topic, increase the spectrum of the learning knot known in literature. This set of learning knot represents the starting point needed for the design of effective teaching strategies. Learning knots may be related to naïve idea of student of particular alternative conception raised by the following a particular learning path. The main goal of the

Content Learning Research is the individuation, the implementation and the development learning activity that are designed on the specific needs due to the specific topic addressed and the study of the best strategies that could be used to address particular learning problems.

I.5 Design based Research

The Design Based Research (DBR) is a type of research methodology used by educational researchers to conceptualized, design and experiment teaching interventions in environment which are designed and systematically changes by the researchers (Barab, 2006). Coob et al. (2003) describe the DBR as: *Prototypically, design experiments entail both "engineering" particular forms of learning and systematically studying those forms of learning within the context defined by means of supporting them. This designed context is subject to test and revision, and the successive iteration that result play a role similar to that of systematic variation of experiment.*

This methodology of research is extremely useful in the development of the educational theory because this it allows the researcher to overcome the problem of the analysis of the environment as it is, moving to the broader goal of the examination of how the systematic changes that he introduces influence the learning and the practice (Barab & Squire, 2004). In this type of research the role of the context is pivotal; it is an important part of the complex causal mechanism that gives rise to the phenomenon under study (Maxwell, 2004).

The foundation of the DBR research methodologies is frequently referred to Brown (1992) and Collins (1992).

In complex systems, as the learning environments, the test of the effect produced by the change of a single variables is extremely difficult, the iterative character of the DBR approach helps to demystify this problem Barab, 2006). In particular the process evolves collecting evidence of data done over time of this reclusively activity and "feeding" the further design with them (Brown, 1992; Collins, 1992). In this way may be explored the conditions under which a particular interaction or occurrence could happened (Shavelson & Towne, 2002) and understand the underlying reasons why something is happening (Confrey, 2006). In addition, another factor related to the importance of the DBR methodology, is the not validity in education of the "factoring assumption" of experimental psychology (Greeno, 2006). Following this assumption, would be possible to analyze individual cognitive process apart from a particular context; DBR, instead, consider the individual and the learning environment inseparable. This argumentation, called "core assumption" (Barab, 2006) highlight that the meaning of any content is mutually determined through local contextual particulars (Kirshner & Whitson, 1997; Brown et al. 1989) and, as argued by Salomon (1993), cognition, rather than being a disembodied process occurring in the confines of the mind is a distributed process spread out across the knower, the environment and even the meaning of the activity.

In addition one of the main problems that had to be overcome in the DBR is the necessity to export the result obtained by the researcher in a particular controlled environment to another environments that differs from the previous one or that is not so well controlled as a research environment. So, a last important thinks is that the DBR activity had to describe both the theory and the particulars in a way that allows others to understand how to re-contextualize the theory-in-context with respect to their local particular environment (Barab, 2006).

According to Collins et al. (2004), Design-based Research intends to address several needs and issues central to the study of learning, including the need to address theoretical questions about the nature of learning in context, to the study learning phenomena in real world situations rather than in the laboratory, go beyond narrow measures of learning and derive research findings from formative evaluation.

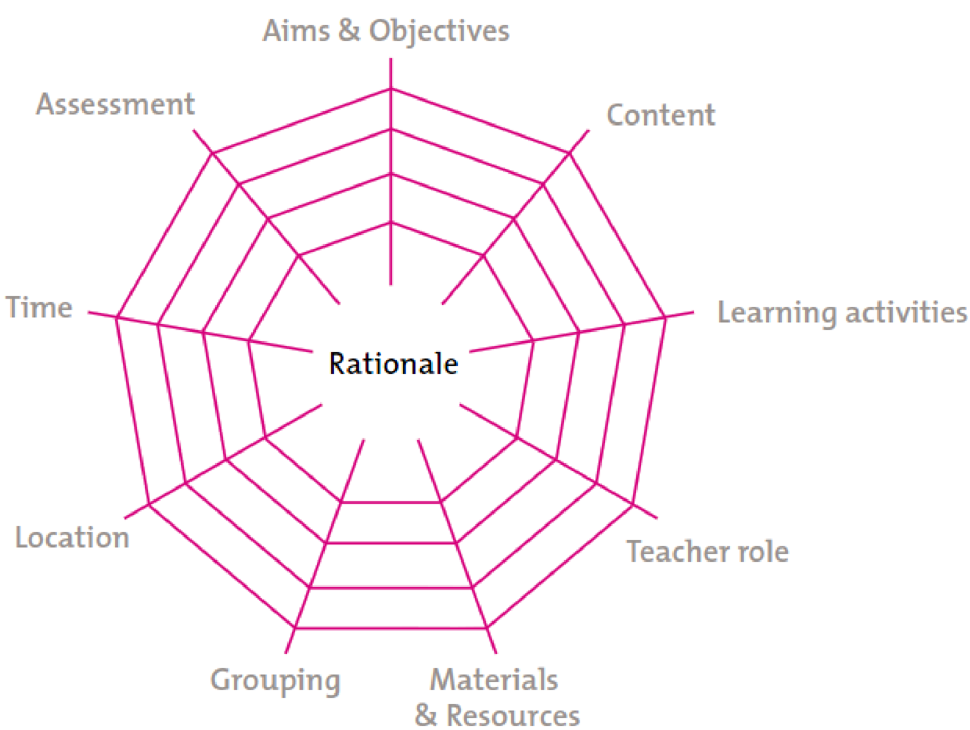
To reach these aims are some important characteristics that design-based research experiments must have as the addressing complex problems in real, authentic contexts in collaboration with practitioners, applying integrating known and hypothetical design principles to render plausible solutions, conducting rigorous and reflective inquiry to test and refine innovative learning environments, intertwined goals of, designing learning environments and, developing theories of learning, research and development through continuous cycles of design, enactment, analysis, and redesign; research on designs that must lead to sharable theories that help communicate relevant implications to practitioners and other educational designers; research must account for how designs function in authentic settings; development of such accounts relies on methods that can document and connect processes of enactment to outcomes of interest (Sandoval & Bell, 2004).

I.6 Curricular Research

The definition of "curriculum" has different meaning in different context of educational research (Beauchamp, 1986; Jackson, 1992; Pinar et al., 1995; Walker, 2003) even if the there are few substantive distinctions between them (Jackson, 1992; Clements, 2007).

To analyze the curriculum is useful to divide the curriculum documentation in levels depending by the audience for they are addressed: Supra (international), Macro (national), Meso (school, institute), Micro (classroom, teacher), Nano (individual, pupil). The higher curriculum levels affect the lower ones, especially if they have a mandatory status that limits the room to maneuver for large target groups and curriculum products, including those at micro level, may vary strongly in their scope and scale, ranging from generic to very specific one. The challenge for professional curriculum developers who operate on different levels is to anticipate these, not only concerning the product characteristics, but also, in collaboration with the many parties involved, regarding the change strategy. As concern the educational research, provide an effectively representation of the subject matter is pivotal and a second distinction concerns the different forms in which curricula could be represented was provide by John Goodlad (1979) and van den Akker (2003). They categorize curricula in three main and in six secondary forms: Intended curricula split in Ideal and Formal/written forms, Implemented curricula split in Perceive and Operational forms and Attained Curricola split in Experiential and learned form. The Ideal form is related to the rationale or basic philosophy underlying a curriculum; Formal/Written to the intentions as specified in curriculum documents and/or materials; Perceived to curriculum as interpreted by its users (especially teachers); Operational to the actual process of teaching and learning (curriculum-in-action); Experiential to the learning experiences as perceived by learners and Learned to the resulting learning outcomes of learners.

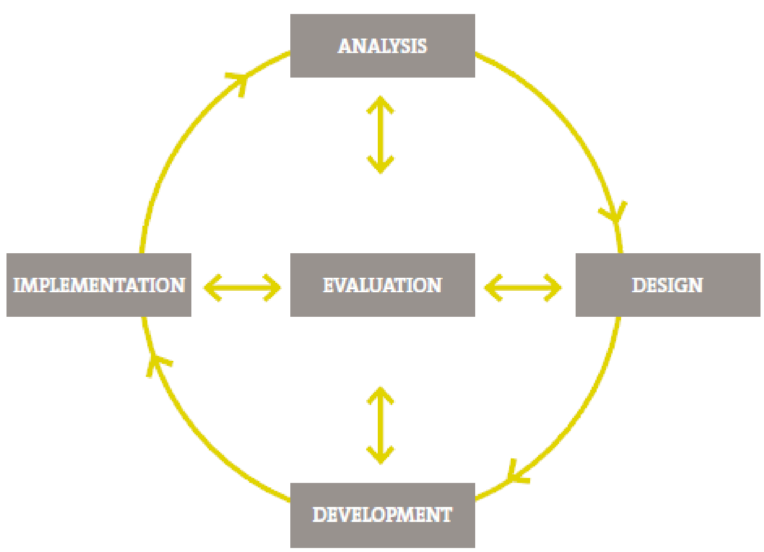
Curriculum and curricular modification involve several different subject that are interrelated one with each other. To emphasize this aspect van den Akker (2003) propose in his work to represent curriculum as spider web (see next Figure) in which the main subject and aspect of the curriculum and the curricular research take place. Rational of the curriculum was put in the center of the spider web and the components involved by the curriculum are placed around becoming the nine threads of the spider web. Each one of these is concerning an aspect of learning and the learning program for pupils that answer to a specific question: Rationale (Why are they learning?), Aims and objectives (Towards which goals are they learning?), Content (What are they learning?), Learning activities (How are they learning?), Teacher role (How is the teacher facilitating their learning?), Materials and resources (With what are they learning?), Grouping (With whom are they learning?), Location (Where are they learning?), Time (When are they learning?) Assessment (How is their learning assessed?)



Curriculum design or innovation can start with any component of this spider web even if traditionally the learning content receives the most attention.

The relevance of the ten components varies by the five curriculum levels. For instance at macro level the ‘what questions’ concerning objectives and content components usually receive more attention than the ‘how questions’ concerning pedagogy, educational materials, and the learning environment, but the overall consistency is crucial for the success and the sustainability implementation of innovations.

There are three main perspectives: 1) substantive perspective that focus on question about what knowledge is of most valuable for teaching and learning; 2) technical professional perspective that refers to how to address curriculum development tasks, especially the professional challenge of successfully translating intentions into curriculum products, that are used in practice and that lead to desirable learning outcomes; 3) socio-political perspective referring to curriculum decision-making processes and, indeed, battlefields, where values and interests of different stakeholders play a role (Thijs & van der Akker, 2009)



Curriculum development is focused on the improvement and innovation of education. Usually processes of curricular development take place in several years and, as Van den Akker & Kuiper (2007) show, are usually characterized by multi components cyclical structure. In the figure below is represented a five core activities model.

In this cyclic process, the five components take place interactively even if the usually starting point is the analysis of the existing setting and the evaluation process plays an important role casting light on the users' wishes and possibilities in their practical context and reveal the best way to attune the product to the practical setting.

Visscher-Voerman & Gustafson (2004) highlight four types of curriculum development approaches: instrumental, communicative, artistic and pragmatic approach.
The instrumental approach emphasizes the importance of a systematic design process and it is based on the Taylor (1949) ideas. The core of his theory is based on four important questions: 1) Which objectives should education aim for? 2) Which learning experiences are most suitable in order to obtain these objectives? 3) How could these learning experiences be organized effectively? 4) How can we determine whether the objectives have been achieved? Those are related to 4 components of the design research process: Objectives, Learning experiences, Organization and Evaluation. This approach acts mainly at macro level and is emphasizes the importance of a rational and goal directed approach.
The communicative approach emphasizes the importance of relational strategies the pivotal goals is the building of relationships with stakeholders and soliciting the input of developers and other subjects. Designing is regarded as a social process in which the each subject has his own vision on the problem situation and the desired improvement. This curricular design process is characterized by three steps: 1) The platform of ideas, in which designers and the other subjects involved present their views and opinions about the problem, while striving for consensus; 2) Deliberation, in which the designers

and the other subjects generate possible solutions for the problem identifying them and discussing the most desirable solutions; 3)Design, in which the results of the deliberation phase are transformed into a draft of the final product. The main added value of this approach is that the broad social support to the final product will be high, but, at the same time, the deliberation processes can be very time-consuming.
Artistic approach emphasizes the creativity of the designer. There are no objective criteria or fixed procedures for it, all depends by his creative and foresight ability and in particular the curricular designer had to use his connoisseurship skills (Elliot Eisner 1979) to individuate what is educational relevant.
In the pragmatic approach the focuses was on the practical usability of curricular products. Design and evaluation activities take place interactively: in the first phase an analysis of the relevant literature was done and a draft version of the product was improved using a cyclic approach based on design, evaluation and revision.

These four different approaches to curriculum development research are summarized by Thijs & van der Akker (2009) in the following table highlighting so how there is not a best approach, but how the efficiency of the approaches depends on the considered level of curricula. For instance they argue that the communicative or instrumental approach is often used, while the artistic one is more suitable for use at micro level, in the classroom.

	Instrumental approach	Communicative approach	Artistic approach	Pragmatic approach
Sequence of activities	Logical sequence	No strict sequence	Completely open process	Cyclical
Characterization of activities	Rational process	Intensive deliberation during a part of the process	Creative reflection during the whole process	Frequent evaluation with users
A good curriculum	meeting predetermined requirements	meeting requirements about which a broad consensus exists	meeting the designer's requirements	meeting the users´ requirements

I.7 The theoretical framework of this research

The aim of this work of thesis is the development of a vertical learning path as concern electromagnetism addressing in particular the phenomenology of the electromagnetic induction from primary to high school, so this work is a curricular research in which each learning intervention was designed using the approach proposed by the Model of Educational Reconstruction and will be tested in class using a Design Based Research approach that had proved in literature to be one of the best way of do research when there is the need to design new instrument, experiments and learning path ensuring that in the final product also the content and the pedagogical elements are taken into account.

The research work of this thesis, being centered on a specific topic, is a content learning research and this chose was done due to necessity to address specific learning knots typical of the topic addressed. The choice of electromagnetism and the electromagnetic induction topic that had to be addressed was drive by two main motivations. The first one is cultural and is related to the increasing importance that these phenomena have in everyday life. The second is cognitive and is related to the importance that also pupils has to acquire the skills needed to master multivariable situation in a way that allows them to identify the important elements and the general rules that drive the processes.

As concern instead the aspect of the curricular research, having in mind to start with the addressing of the electromagnetism also with primary pupils, it had to be done to guarantee the right development and interconnection between the different levels of education without creating gap or excessive superposition that could hinder or slow down the pupils approach to the subject.

II. RESEARCH METHODS

Quantitative and qualitative researches are two different approaches to the investigation in physic research. The choice of the methods that one had to use depends strongly from the type of investigation that one wants to investigate. These two approaches have two different roots that arise from two different philosophical assumptions that shape the ways in which researchers approach problems and collect and analyze data (Ary et al, 2010).

Quantitative research founds its roots in the positivism at which bases there are the idea that general principles or law govern the social world and, through objective methods, of research look for the discovery of these principles.

Qualitative research instead is look at the individual and his world as something of interconnected. It sees social reality as unique: researchers can only understand human behaviors by focusing on the meanings that events have for the people involved. The focus was not only what people do, but also at know they think and feel and you must attempt to understand their reality.

During the Twentieth Century the dominating approach in education research was the quantitative one. However, at the end of the century, researcher began to put it in discussion looking for new way to investigate the pupils reasoning. For instance, Guba & Lincoln (1988) argued that the use of the quantitative methods in highly controlled settings ignored the participants' perspectives and experiences. This new way, the qualitative research, was first seen as a dichotomy approach with respect to the quantitative one, but, afterwards, quantitative and qualitative started to look at these two methodologies as complementary approaches (Pring, 2004).

The research done using a combination of the both methods are called mixed method research and research literature showed that the findings of the mixed research method are more reliable and provide a more complete explanation of the research problem than the single ones but are not always implementable (Creswell & Plano Clark, 2006).

The choice between these three methods (quantitative, qualitative and mixed) depends by the suitability of the particular method and what the researches want to find out in his study.

Below are reported the differences between quantitative and qualitative approaches as concern purpose, design, approach, tools, sample and analysis (Ary et al, 2010).

	Quantitative	Qualitative
Purpose	To study relationships, cause and effect	To examine a phenomenon as it is, in rich detail
Design	Developed prior to study	Flexible, evolves during study
Approach	Deductive; tests theory	Inductive; may generate theory
Tools	Uses preselected instruments	The researcher is primary data collection tool
Sample	Uses large samples	Uses small samples
Analysis	Statistical analysis of numeric data	Narrative description and interpretation

II.1 Qualitative research

Qualitative researchers look at the whole situation, without breaks it into variables. The goal is to reach a holistic picture and a depth understanding that could not be reach by means a simple numeric analysis of data. Researchers would focus on a small group of students and study them in great detail through observation and detailed interviews. There are several different types of qualitative research, the main are: the basic interpretative studies, the case studies, the document or content analysis, the ethnography research, the grounded theory, the historical studies, the narrative inquiry, and the phenomenological studies.

Basic interpretative studies are the most simple and most common qualitative studies; the goal of the basic interpretative studies is to understand the world or the experiences of another. Dare are collected using as interviews, observations, and document review.

The case study consists in a deep study of a “case” (such as one student, one class, one organization, or one program). The goal is the detailed description and understanding of the entity, the "case". The set of methods that can be used in a case study is wide (interviews, observation, archives…) and generally the inference deduced in the case studies could be generalized.

The document or content analysis focuses on the study of recorded materials to investigate specific aspects (for instance the analysis of the ways in which textbook introduces the idea of magnetic field). The material took into account may be public records, textbooks, letters, films, tapes, multimedia software, diaries, themes, reports.

Ethnography is a depth study of culture or social groups' behavior in the selected environment. Researchers observe the groups behaviors in their environment, without imposing any simulation or structure. This type of study requires data-gathering procedures that work also at macro than at micro level. Mixes of different methods are used: long observation of the setting, interview of the members of the group, and study of the documents and the artifacts. An example of ethnographic study may be concerning for instance the investigation of the different educational experiences that may take place in a metropolis instead of a small in a village.

Grounded theory researches are aimed to develop a theory of social phenomena based on the field data collected in a study. Staring from an inductive analysis of the data, the researcher constructs concepts from which, introducing plausible relation between these concepts, build a theory. For these reason, for the resulting theory is thus said that this theory is grounded in the data.

Historical studies are concerning the analysis of documents, artifacts and (if possible) interviews of witness. The quality of this typology of research depends on the accuracy and the completeness of the source material and look to investigate for instance the development of the scientific curricular in the two last decades in Europe.

Narrative inquiry researches examine the stories of people telling about their lives and co-construct a narrative analysis of those stories. For instance a research of this type could be done to investigate the reflection of the teacher concerning a specific learning path.

Phenomenological studies lying on the assumption that the perception of the reality is mediated by the subject's perspective and then a specific experience could have different meaning for different subjects. Using unstructured interview, the researcher explore the subject's thoughts and feelings to elicit the essence of an individual's experience.

A general summary view of the different type of qualitative research was proposed by Ary et al (2010) as reported in the following table:

Type	Major Question
Basic interpretive studies	How are events, processes, and activities perceived by the participant?
Case study	What are the characteristics of this individual, organization, or group?
Document analysis	What can be learned about this phenomenon by studying certain documents?
Ethnography	What are the culture and perspectives of this group of people in its natural setting?
Grounded theory	What theory can be derived inductively about a phenomenon from the data collected in a particular setting?
Historical studies	What insights or conclusions can be reached about this past event?
Narrative inquiry	What insights and understandings about an issue emerge from examining life stories?
Phenomenological study	What does this experience mean for the participants in the experience?

II.2 Quantitative research

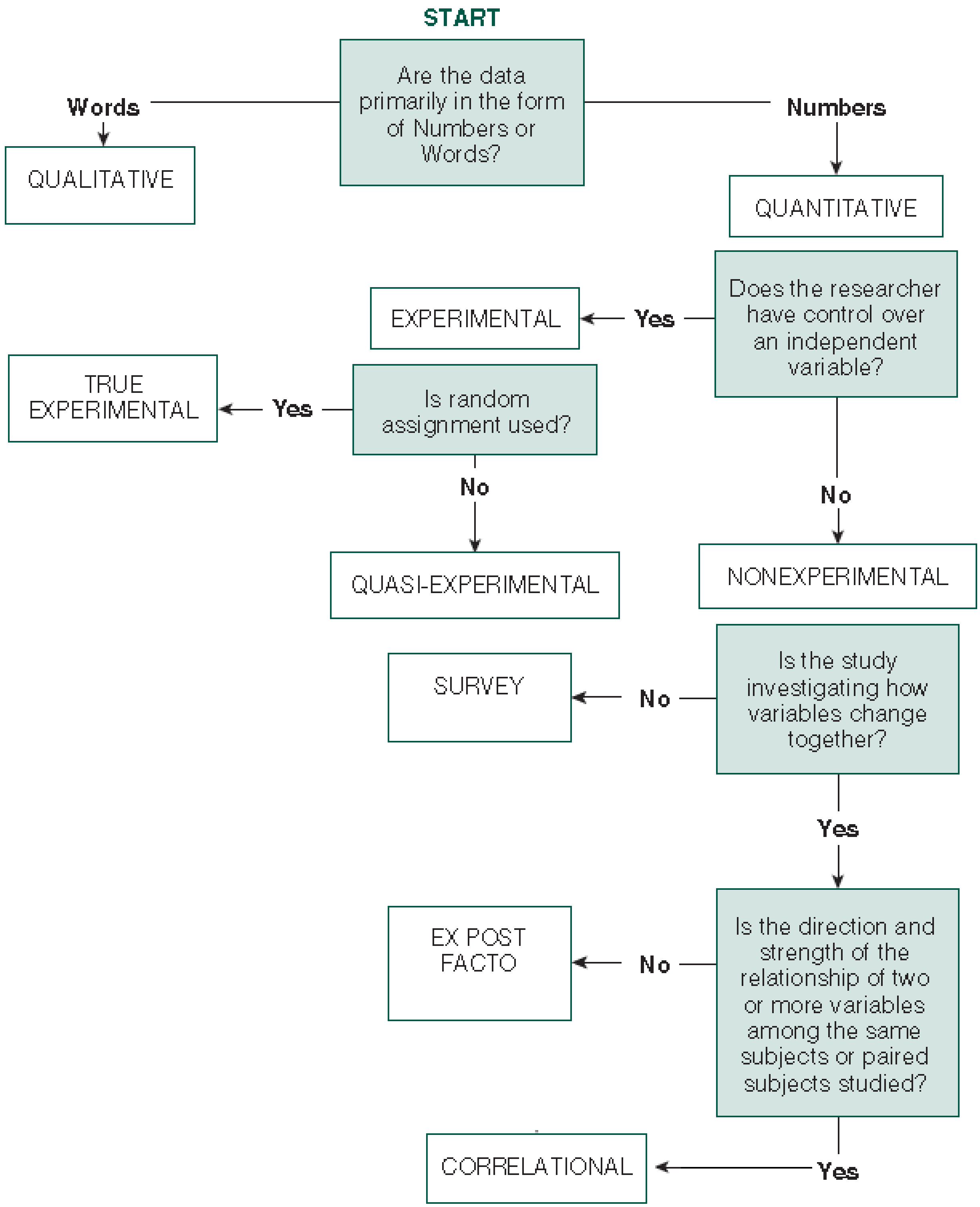
Quantitative research may be divided in two sub category: the experimental quantitative research and the non-experimental quantitative research.

Experimental research involves the study of the effect of the systematic manipulation of one variable on another variable(s). The manipulated variable is called the *experimental treatment* or the independent variable. The observed and measured variable is called the *dependent variable*. For instance, a researcher, taking into account two “equal” classes (with same teachers, same program, same age, located in the same village, having the same gender distribution,…) propose the same activity to both classes changing only one aspect of the teaching strategies and submit the same pre-test and a post-test to both classes and, then, looking at the difference of the grades that students obtain in the tests, the researcher do some inferences as the validity of the experimented strategy.

In this type of research the control of the variables (also the one that had to be the same or differ among the sample) is pivotal. But being impossible to considerate the entire variable that may be involved in the definition of the sample and the presence of possible hidden variables (variables that could not be take into account), the choice of the experimental classes out of the set of the other classes (that will be considered as control group) is done randomly. With random assignment the assignment is independent of the researcher’s personal judgment or the characteristics of the subjects themselves. But, however, not always researchers can randomly choice the class that will be involved into the experimentation; in this case, the research is called *quasi-experimental***.**

In non-experimental quantitatively research, the researcher instead could not manipulates the variables, it may only individuate them and look for a relationship between them. There are three types of non-experimental quantitatively research: the ex post facto and correlational research and the survey research. In the ex post facto research, the researcher compares groups differing on the preexisting independent variables to determinate the relationship to the dependent variables; the variables involved in this type of research are called *categorical variables*. The conclusions that may be inferred by investigations of this type had to be express in a very careful way because the research could not have a real control of the involved variables and so this aspect had to be taken into account. Apart from this important observation, the ex post facto researches are useful to investigate aspect as for instance the difference of the scholar grades between the full-time and the part-time student. The correlation researches instead gather data from one or two variable(s) and then seek to determinate if there is a correlation between them. The degree of correlation is expressed by a coefficient (called *coefficient of correlation*). If the coefficient of correlation between two variables is positive, it is said that the two variables vary directly, if it is negative, it is said that the two variables vary inversely. An example of research of this type may be to look at if there is for the students a correlation between the grades of mats and the grades of physic. The ex post facto and the correlational research look both to investigate the relation between the variables, but the main difference between them is that in the first one the researcher divides the participants into at least two groups on one variable and then he compares them on the other variable, while in correlational research, researcher deals with one group of individuals measured on at least two continuous variables. In the end, survey research uses questionnaire and/or interviews to gather information from groups of individuals. Survey research are also called descriptive research and are used in research education to measure for instance what kind of scientific education student ask to their schools.

Briefly, the type of quantitative research could be summarized as done by Ary et al (2010) in the following schema:


START
Are the data primarily in the form of Numbers or Words?
Words
QUALITATIVE
Numbers
QUANTITATIVE
Does the researcher have control over an independent variable?
Yes
EXPERIMENTAL
Is random assignment used?
Yes
TRUE EXPERIMENTAL
No
QUASI-EXPERIMENTAL
No
NONEXPERIMENTAL
Is the study investigating how variables change together?
No
SURVEY
Yes
Is the direction and strength of the relationship of two or more variables among the same subjects or paired subjects studied?
No
EX POST FACTO
Yes
CORRELATIONAL

II.3 The methods of this research

In the research proposed in this thesis, the adopted research methods are different. In particular were used mixed or qualitative researches. The choice between mixed or qualitative depends by the different outcomes that were looked for in each work and the age of the students (or the pupils) involved. For instance pure qualitative investigation was performed during the Conceptual Laboratory of Operative Exploration (CLOE) and mixed research methods are used in the experimentation of learning path in high school classroom.

CLOE labs provide to pupils informal contexts that stimulate conceptual reasoning and offers anchors for the construction of the first steps in scientific knowledge from the common sense vision. Research based CLOE labs are carried out by a researcher on a specific topic, based on a semi-structured interview protocol, which represents an open work environment through the proposal of everyday life scenarios. Phenomena in everyday situations are explored following sequences of reasoning by means of simple hands-on apparatus in different contexts. A research focused on construction of formal thinking through CLOE allows to identify students' spontaneous ideas and conceptual paths into the evolution of reasoning in the interpretation of magnetic and electromagnetic phenomena and to follow this construction personal worksheets and video-audio recording of the discussion were used that will be analyzed as phenomenological and case studies.

Instead for high school level students was also used in addition pretest and posttest questionnaire to collect data to perform a quantitative research that will integrate the qualitative data coming out from the analysis of the discussion and the inquired based tutorial used during the experimentation.

In particular for the analysis of the quantitative data the ANOVA strategy was used. ANOVA is a collection of statistical models aimed to study the variance from several approaches. Usually, in several cases, the linearized model was used. This particular model lies on the assumption concerning the distribution of the responses: independences of cases, the distribution of the residual is normal and the variance in the whole group considered is the same. The outcomes of the ANOVA test is an index that, depending by its value, accept or refuse the hypothesis that two (or more) different groups has the same mean or not.

III STRATEGIES

III.1 Problem Solving

Problem Solving is one of the strategies that mainly promote conceptual change. This methodology is a strategy of learning based on the use of problems in which the pupil is called to assume the responsibility of solution. Popular Problem Solving (Watts, 1991; Michelini 2005) is particular useful to create different situations in which the variation of the quantity of the magnetic flux through the concatenating surface in time define the synthesis expressed by Lenz law. In addition, for its nature of challenge, especially during the work in groups, the Popular Problem Solving allows to increase the necessity that the proposed solutions had to be based on persuasive argumentations.

The task becoming so a useful opportunity to make a deep reflection on an area of the subject that is much wider than the one individuated by the specific problem. In particular, the electromagnetic induction is a topic that requires for its interpretation the identification of new concepts that have roles and meanings that are strictly dependent with the context in which they are used.

In the main time, research works on activity of guidance highlight the need of formative intervention modules that has considerable cognitive gains realized at several school levels. The Problem Solving for Guidance (PSO) strategy changes the standard PPS procedures looking for operative solutions without constrain in the approach and in the disciplinary area.

PSO strategy is constituted by six phases that alternates individual and group work phases. The first phase is individual and is concerning the study and the description of the task that has to reach operatively and the design of the strategy that learner plans to follow, the choice and the optimization of the resources. The second phase is a group phase in which the individual project are discussed, the sharing of a goal and one or more strategies aimed to reach it, the peers cooperation to the organization and the realization of the shared procedure(s). During the third phase the analysis and the interpretation of the results was done in group and the realization of a report that, overcoming the simple narrative dimension, look for a global view of the problems related to the task based on the instrument and the disciplinary methods used. The fourth phase consists in the creation of two instruments for guidance: a multiple choice psychological questionnaire and a personal critical report on the experiences done. During the fifth phase, group discussions concerning the analysis of the role for the guidance of the experiences done. And last, during the sixth phase, every participant realizes a personal report on the whole experience.

III.2 Semiotic

Looking at the etymology of the word "semiotic", it derives by the Greek word used to indicate sign and signal. Today give a definition of "semiotic" is hard to do because this term has two independent roots (Shank, 1995). One root had a European origin and was founded to reconfigure the study of language (Saussure, 1959), the other in United States of America in the framework of the pragmatist theory (Peirce, 1955) have. Saussure (1916) defined the semiotic as the science concerned "the role of signs as part of social life" and "the laws governing them". During the last century the interdisciplinary aspect of the semiotic was highlighted and it was applied in different context. With respect to the context of the educational research, even that there was sign of opening as for instance during the thirties by Vygotsky, (1978), the amalgamation between semiotic and education research has never really crystallize (Danesi, 2010). Only in recent years this strand of research start to be systematically investigate; example of researches of this type were Semetsky (2010), Mariotti (2009), Bartolini & Mariotti (2008), Bartolini et al. (2002).

Pierce (1995), from the other way, developed a model in which the two basic processes involved in semiosis can be characterized as "know-how" and "knowledge". The latter is the desired end-state of any learning process; but the former entails creative and imaginative processes that must be activated in order for learning to occur in the first place and indeed, Danesi (2010) defined the semiotic as follow:

Semiotics is ultimately a form of inquiry into how humans shape raw sensory information into knowledge-based categories through sign-interpretation and sign-creation, that is, through the use of forms that stand for the categories. Signs that penetrate the flux of information are intelligent selections which are taken in by our senses or our intuitions, allowing us to encode what we perceive as meaningful in it and, thus, to learn and remember it.

In early childhood behaviors the difference between semiosis and human action is manifest (Danesi, 2010). When a child meets a new object, his first spontaneous approach is to explore that object using his senses. This exploratory phase, called sensory cognizing, allows the child to re-cognize these object the next time he meets it without the need to re-explore it an then, after the infants grows, s/he start to starts to engage more and more in semiosic behavior that clearly transcends this primary sensory cognizing phase (Sebeok and Danesi, 2000) and so the object starts to assume a new mental form of knowledge in the child mind. In this process that psychologist called displacement, a child become more adapted at using signs to represent the world (Danesi, 2010). Gradually, while a child increases with the growing its understanding of the world through signs, he makes a vital psychosocial connection between his developing bodies and the conscious thoughts to that world. Signs constitute the *representational glue* (Danesi, 2010) that interconnects body, mind, and the surrounding world in a holistic fashion. In addition, while in the first phase of the use of the signs the child does comparison between his own attempts with the repertoire in the specific context, then the signs acquired in a specific context will become cognitively dominant and eventually they mediate and regulate the child's thoughts, actions, and behaviors. As said by Danesi (2010): culture, context, and experience thus reshape the inbuilt learning system for the developing human being into a filter that allows him/her to reorganize the raw, yet functional, information: to process it into meaningful wholes. So the understanding and the interpretation of the world is not direct, but is mediated by historically-based signs and the referential domains that they elicit within mind-space (Danesi, 2010).

The introduction of the exploration of artifact constitute an important context in which create a bridge between semiotic and education research that, through the structured exploration of selected artifact could promote the exploitation of the semiotic aspect of the way in which pupils applied the knowledge acquired by them to exotic (new) situations.

III.3 Inquired Based Learning

Inquiry based learning is method of learning developed by Bruner (1961). This method implies an active learning approach in which the learner is the center of the learning process. In the context of the Scientific Education Research, during the nineties, the Inquiry Based Learning (IBL) was mainly developed in the USA by the McDermont's (1992) research groups. Now IBL is one of the main adopted approaches in learning strategies.

The core of the IBL is the formulation of specific questions related to particular emblematic and/or problematic situation. The role of these questions is to promote reasoning in the learner's mind while he/she is exploring the phenomenology

In particular, Banchi & Bell (2008) argue that there are four levels of inquiry-based learning in science education:

1) confirmation inquiry: it is mainly used when there is the need to reinforce an idea that was already introduced and the focus of the research is on the way in which student argue (eventually experimentally) them.

2) structured inquiry: in this type of inquiry question and procedures are provided by teachers however students generate an explanation supported by the evidence they have collected.

3) guided inquiry: teacher provides to students only the questions, and students had to design the procedure to test these questions and analyze the result. This kind of inquiry is more involved than structured inquiry, and so, usually, it is more successful when students have had numerous opportunities to learn and practice different ways to plan experiments and record data.

4) open inquiry: student has the opportunity to act like a real scientist, deriving questions, designing and carrying out investigations, and communicating their results. This is the highest level of inquiry and it requires the most scientific reasoning and cognitive demands from students.

In the framework of the IBL the teacher's role is completely different respect with the usual role that he assumes. In the IBL teacher is not the bearer of the expert knowledge, but he is a facilitator and has also a role in the motivation of the students.

III.4 Reasoning and critical details approach

Common knowledge, according to Bachelard (1938), presents characteristics which distinguish it clearly from the scientific approach: generally common thought is formulated in vague terms and is constituted of scattered and unrelated elements: it is knowledge in bits and pieces so to attain another - scientific - level of thought, one need to surmount obstacles of a different nature (Viennot, 2001).

Referring to Piaget's theory, the role of the learners is pivotal in the process of learning even if it is referred to the a simple "assimilation" of new knowledge into an existing structure, or to the extension constituted by "adaptation", which is in itself the result of a process of "equilibration". Learning is always a question of negotiating with one's own knowledge (Inhelder and Piaget 1955; Piaget, 1975) so, for a teacher is crucial to know which are the a-priori ideas and the ways of thinking of the involved learners.

In the work of research education the knowing of two opposed aspects is crucial for the researchers: the physical theories and the familiar reasoning on the other (Viennot, 2001).

When a student faces a learning path, the single student reasoning is impossible to foresight, but the form of the reasoning product in a group of student is not only the product of chance. Recognizable trends of thought that are not compatible with taught theory are found ,and are remarkably frequent and stable both during and after instruction, even in "higher" education (Viennot, 2001). Such reasoning is independent by any instruction received at school, the earliest descriptions referred to "spontaneous" or "natural" forms of reasoning. Some are manifest before any instruction in physics at school, and are therefore called "preconceptions". There are common lines of reasoning to which we are all attached. Their relative degree of coherence contributes to their resistance. The best way to promote a change in this pre or spontaneous conception is to cast light on incoherence produced by them or shot that they have no counterpart in the real world, but usually it is not sufficient to cast light on, or to provoke a critical examination because in this way there is the danger to make the process of learning bored and uncertain mastered because academic knowledge and natural reasoning may coexist in students' minds.

III.5 Conceptual change

Thomas Kuhn (1962) with his work provides the roots for the further development of the theory of the conceptual change (Vosniadou, 2008). Kuhn's work, as well as a great influence on the historians and the philosophers of the science, effect also researcher of other subjects area as psychology and science education. In particular, as concern science education, his proposal provided a needed theoretical framework able to interpret students' difficulties. Researchers realize that students has also persistent pre-conception, misconception or alternative believes (Viennot, 1979; Driver & Easley, 1978; McCloskey, 1983) that seems to be really close to the ones highlighted in earlier physics theories (McCloskey, 1983). These and similar consideration become the starting point of a deeper analysis of this first insights and Posner et al. (1982) draw an analogy between the need of changes needed by the students and the Kuhn explanation of the changing that there was in the history of science. Posner et al (1982), integrating Kuhn's ideas with Piaget's notions of accommodation and assimilation construct an instructional theory based on four pivotal conditions: 1) there must be dissatisfaction with the previous conception, 2) there must be a new conception that is intelligible, 3) the new conception must appear to be plausible, 4) the new conception should suggest the possibility of a fruitful program.

This theoretical framework, called 'classical approach' to conceptual change, was the leading paradigm in education research for several years (Vosniadou, 2008). In these framework, student are seen as scientist that explore new theories and the main way in which conceptual change was promoted was through cognitive conflict between student knowledge and explored phenomena. This first approach to conceptual change was criticized (Vosniadou et al., 2007; Arabatzis & Kindi, 2008) in particular as concern the space of validity of the conceptual change theory enlarging it to other field that differs from the scientific one. So, today, most researchers agree that researches on conceptual change investigate how concepts change with learning and development in specific subjects-mater areas of knowledge, focusing more specifically on explaining students' difficulties the more advanced and counterintuitive concepts in these area (Vosniadou, 2008). In particular, recently, the term 'controversial conceptual change' is used to point out to research that are related to process of conceptual change that are strictly related to fields that are strongly related to strong emotional effect (i.e. peace and ideological differences education).

Even if the conceptual change seems to be an effective approach, its definition is not univocal and some of its aspect are under discussion between researchers. One of the main points of discussion is the structure of the students' knowledge: while some researcher describe the student knowledge as something that has a 'theory-like' structure, other authors (Chi, 2008; Inagaki & Hatano, 2008) prefer to do not use the terms 'theory' using lass loader terms as 'schema' or are completely against to the idea that students' initial knowledge structure are theory-like (diSessa, 2008). The main represents of these two schools of thought are diSessa (2008) and Vosniadou et al. (2008) but there are also intermeddled position, as the one of Brown and Hammer (2008) that found in the description of complex systems evidences for both of them.

Understand what concepts are and how they change is a still open problem (Vosniadou, 2008). The first one generally was neglected and/or researchers use an historical view of concepts (Murphy & Medin, 2005; Fodor, 1996). As concern the ways in which concepts change, researches argue that they change in several ways from the more mundane to the most radical (Thagard, 1992; Thagard, 2008) where radical change means a change of that a concept shift from one ontological category to another (even if it requires or not the construction of a new ontological category).

Another point of debate is the process and the mechanism of conceptual change. In Kuhn theory, it happened in a short interval of time and it will be seen as a suddenly change. Even if this description may happened during learning processes, researches shown that it is not the usual way in which the conceptual change takes place (Vosniadou, 2008). Empirical evidences show that conceptual change, even in the case of radical conceptual change, is a slow and conservative process (Caravita & Allden, 1994; Vosniadou, 2003; Hatano & Inagaki, 1994; Wiser & Smith, 2008). Vosniadou (2008) claims that 'learners use mainly additive, enrichment types of mechanism that are largely conscious and that these mechanisms can produce conceptual changes in the long run'. They operate changing one by one the beliefs and assumption of the previous theory that are in conflict with the new one; in addition Chi (2008) argue that some misconception rise up when new information is added on the wrong schema.

Also the role of student seen as a scientist was criticized. In particular, the researcher that argue that pupils embedded their knowledge in theory-like structure, highlight the lack of metaconceptual awareness, difficulties in engaging in systematic hypothesis testing, lack of knowledge about the role of theories and scientific models and general epistemological understanding (Wiser & Smith, 2008). In addition, in the last years, some attention has started to be paid to motivational and effective factor in conceptual change (Sinatra & Mason, 2008; Murphy & Alexander, 2008).

III.6 Pedagogical Content Knowledge

As concern the teachers' formation, the most used methodology founds its roots in the Schulman's theory of the Pedagogical Content Knowledge - PCK - (Schulman, 1987; Schulman, 1986). This particular approach is characterized by the need of the synthesis of the pedagogical knowledge and the content knowledge aspects. The content knowledge, that is defined as the knowledge relate to the subject matter, is important in the teachers' formation. Do not have a comprehensive base of the content knowledge can be quite prohibitive for a teacher, and it will affect the students that can receive incorrect information and develop misconception about the content area (Pfundt & Duit, 2000; National Research Council, 2000). But have only a good preparation as concern the Content Knowledge is not enough for one teacher; he had to acquire also a good level of Pedagogical Knowledge. This Pedagogical Knowledge is defined as a deep knowledge about the processes and the practice and methods of teaching and learning that and it encompasses overall educational purposes, values and aims (Koehler & Mishra, 2008). In Schulman's conceptualization of PCK the notion of the transformation of the subject matter for teaching (Koehler & Mishra, 2008) and the synthesis of the Content and the Pedagogical Knowledge are central aspects. In his view, to perform an effective teaching formation, these two types of aspects had to be addressed together. In fact, according to Schulman (1986), this transformation of the subject occurs as the teacher interprets the subject matter, finds multiple ways to represent it and adapts and tailored the instructional materials to alternative conceptions and students' prior knowledge. Do a PCK formation means to work on the acquisition by the teachers of the skills needed to transforms educational tools and content to maximize the quality of learning. Teachers had to acquire this particular skill and had to be able to transform and the reconstruct the content knowledge on the basis of the single pupils needs; it is necessary for the teacher to be able to transform the expert knowledge and to adapt the educational tools to the learners needs. In particular, to be able to address in class the main learning knot related to a particular topic and reconstruct the subject, teachers had also to know: the main naïve students' models (or representations) that they adopt in the interpretation of the phenomena, main ways of evolution of these models, the roles and the uses of the educational tools that best fit the students' needs and the capability of choose and adapt them.

Even if PCK and MRE are related to the re-construction of the subject by the learners' needs, they differs from one to the other because the PCK is a level that had to be reached to provide an effective teaching, while the MRE is a process aimed to the production of effective teaching matherials.

III.7 The Strategies of this research

As concern strategies in this work of thesis several strategies were adopted. This choice, almost drive also by the choice of a mixed method of analysis of the data, was done to be able to collect several different type of data on the development of the pupils' reasoning.

For instance a semeiotic strategies based on the analysis of the artifacts was adopted to explore how pupils and student re-interpret and re-use the knowledge that they had constructed during the proposed learning paths in exotic and / or everyday life context.

The inquired based learning was adopted during the learning paths to propose to student situation that had to be analyzed and discussed between peer using argumentative approach creating so anchoring situation that could be re-used by the student in the interpretation of artifact or in the addressing of particular difficult problem solving-like situations.

In this way, in addition to the possibility for the researcher to look at different aspects of the development of the student and pupils reasoning, the learning paths are characterized by a strong component of active learning that allows pupils to be personally involved in the process of the construction of the knowledge.

The use of the different strategies adopted in the different activities will be justified in depth in the presentation of the single activity, but the general approach of the research is to adopt the widest range of possible strategies during the whole work, but individuating for each activity the best strategy that had to be used.

IV. LEARNING KNOTS

IV.1 Learning knots as concern electromagnetism highlighted by research literature

As concern electromagnetism the research literature highlights a series of several learning knots for different schools grade. The work of Maloney et all. (2001) gives a wide spectrum of the problematical situations, that during the course of electricity and magnetism students had to face ad at university level.

In particular, as concern magnetism, electromagnetism and the concept of field, Maloney et all (2001) found that, even if in the straightforward problems the superposition of field is well applied by the students, they will fail in situations that are little more complicated than these. In addition students, even after the course, had problems thinking through the steps from a uniform field to a uniform force to a uniform acceleration, and the interpretation of the field strength coming from the field lines representation or the equipotential lines representation seems also to be confusing for many students (e.g. students associate large distances between equipotential lines with stronger field). There are also a variety of ways that students seem to be interpreting the effects of a magnetic field on a moving charged, in particular some students confuse the electric force and magnetic force, or give a fluid flow interpretation of the effect of the magnetic field on the moving charged particle. In particular, as concern electromagnetic induction even if student know the nature of the process they are not able to identify the whole spectra of the situations that could produces a variation of the flux interlaced to the circuit. The recognition of the validity of the Newton's third law in electric and magnetic phenomena is often neglected and in particular as concern the interaction between two wires currying currents.

Another example of general investigation concerning the main learning knots concerning electromagnetism was done by Guisasola et all (2004). They, working with university students (in this case the students were enrolled in the first three years of engineering), found that the students explanatory models of the electromagnetic phenomena could be categorize in four main category that the authors labeled as: 1) Inherent nature of matter, 2) Ingenuous realistic, 3) Electrical, 4) Amperian. The first one was adopted by 15% of the students that interpret the magnetic phenomena are attributed to "qualities" belonging to the matter. The second one was also used by another 15% of the student interpret and identify the field lines as real entity and describe the magnetic interaction as a consequence of the attraction and repulsion of the field lines. Half of the students instead use the electrical model that identify the electric charge (in movement or at rest) as the sources of the magnetic field; magnet are considered as charged bodies and magnetic interaction are explained as Coulomb's central forces. The last category, adopted by the remaining 20% of the students, identifies charges in movement as sources of the magnetic field using an Ampere's model to explain the relationship between magnets and coils current as sources of the field.

In literature, alongside of these works that investigate through the implementation of questionnaires the whole set of the learning knots present in the students' formation, there are other valuable works that are aimed to the deeper study of the students model through the use of interview (eventually in combination with questionnaires).
Also aimed to the exploration of the students' models is the work of Borges et all (1998), that, through the use of interviews based on a sequence of prediction-observation-explanation situations, working with secondary school students coming from technical schools, teachers, engineers and technicians, identified five mental models used by the students to interpret magnetism. In the first model, students see magnetism as an attraction on exerted on object in the region surrounding the magnet

and it is an intrinsic property of magnets. In the second model, magnetism is seen as a cloud (or a region of influence) that surrounded the magnet within the other objects are acted upon and, as in the first model, magnetism is considered as an intrinsic properties of the magnets. In the third model, magnetism is seen as due to the attraction between unlike charges; magnetic pole are seen as regions that have an excess or a lack of electricity and of the students referred to magnetic poles labeling them positive and negative pole. In the fourth models students seen the magnetism as electric polarization; it differs from the previous model because in these model students give a microscopic explanation (positive and negative charges are separated into the magnet and so they giving rise to the poles). In the fifth model, the field model, students instead of a direct interaction between objects and magnets use a field like relationship, but this last consideration is not found in all the students that use a field model. Three different views of the origin of the magnetism were identified: 1) magnetism is created by micro-current circulating inside magnets – Ampere/Weber model; 2) the existence of small permanent dipoles – Weiss's domain theory 3) spin and orbital magnetic moments (used by very few students).

Also Greca et al (2006), working with college students, investigated the mental representations that students used. Their finding suggested that most of the students work with propositions that are not related or not interpreted according to mental models, but they use formulae and definition as routinely to solve problems. Only few students provide evidences of model construction and, among of these two groups there is a considerable group of students that had an intermediate situation.

Other works are instead more focused on specific learning knots as for instance the work on student's idea of fields done by Rainson & Viennot (1992) that highlighted how the concepts of electric field as a superposition it's a difficult barrier that has to be overcome by the high school students. In particular difficulties are founded that students have difficulties in the use of the Gauss's theorem and in particular into the idea that only the charges contained into the surface could create a field on a given closed surface; In addition students are also reluctant to accept the idea that the field can go through an insulator, particularly because in it “the charges cannot move”.

The concept of field is a transdisciplinary topic and also working on the electric field Tornquist et all. (1993) found that the second year university students use often to attach far too much reality to the filed lines and often they treat them as isolated entities in the Euclidean Space instead of a set of curves representing a vector property of the space. It means, in authors’ opinion, that the hierarchical sequence between the concepts is not fully understood and it suggest that there is confusion between the multi-representations and highlight the need of further studies on the role that the representations play in students’ concept formation (for instance Herrmann et al (2000) suggest to represent field graphically drawing also the orthogonal surface in addition to the field lines in order to identify clearly also the circulation source in addition to the flux sources.
This problematic is strictly related to the role of the representation of field that was widely analyzed in literature.

Maloney (1985) also said that one reason for the difficulties that the students had to face taking into account magnetic problems is that magnetic force situations are three dimensional and the right hand rule is an unusual procedure which is often misunderstood. With the same opinion, Chabay e Scherwood (2005) highlight how electromagnetism is a topic that requires a level of abstraction and mathematical sophistication far beyond what students have experienced before: all of the quantities are invisible being microscopic or abstract (e.g. electrons, field and flux) that usually, for timing reason, are introduced one after the other in a quick sequence and, as also noticed students had for the first time to think necessary and visualize phenomena in three dimensions.

As concern more specifically the electromagnetic induction, Thong & Gunstone, (2008), using interviews investigate the models that the students use to interpret the electromagnetic induction, highlight the presence of other Three previously unreported alternative conceptions were identified in the study: 1) induced current varies proportionately with the current in the solenoid; 2) there must be contact between magnetic flux and the external coil in order for any electromotive force to be induced in the coil; 3) Coulomb or electrostatic potential difference is present in an induced electric field. Moreover, Bagno & Elyon, (1997), working with high school students, highlight that only 10% of the sample recognize that a change in the magnetic field is accompanied by an electric field and the authors associate this findings to the conclusion that students do not relate the labels Lenz's law or induced electromotive force to the production of an electric field.

As concern pupils, instead, there are few research works that address directly the pupils learning knots related to the concept of magnetic field. One of the most interesting is the one of Bar et al (2007) in which the outers investigating the interpretation that the pupils give to phenomena of action at distance (gravity electrostatic and magnetism) highlights the pupils need of a medium for the action at distance. The pupils' main naïve candidate for this role is the air (80% of the 9 years old pupils involved; 35% for the older ones) or a stream of particles that initiating from the magnet and reaching the iron that, in authors' opinion highlight the spontaneous need of connection.

IV.2 Learning knots and History of Science: the case of Faraday's field lines

Literature in physics education emphasizes the important role of active involvement of the student in construction of knowledge (Viennot and Raison, 1999; Vosniadou, 2001) and how the personal involvement produces the development of formal thinking necessary to build a bridge between the ideas of common sense and scientific interpretation to overcome the conceptual knots (Michelini, 2005; McDermott, 2004). It is therefore essential to provide situations in which the students personally investigate the knowledge and the concepts with tools and methods that can reproduce the experience of research. The analysis of the development of the history of physics and in particular the elements that characterized the scientific revolutions (Kuhn, 1962) may be the ideal setting from which to begin the design of educational activities.

Historically, for what concerns the electromagnetic induction, Faraday was the first researcher who proposed an interesting and useful use of field lines. The description of magnetic effects in terms of magnetic lines introduced a great change in the type of models used to describe the phenomena. With the field lines models move from an Ampèrian description, which is based on the forces acting at a distance, to a description tied to the concept of field. This radical change is a scientific revolution that whit Maxwell and his flux tubes completely changeed the interpretation of electromagnetic phenomena. Furthermore, as suggested in some educational researches (Bradamante, 2007) an approach based on the flux tubes has been shown to be of fundamental importance in building the bridge necessary to move from a description based on the action at a distance to one based on the concept of field.

In 1821, after having devoted his previous studies to chemistry, Faraday began to address issues specifically related to electricity. Just in 1821 a brilliant series of his research culminated in the discovery of electromagnetic rotations. Magnetic continues rotations, discovered by Faraday, was the major challenge to the electrical theory of

Ampère, which deals exclusively of attraction and repulsion, but not rotations. Faraday published his discovery immediately in a paper entitled *On some new electro-magnetical motions, and over the Theory of Magnetism* (1821) and sent to various scientific communities small devices that produce these rotations.

The main objective of researchers at the time that dealt with electromagnetism, however, was to find the reverse effect to the one discovered by Ørsted. So they wanted to study the effect exerted by the magnetism on electricity. The goal was achieved by Faraday with the discovery of electromagnetic induction. This phenomenon, however, brought with him some unexpected features. First it was a transient phenomenon, namely that the passage of the induced current occurred only when you close the circuit inductor or when approaching the magnet, and also, opening the inductor circuit or taking away the magnet, is generated in the circuit an induced current with opposite direction to the previous one.

Faraday discovered electromagnetic induction in 1831, but his first work on the subject was published only in April 1832. He, in fact, because of the transience of the phenomenon, was conscious of being the only one who made this discovery and before publishing something about it he decided to devote himself to a deeper analysis of the phenomenon in order to achieve greater understanding of the important factors related to the observed phenomenon.

Faraday initially identified two types of induction: an electrovoltaic, and a magnetoelectric. The first was due to the flow of current, whereas the second was due to magnetism. According to Faraday electrovoltaic induction could be based on the concept of interacting current and the electrotonic status. This last concept was introduced by Faraday himself to explain the transience of the phenomenon. He suppose that the passage of current in the inductor circuit create this particular state that opposed themselves to the flow of the induced current interrupting it quickly. Opening the inductor circuit the electrotonic status stopped and generate a current opposite to that previously observed. In the magnetoelectric induction the effect depend not only on the configuration of the system, but also by the motion by which the configuration of the system was reached. Initially, in order to find an appropriate reference system to describe the phenomenon, Faraday used an ampèric approach to the problem, but this proved to be unsuitable. Was then that Faraday decided to take into account the magnetic curves that the iron filings form in the presence of a magnet and, according to them, he was able to explain the regularities that he had observed in the magnetoelectric induction. So Faraday reaches the conclusion that the electric wire and the magnet moved relative to one another by ensuring that the curves were cut from the magnetic wire.

Faraday at this point however found by himself two explanation models for the same phenomenon that are incompatible one with the other: the first requires the existence of the electrotonic state, the second the cutting of magnetic field by the circuit. These two models came into open conflict when Faraday concern itself with the experiment of Arago . In particular Faraday realized that this experiment would be interpreted in terms of magnetic curves only if it was possible to assume the existence of curves even around the thread path from the current. Arago's experiment interpretation was crucial to place in discussion the distinction between magnetoelectric and electrovoltaic induction, but was not sufficient to give an explanation of the elettrovoltaic effects observed in the absence of relative motion between the circuits constituting the system. This problem for a long time gripped the Faraday's mind who managed to reach a resolution until March of 1832, just before his article was printed. Faraday realized that he could unify the two type of induction dealing with in terms of magnetic line cut, assigning also to the wire in which flows the current some magnetic curves which were free to move at the time of closing and opening the circuit. The introduction of these magnetic curves, which Faraday begun to call lines of force, will be crucial for the development of the theory of the electromagnetic field. Perhaps at the same time, however, the lack of a rigorous mathematical treatment, involved an initial rejection of his theories. Indeed in 1832, when Faraday proposed his concept of the magnetic curve, was not understood by his contemporaries and his ideas did not find an immediate success. This distrust in the work of Faraday lasted until the mid-forties, when W. Thomson became aware of the importance of these ideas and began to give them a mathematical basis. Later this work was completed and developed by Maxwell.

Reading the historical reconstruction above it is evident that it cannot be directly used as a guideline for an educational activity. For a student follow the route taken by Faraday would be very cumbersome. Faraday's ideas can at the best be the subject of a discussion in class, but not a learning path. The analysis of historical development allows the identification of what were the key points on which developed the theory and what are the crucial experiments useful for the emergence of new concepts.

Analyzing Faraday ideas by a didactic point of view, he has set a goal of a general nature: discovering the opposite effect to that one discovered by Ørsted. To achieve this Faraday began an explorative investigation of magnetic and electric phenomena and their possible correlations. After that he had obtained a picture of the know effects of the various experiments he grouped experiments into categories and then tried to give a specific explanation for each one of this categories. Later he tried to give a unified explanation applicable to all categories of experiments. In this way he developed and tested a model (that one based on the field lines) and then tried to extend it in a different context than one where it was developed. The next step of Faraday is indeed to extend the field of applicability of his model taking into account the interaction between magnetic field and matter. Again Faraday starts with an experimental exploration and a categorization of the experiments and a partial explanation for each of the categories identified. Finally, introduces a general explanation in agreement with the model previously developed.

The analysis of the historical development of Faraday's research as well as allowing an analysis of the methodology used by him, can also allow to identify which are the tools and the materials that we had to offered to students to provide them the best environment in which they can work.

In particular, as regards the first experimental exploration, we had to ensure that students have available, in addition to the magnets and the coils, a variable current power generators and objects of various kinds and in particular a rotating disk of aluminum that will enable them to carry out an experiment similar to Arago experiment. Besides this, students must be empowered to have an idea (albeit vague) of the representation of the field lines and the students' task had to be the discover of how this geometrical instrument should be used as part of the electromagnetic phenomena.

In this way the students have at their disposal all the elements to achieve those crucial experiments, which enabled Faraday to develop the idea of magnetic field. In particular, doing in advance an historical analysis of the historical development of the main physical concepts makes possible to identify which are the important elements to ensure that students can be empowered to take their own path of research and analysis of phenomena.

V. A BRIEFLY HISTORY OF THE DEVELOPMENT OF THE ELECTROMAGNETIC THEORIES

The development of the electromagnetic theories during the Nineteenth century can be seen as the result of the juxtaposition of two different methods of interpretation of electromagnetic phenomena. These two strands of research, which for convenience of notation are usually identify as the 'strand of the action at a distance' and the 'strand of the action at contact', were based on assumptions that were completely opposite one to each other. The first strand of research looks for an interpretation of the electromagnetic phenomena in terms of laws of force that are similar to that one that Newton formulated for the gravitation: it means that this laws are laws of force that act instantaneously and that depend exclusively on the characteristics of the interacting objects. The Clausius' law is the ultimate expression of this kind of interpretation of nature. The second strand, instead, uses as pivotal concept the concept of electromagnetic field and reached its climax with the Faraday-Maxwell duo.

The difference between these two strands however are not limited to the type of interaction supposed; starting from the type of action selected by each strand there are important consequences which must be taken into account. The strand that choose to assume as a fundamental element of his theory the action at a distance will had to develop a theory that has a global approach to the whole world (with Newtonian like laws of force, everything interacts with everything instantaneously) and in addition the action at a distance was almost always accompanied by a vision of discrete entities identified as sources of force. Assuming instead action at contact, this choice allows having a local view of the interaction and the energy balancing of the system and in addition it historically was associated to the need of ether(s) through which the interaction could propagates.

The interaction at a distance, however, has also raises issues related to the idea of causality. Already as concern the Newton laws Hume argues that '*distant objects may sometimes seem productive of each other, they are commonly found upon examination to be linked by a chain of causes, which are contiguous among themselves, and to the distant objects; and when in any particular instance we cannot discover this connection, we still presume it to exist. We may therefore consider the relation of contiguity as essential to that of causation*' (Hume, Treatise, libro I. parte III, sezione II).

In addition to this conceptual difficulty to the explanation of the causality relations in the model constructed on the idea of action at a distance, the real added value of the Farady-Maxwell theory was its predictive capability and its graphical representation that, if applied in a correct way, allow to interpret in a simple intelligible way the phenomenology.

V.1 The earlier observation of the electromagnetic phenomena

In the eighteenth century electrical and magnetic phenomena were treated separately because the equipment of the time, i.e. the electrostatic machines, was not able to generate situations in which the correlation between these two types of effects was observable. Studies that highlighted the correlation between these two type of phenomena were sporadic and casual. With the invention of the voltaic battery the experimenters had finally at their disposal a tool that was able to produce a durable current of a noticeable intensity. This allowed them to obtain and analyzed situations where both the effects were detectible.

In particular, in 1820, Ørsted, using the voltaic pile, make his famous experiment in which he showed experimentally that there is a correlation between the effects of electric and magnetic effects. As said before, Ørsted was not the first totempt to highlight a correlation between these two types of effects; other researchers have since long time studied this correlation, but the success of the Ørsted methodology consisted was that it was the first that implement the observations for his experiments using a closed circuit. Several other researchers, such as Romagnosi, used for their experiments open circuits approaching magnetic needle to the ends of the voltaic battery.

The interpretation that Ørsted gave of its exploration was influenced by two main factor: its chemist formation and its agreement with the cultural strand of the Naturphilosophie. From its chemist formation Ørsted took the idea of two current carrying into the wire, and from the Naturphilosophie the idea of conflict between dichotomy entities that, through their conflict, do not cancel each other, but will be synthetized in a higher state of synthesis. This view, applied to the observed phenomena, drove him to argue that the magnetic effects measurable around of the wire are due to the conflict of the two opposite current flowing into the wire.

So, Ørsted, in its experiment assumed that the wire is crossed by two currents interacting one with the other through a conflict that generate “circular forces” around the wire. Starting from this idea and using his geometrical knowledge, for Ampère was not difficult to see the shape assumed by the magnetic action a wire wound in a helix. This was the starting point of the Ampére theories that in the following years will describe the mutual action that there are between two wires helically wounded. Ampère therefore proposes a new theory of magnetism that seen it as due to electricity in motion.

The Ampère’s theory, explaining the magnetism in terms of currents inside the metal, however, had one big problem: as pointed out by Fresnel, if we consider a magnetic iron, in it, according to the ideas of Ampère, there are circular currents, but the iron being a not perfect conductor, should heat up. Experimentally, however, it does not appear that the magnets have a temperature higher than the environment. But, while the Fresnel’s objection refutes the Ampère’s model, one of his suggestions will drove Ampère to propose a new idea of the structure of matter. Fresnel fact, in a note addressed to Ampere, suggested to localize the currents inside the molecules. Doing so, not only Ampère saved his model but it was the beginning of a new line of research: the molecular electrodynamics.

Ampère was strongly convinced of the validity of his model and proposed it as a ground on which explain many phenomena in various physical situation. This aspect, if from one hand was the main value of the Ampère’s model, from the other hand made it difficult to be accepted because accept it meant to accept as good a theory about the ultimate structure of the matter.

In fact, several researchers, particularly in France, oppose themselves to this new idea of molecule, but nevertheless this, the ampere ideas managed to survive thanks to the work of Weber that starting from the Ampère’s ideas developed them founding so the strand of research that called of the “action at a distance. "

V.2 Weber-Clausius- Schwarzschild

The starting point of the Weber's work was a refinement of Ampere's law of interaction between two wires carrying current. According to Weber's, Ampère's law is incomplete because it refers only to small infinitesimal elements of current of the wire and not to the electric matters that pass through the circuit. This limit of the Ampère laws, was also known by Ampère himself who wrote that the electrodynamics theory will be complete only when an elementary law between electrical 'molecules', dependent on the speed of them will be found.

This suggestion was caught and developed by Weber that to obtain a law of force that was in agreement with the experimental result had to introduce in his law of force between charged particles terms that are related to the position, velocity and speed of the particles obtaining the following formulation for its law of force: $F = \frac{ee\prime}{r^2}\left[1 - \frac{1}{c_W^2}\left(\frac{dr}{dt}\right)^2 + \frac{2}{c_W^2} r \frac{d^2r}{dt^2}\right]$ where e and e' are the electrical masses and r is the distance between the two charged particles.

An interesting thing that had to be noticed is that for the first time in electromagnetism, in the development of the Weber's theory come out the idea of speed limit and could be mathematically proved that from the Weber force could be deduced the Faraday's law of induction.

Weber's law of force was developed around the half of the eighteen century, following experimental observations and consequently development of theory, highlight the need of developed furthermore the formulation of this law of force and several researchers worked on it. The one who reached the right formulation was Clausius that introduce also a law for the potential of his force. Indeed Schwarzschild introduced the idea of the retard of the propagation in the action of the Clausius law.

V.3 Faraday-Maxwell

At the beginning of the nineteenth century were known three ways in which the mechanical action could be transmitted: the collision, the remote action and the action in a continuous medium. While the gravitation was still considered as due to action at a distance throughout the nineteenth century, the electromagnetism began to assume at the eyes of the researchers a characterization in terms of action at contact. In particular the argumentation that supported that idea were that the propagation of electromagnetic actions it appeared to be dependent by the changes of the intermediate space between the interacting elements, the interaction required a propagation time and finally there was the conviction that there could be a mechanical model that was able to describe the propagation of the action through the medium.

Historically, for what concerns the electromagnetic induction, Faraday was the first researcher who proposed an interesting and useful use of field lines. The description of magnetic effects in terms of magnetic lines introduced a major change in the type of model used to describe the phenomena. With the field lines we go from an ampèrian description, which is based on the forces acting at a distance, to a description tied to the concept of field. This radical change is a scientific revolution that with Maxwell and his flux tubes completely changeed the interpretation of electromagnetic phenomena. Furthermore, as suggested in some educational researches [Bradamante, 2007] an approach based on the flux tubes has been shown to be of fundamental importance in building the bridge necessary to move from a description based on the action at a distance to one based on the concept of field.

Generally in today education the use of field lines is related only to the analysis of situations in which the magnetic field is static (such as in the case of permanent magnets or circuits in which flows a constant current). This attitude, however, can lead to the formation of conceptual knots such as those concerning the role of relative motion in the context of electromagnetic induction. Instead, if, as Faraday did, we extend this static approach to the case of variable currents assuming that the lines are moving when there is a variation of the intensity of current in the circuit, we can, through their visualization, giving to students a tool that allows them to face and overcome these particular conceptual knots. As the static description, this dynamic description is predominantly geometric and the use of animations and simulations can facilitate an initial approach to analyzing these phenomena.

In 1821, after having devoted his previous studies to chemistry, Faraday began to address issues specifically related to electricity. Just in 1821 a brilliant series of his research culminated in the discovery of electromagnetic rotations. Magnetic continues rotations, discovered by Faraday, was the major challenge to the electrical theory of Ampere, which deals exclusively of attraction and repulsion, but not rotations. Faraday published his discovery immediately in a paper entitled On some new electro-magnetical motions, and over the Theory of Magnetism (1821) and sent to various scientific communities small devices that produce these rotations.

The main objective of researchers at the time that dealt with electromagnetism, however, was to find the reverse effect to the one discovered by Ørsted. So they wanted to study the effect exerted by the magnetism on electricity. The goal was achieved by Faraday with the discovery of electromagnetic induction. This phenomenon, however, brought with him some unexpected features. First it was a transient phenomenon, namely that the passage of the induced current occurred only when you close the circuit inductor or when approaching the magnet, and also, opening the inductor circuit or taking away the magnet, is generated in the circuit an induced current with opposite direction to the previous one.

Faraday discovered electromagnetic induction in 1831, but his first work on the subject was published only in April 1832. He, in fact, because of the transience of the phenomenon, was conscious of being the only one who made this discovery and before publishing something about it he decided to devote himself to a deeper analysis of the phenomenon in order to achieve greater understanding of the important factors related to the observed phenomenon.

Faraday initially identified two types of induction: an electrovoltaic, and an magnetoelectric. The first was due to the passage of current, whereas the second was due to magnetism. According to Faraday electrovoltaic induction could be based on the concept of interacting current and the electrotonic status. This last concept was introduced by Faraday himself to explain the transience of the phenomenon. He suppose that the passage of current in the inductor circuit create this particular state that opposed themselves to the flow of the induced current interrupting it quickly. Opening the inductor circuit the electrotonic status stopped and generate a current opposite to that previously observed. In the magnetoelectric induction the effect depend not only on the configuration of the system, but also by the motion by which the configuration of the system was reached. Initially, in order to find an appropriate reference system to describe the phenomenon, Faraday used an ampèric approach to the problem, but this proved to be unsuitable. Was then that Faraday decided to take into account the magnetic curves that the iron filings form in the presence of a magnet and, according to them, he was able to explain the regularities that he had observed in the magnetoelectric induction. So Faraday reach the conclusion that the electric wire and the magnet moved relative to one another by ensuring that the curves were cut from the magnetic wire.

Faraday at this point however found by himself two explanation model for the same phenomenon that are incompatible one with the other: the first requires the existence of the electrotonic state, the second the cutting of magnetic field by the circuit. These two models came into open conflict when Faraday concern itself with the experiment of Arago . In particular Faraday realized that this experiment would be interpreted in terms of magnetic curves only if it was possible to assume the existence of curves even around the thread path from the current. Arago's experiment interpretation was crucial to place in discussion the distinction between magnetoelectric and electrovoltaic induction, but was not sufficient to give an explanation of the elettrovoltaic effects observed in the absence of relative motion between the circuits constituting the system. This problem for a long time gripped the Faraday's mind who managed to reach a resolution until March of 1832, just before his article was printed. Faraday realized that he could unify the two type of induction dealing with in terms of magnetic line cut, assigning also to the wire in which flows the current some magnetic curves which were free to move at the time of closing and opening the circuit. The introduction of these magnetic curves, which Faraday begun to call lines of force, will be crucial for the development of the theory of the electromagnetic field. Perhaps at the same time, however, the lack of a rigorous mathematical treatment, involved an initial rejection of his theories. Indeed in 1832, when Faraday proposed his concept of the magnetic curve, was not understood by his contemporaries and his ideas did not find an immediate success. This distrust in the work of Faraday lasted until the mid-forties, when W. Thomson became aware of the importance of these ideas and began to give them a mathematical basis. Later this work was completed and developed by Maxwell.

Reading the historical reconstruction above it is evident that it cannot be directly used as a guideline for an educational activity. For a student follow the route taken by Faraday would be very cumbersome. In my opinion the historical development of Faraday's ideas can at the best be the subject of a discussion in class, but not a learning path. The analysis of historical development allows the identification of what were the key points on which developed the theory and what are the crucial experiments useful for the emergence of new concepts.

Let us analyze the development of the ideas of Faraday by a didactic point of view: we consider Faraday as a student and see what was the methodology of work that he has followed. As a first step Faraday has set a goal of a general nature: discovering the opposite effect to that one discovered by Ørsted. To achieve this Faraday began an explorative investigation of magnetic and electric phenomena and their possible correlations. After that he had obtained a picture of the know effects of the various experiments he grouped experiments into categories and then tried to give a specific explanation for each one of this categories. Later he tried to give a unified explanation applicable to all categories of experiments. In this way he developed and tested a model (that one based on the field lines) and then tried to extend it in a different context than one where it was developed. The next step of Faraday is indeed to extend the field of applicability of his model taking into account the interaction between magnetic field and matter. Again Faraday starts with an experimental exploration and a categorization of the experiments and a partial explanation for each of the categories identified. Finally, introduces a general explanation in agreement with the model previously developed.

The analysis of the historical development of Faraday's research as well as allowing an analysis of the methodology used by him, can also allows us to identify which are the tools and the materials that we had to offered to students to provide them the best environment in which they can work.

In particular, as regards the first experimental exploration, we had to ensure that students have available, in addition to the magnets and the coils, a variable current power generators and objects of various kinds and in particular a rotating disk of aluminum that will enable them to carry out an experiment similar to Arago experiment. Besides this, students must be empowered to have an idea (albeit vague) of the representation of the field lines and the students' task had to be the discover of how this geometrical instrument should be used as part of the electromagnetic phenomena.

In this way the students have at their disposal all the elements to achieve those crucial experiments, which enabled Faraday to develop the idea of magnetic field.

V.4 The Hertz's representation of the main models of the nineteenth century as concern electromagnetism

Hertz, analyzing the models developed during the nineteenth century identified four types interpretation:

1) pure action at a distance, the force is exerted at the presence of the two bodies, the medium between the two is not taken into account and the action propagates with infinite speed;

2) potential theory, there is still an idea of action at a distance, the charges are still seen as the sources of the force, however, it is assumed that each interacting body try continually to exercise on all the surrounding points attractions of magnitude and direction defined, i.e. one body exerts an action on the whole space.

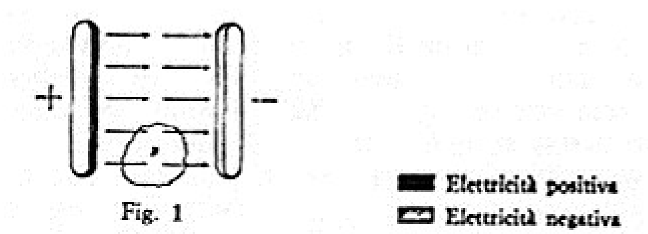


Fig. 1

The charges on the plates determine the forces, indicated by arrows, which however do not change the medium interposed, "it does not matter if the space between the plates is filled or empty". The potential is in some way a help to represent the forces at the points surrounding the charges, but the medium has no effect on them. This second point of view can be attributed to the schools of the action at a distance at a finite speed.

3) Forces induce changes in space (supposed to be not empty at any point) and these give rise to new forces at a distance. The attractions between distant bodies then depend

in part on their direct interaction and partly from the influence of the changes in the medium. It's always action at a distance, however the forces due to the free charges act on the dielectric plates interposed polarizing it. The parts of the dielectric become polarized and so become also a source of force. Hertz distinguishes two cases:

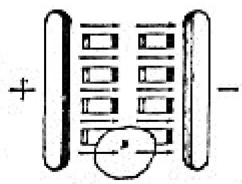


Fig. 2

Elettricità positiva
Elettricità negativa

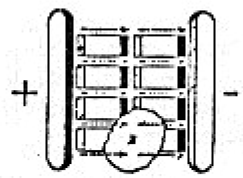


Fig. 3

In both it is assumed to be ether the medium interposed between the plates of the capacitor. The rectangles represent the polarized ether, while B represents an empity space. In B the polarizations of the medium disappear while the force remains. In the first case the medium plays a small part in the action and then role of free charges on the plates is pivotal. In the second case is preponderant the action of the dielectric, in the limit case may be considered that all the energy is in the medium and the forces at a distance are infinitely small and therefore there is no free electricity (The mathematical treatment of this limiting case leads to Maxwell's equations).

4. pure action through a medium; modifications or polarizations of the medium are real and the bodies act on each other through it, but, unlike before, it do not admit that these polarizations are the result of forces at a distance; instead the existence of all of these forces at a distance is neglected and does not exist the electricity from which these forces are supposed to be generated. Considered from the mathematical point of view this fourth method of treatment can be regarded as completely coincident with the limiting case of the third. But from the physical point of view the two differ fundamentally.

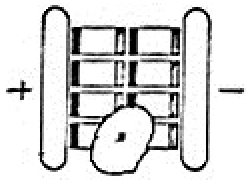
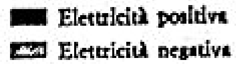


Fig. 4



The parts of the dielectric in fact are polarized in the opposite direction compared to the previous case, thus giving reason of the charges that are located on the plates and not vice versa as in the previous case. The charges on the plates are then either not seen as free charges, or source of actions. The emphasis is instead on the medium, the ether, which is the seat of electrical action. In fact, if in B is removed the ether, there's nothing left in this space, i.e. there is no action.

VI. RESEARCHES WITH PUPILS

VI.1 Introduction

As concern the specific case of the electromagnetism, research literature in physics education at all school level (Stefanel, 2005), highlights the presence of several typical conceptual knots in students' knowledge related to the concept of field also in static (Viennot, L. and Rainson, 1992; Guisasola et al, 1999; Tornkwist & Pettersson, 1993) and in dynamic situations (Thong & Gunstone, 2008, Maloney et al, 2001). Interesting results emerging in experimental intervention of research in primary school on electromagnetic phenomena (Michelini & Vercellati, 2010) and the important role of gradual building of concepts in learning (Vosniadou, 2008; Michelini, 2005) suggest the need to create a vertical curricula based on a continuum learning process that starts facing electromagnetic phenomena in primary school (Michelini & Vercellati, 2010).

As concern pupils' difficulties in magnetic, electric and electromagnetic phenomena and the idea of field the research literature highlighted how they are related to several factor as for instance an "at a distance" interaction vision (Bradamante et al 2005), and has the presence of several alternative models for the interpretation of the magnetic phenomena (Borges & Gilbert, 1998, Erickson, 1994) and, in addition, as concern the phenomena of the electromagnetic induction, several pupils represent the relationships in relational forms and seem to do not have access to a more global vision that includes several other situations (Michelini, Viola 2009). Understand that the interpretation of the phenomena of induction are due to a change in the flux of the magnetic flux through the circuit require the use a global perspective in which all the variables related to the production of the flux change and the rate of this change are simultaneously involved. Pupils must therefore learn to take this into account and it is particularly important that they became able to identify the emblematic situations that constitute the background of the operative space of the variables involved. Even the expert physicist, to interpret electromagnetic induction, needs to have in mind how the rate of change of flux can be produced by a variety of situations and he can do this only if he has a clear vision of the space of the variables involved and the different ways in which they can act in different situations. This is the first step of the process that will allow pupil to associate the right physical meanings to the physical laws becoming able to manage them and their roles. In cases like the ones that involves phenomena of electromagnetic induction the needs to keep in mind the space of variables and the ways in which these variables are able to produce significant variation of the magnetic flux are pivotal, pupils had to be able to master the phenomenology. Where, especially for children, 'master the phenomenology' cannot means 'make a collection of experiments', but it means to look at what happens in the different situations explored with the aim to gradually develops and rearrange all the experiences in an interpretive idea (that the physicist formalizes as the flux). That in the framework of the construction formal thinking turns out to be a conceptualization of the relationships between a certain groups of variables, but, as several work of research shown, abstraction is not a level in itself; it has to be gained gradually through a process of enlargement of abstract referent and interpretive frameworks and it cannot be done without the experimental construction of the referents. For these reason, the phenomenological experience must be the very first step in the construction of the formal entities that should not be postponed at certain age with surrogate models. In fact the development of formal thinking requires the identification of phenomenological aspects and their placement in a justification and explanatory schema that is related to a local view of the observed behavior and it will reach the interpretative dimensions only when, overcoming the zones of proximal development, it will extend themselves to different contexts preserving core elements and patterns of reference that constitute the core of the interpretative models in applicative terms. Three main elements are involved in this process:

- the analysis and the comparison of the simple phenomenological aspects,

- a reflection on the justifications of the phenomena that leads to the identification of conceptual references and argumentations aimed to highlight useful ideas to find path of argumentation,
- the identification of entities that represent the conceptual framework needed to reach scientific interpretations which validity is recognizable in very different phenomenological contexts.

The second element, the reflection on the phenomenology, usually is not activated spontaneously and so specific strategies had to be developed to promote pupils to explicit the useful conceptual referents. To provide to pupils a specific environment in which they can explore experimentally the phenomenology of the physic world, the Conceptual Laboratories of Operative Exploration (CLOE) were developed.

VI.2 The strategy: Conceptual Laboratory of Operative Exploration (CLOE)

Conceptual Laboratories of Operative Exploration (CLOE) were designed by the research unit in physics education of the University of Udine to provide to pupils an informal environment in which explore the phenomena (Michelini, 2005).

Several research based on CLOE labs were carried out on particular topics – i.e. thermal phenomena (Michelini & Stefanel, 2010), circuits and current (Testa, 2008) and electrostatic (Michelini & Mossenta, 2010). Every CLOE labs is carried out by a researcher on a specific topic and it is based on a semi-structured interview protocol, which represents an open work environment through the proposal of everyday life scenarios. Phenomena in everyday situations are explored following sequences of reasoning by means of simple hands-on apparatus in different contexts providing so an informal workshop that stimulates pupils' conceptual reasoning and offers anchors for the construction of their first steps in scientific knowledge starting from the common sense vision (Bradamante & Michelini, 2006). In CLOE labs through everyday-like scenarios (realize with poor everyday objects) pupils explore the phenomenology, structuring their knowledge in the building of the connections between the explored situations and their personal experiences. In this way the experimental observations, the peers' discussions and the stimulating role of the researcher create the conditions of the environment in which a reflective inquiry process could affectively take place (McDermott, 1996; Lyons, 2010; Brookfield, 2000; Schön 1991).

In particular as concern electromagnetism, previous studies (Fedele et al., 2005) shown that some basic concepts of magnetic phenomena, such as the types of interaction between magnets and other materials and magnetic poles, are possible to be address in this way. Furthermore, similar studies on the electrical circuits have shown how children learn to manage circuits in functional terms, overcoming local visions associated with the role of individual elements (Testa et al., 2008).

With the aim to investigate how pupils develop interpretative ability to explain situations and artifacts from the results of several phenomenological investigations of physic quantities, specific activities were designed in the framework of the Conceptual Laboratory of Operative Exploration producing so a learning path suitable both for primary and middle school pupils.

VI.3 Brief overview of the research work done with pupils

Research work with pupils was realized using the CLOE lab strategy and it was constitute by three main activity of experimentation.

The first one is the investigation of the pupils' naïve ideas, perspective and way of learning. It was done through a laboratorial activity, that proposing everyday life scenarios, allows pupils to explore situations in which magnetic, electric and electromagnetic phenomena was analysed. In this activity pupils discuss between them and, using their own words had to interpret the observed phenomena.

The second activity is constitute by the experimentation of the first version of the learning path paying particular attention on the study of the role of the key experiments and the way in which pupils re-use the knowledge that they acquire during the learning pat in the analysis of everyday scenarios through the study of particular everyday use artefacts.

Then, the third activity was the experimentation of an improved version of the learning path redesigned on the base of the indication acquired by the results of the previous experimentation. That allow for its whole length is schematically represented in Figure P.01.

1) I have a box with several objects.

How can you identify the magnet(s) among them?

2) Holding a magnet, when I approach different objects

Before the experimentation: What type of and how many interactions would you expect to observe?
Experimentation: describe the behavior of the magnet when I approach it to each one of the following: ping pong ball, clip, another magnet, compass
After the experimentation: How many and what kind of behavior do you observe?
How do you categorize the compass?

3) Approaching a clip with magnet

Describe what do you observe:
Is it the magnet that gets attracted to the clip or is it the clip that gets attracted to magnet?
How can you prove (experimentally) your answer?
Do the experimental results concorde with your previous answer? Explain

4) Approaching a magnet with another placed on the table

Before the experimentation: What type of and how many interactions would you expect to observe?

5) Placing two magnets on two floating polystyrene pieces

How do the two magnets interact? Do the experimental results concorde with your previous answer? Explain

6) Two magnets in a pipe

What type of and how many interactions would you expect to observe? How do the two magnets interact? Do the experimental results concorde with your previous answer? Explain

7) Consider a suspended magnet and a compass

Do you think the needle of the compass a magnet? Can you experimentally prove your answer.

8) Placing a compass on the table

Observe the direction of the compass needle
Rotate and place the compass at the same point: Does the direction of the compass needle change? Explain
Explain how can we change the direction of the needle

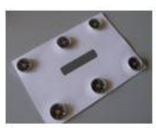
9) Approaching a compass with a magnet

Do you observe a change in the needle's direction? Is it necessary that the magnet touches the compass or is it enough that the magnet gets in to the neighborhood of the compass? Explain

10) Place several compasses on the table

Observe the direction of the compasses needle
How is the direction of the compass needle change? Explain

11) Place a magnet between the compasses



Observe the direction of the compasses needle
How is the direction of the compass needle change? Explain

12) Place a compass board on the table

Observe and describe orientation of the needles. Placing a magnet on the compass board, how does the direction of the needles change?

13) Exploring the space around a magnet with a compass

Draw the lines around the magnet which represents the direction of the compass needle: describe the pattern.
Do they intersect? Explain
Moving the compass along a line, does the compass needle always point towards the magnet? Explain

14) Exploring the tridimensional space surrounding the magnet

Thinking of a pattern that you drew, do you think is it confined to a particular plane or to the whole space surrounding the magnet? Explain

15) Consider a wire carrying a current

Do you expect to see some interaction by approaching the copper wire with a compass. Explain
Do the experiment: is it in concordance with your prevision?
Connect the copper wire to a current generator. On interaction with the compass needle does it change? Explain
How do you interpret it?

16) Place a compass board on the table

Observe and describe orientation of the needles.
See the pattern of a coil and a series of coils carrying a current.
Find similitude and differences of the various pattern observed (including the magnet one)

17) Magnet and coil carrying a current

Do you thin that they interact? Why?
How do they interact?
Do the experimental results concorde with your previous answer? Explain

Figure P0.1 Schematic Representation of the proposed learning path

VI.4 ACTIVITY P1.

Today, electromagnetic phenomena became part of our everyday life. During each day everyone uses several electromagnetic devices to do a wild range of activities and scientific terms as ‘magnetic poles’ and ‘magnetic field’, become part of the common language but this popularization of physics terminologies, however, was obtained through a loss of accuracy of the real physical meaning of these quantities.

Even pupils, playing with several magnetic and/or electric toys, observe in their games some basic electromagnetic behaviour and, spontaneously, they construct their own naïve mental models related to the phenomenology that they had explored (Gilbert et al, 1998). Pupils’ spontaneous models are related to conceptual elements and reasoning on problematic situations that they had faced in their everyday life (Viennot, 2006) and previous researches (Ioannides & Vosnidou, 2001) showed that pupils’ mental models are coherent explanatory frameworks that have the forms of a theory – although they differs from a scientific type of knowledge (Carey, 1985). In addition, Eshach, H. and Schwartz (2006) highlight that pupils have a more spontaneous need of coherence at local level rather than a global ones. Connection between different scientific topics and everyday knowledge is one of the main learning problems in scientific education (Jonassen, 1991).

To investigate the pupils’ naïve ideas and languages as concern electromagnetic phenomena, a first experimental activity was done. With the aim to propose to pupils an environment that is as close as possible to an everyday scenarios, the activity was held in an informal context were the pupils can explore and experiment different situations realize with everyday materials and pupils could interact one with the others (and the researcher) without the restrictions imposed by the classroom environment. In particular in this activity, after a briefly introduction in which are recalled the pupils naïve idea as concern magnets and electric currents by means of simple experimental exploration done with the apparatus listed in Figure P0.1, was proposed to the pupils to explore the phenomenology of the electromagnetic induction phenomena using the apparatus displayed in Figure P1.1 through a the use Popular Problem Solving approach.

Popular Problem Solving had shown to be one of the best strategies able to promote conceptual change (Watts, 1991; Michelini 2005). It is a strategy of learning based on the use of problems in which the pupils are called to assume the responsibility of solutions. Furthermore, the peer's cooperative learning during group works plays a key role in the process of the construction of knowledge when ideas and reasoning-sharing involves cognitive processes, skills and capability (Pontecorvo, 1993; Pontecorvo et al., 1991; Santi, 1995). In this process, pupils had to be able to: organize their information and learn to draw conclusions, share and defend their own ideas, let challenge them with opposing perspectives or arguments, live a conflict and a conceptual uncertainty (Johnson et al., 1995), activate an epistemic curiosity and take a stand and, at last, reformulate, conceptualize, synthesize and integrate them (Comoglio & Cardoso, 1996). In that situation, the Popular Problem Solving allows to increase the pupils' need of development of reasoning and argumentations that had to be based on persuasive argumentations. The task becomes so a useful opportunity to do deep reflections concerning an area of the subject that is much wider than the one defined by the specific task.

In the context of this first experimental investigation, research was focused on the fallowing four research questions:

RQ1 How do pupils approach spontaneously the artifacts exploration looking to the phenomena involved?

RQ2 Which are the operative ways that they recognize and perform to produce electromagnetic induction?

RQ3 Which are the physics quantities that pupils adopt as conceptual referent(s) in the description of the electromagnetic induction?

RQ4 Which representations and formal entities they introduce to explain the electromagnetic induction?

The process of spontaneous approaching to the task was observed. First of all analyzing how pupils spontaneously look at the induction phenomena and describing the apparatus looking in particular if in their description there is a conceptual organization related to the solution of the problem (RQ1). Than attention was focused on the ways adopted to produce electromagnetic induction and on how they recognize the presence of the induction phenomena using the offered equipment (RQ2). Last, but not list, the investigation done by RQ3 and RQ4 on how pupils, starting from their experimental explorations, formalize their results, focusing their attention on crucial elements with (eventually) the introduction of formal entities.

Sample and context

To investigate naïve ideas in an heterogeneous sample of primary pupils, a two hours long CLOE activity was carried out with 52 primary school students coming from different classes visiting the annual festival of science "YOUng 2009". Activity was held in different turns depending by the pupils' ages: 12 pupils were six years old, 17 were eight years old and 23 were ten years old.
The whole CLOE activity, based on the study of the relationship between magnetic field and electricity, was divided in three principal phases: introduction and task assignment (30 min), group experimental exploration (1 hour) and plenary discussion (30 min).
Experimental explorations were done through group discussions, interviews, sketching drawings and writing answers of the posed problems in the form of interpretive challenges on a ludic plane.

In the first phase a semi-structured plenary discussion done with the whole class is focused to attract the pupils attention and create resonance between some important aspects of the phenomenology and the pupils' common sense ideas recalling some aspects of their everyday life that are related to electric and magnetic phenomena – i.e. the behavior of toy magnets and compasses, toys or objects that need an electric current to works, elements used to produce or supply electric current in our houses and so on. During this phase interactive lecture demonstrations (using simple experimental apparatus realized with everyday life materials) were proposed to pupils. Discussion was done using, as in the Rogersian interviews, only the words that pupils use to describe and explain the phenomena.

In the second phase, pupils were leaving completely free to explore phenomena by means of available apparatus in self-organized small groups (groups of minimum 4 and a maximum 5 pupils for each were allowed to promote the cooperative learning)
During the second phase, the equipment available for each group is: a pair of big magnetic plates (with a surface of 10x20 cm) with their holder, analogical micro-ammeters and several coils whit different surfaces and number of circumvolutions and conducting wires to do the connection between the coils and the micro-ammeters (Fig. P1.1). Pupils had to do connection between the different components and try to generate a current.

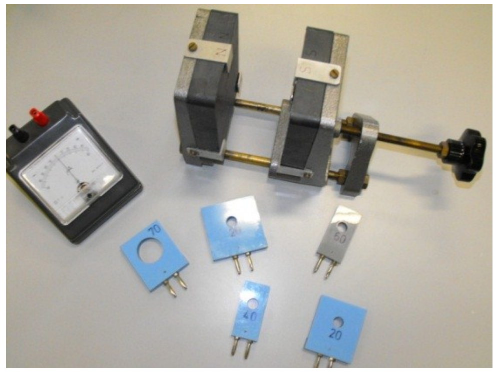


Fig. P1.1 Experimental Equipment

The goals of the plenary discussion in the third phase is to look at the ways in which the comparison of pupils' ideas produces a global vision from the local one by means of the process of cooperative learning that pupils do to individuate a set of shared procures producing current induction starting from the ones identified by pupils. After that, pupils tried to give an explanation of the observed phenomena.

Description of the activity

The problem of generate an electric current without a battery is posed in the context of the analysis of the magnetic effects related to a current. The adopted methodology is those of popular problem solving approach in terms of a challenge that had to be performed with assigned resources. All pupils involved have already seen and played with magnetic toys and/or they have use them in another section of the GEI exhibit (offered in the same context during the annual festival of science "YOUng 2009") and describe with their words the principal propriety of mutual interaction between these particular objects. Taking a compass and creating resonance with the pupils' idea of Earth's magnetic field, pupils introduce the idea to associate to each magnet a magnetic field (Fedele et al., 2006). An operative definition of electrical current is built through an experimental approach (Testa & Michelini, 2008).

Micro-ammeter, that is not part of the everyday experience of the pupils, is introduced in operative way as an instrument able to detect and measure the intensity of an electric current.

The introductory phase provides a review of phenomenological aspects related to the presence of magnetic fields when an electric current occurs. Using a compass and an Ørsted-like GEI exhibition equipment set-up (Michelini et al, 2003), we explore the correlation between electric current and magnetic field. The assigned task is to explore if the reverse process is possible and study the principal elements needed for its realization using the available instruments.

In the experimental phase, pupils work in small groups experimenting themselves the phenomena and using the experimental apparatus equipped how they prefer. In this phase the teacher's role is marginal: pupils explore freely the phenomena while teacher observes the pupils behavior without interfere. Communications between different groups are not interdicted, but each pupil of each group had to write his own notes on his personal worksheet. Each pupil had to describe the apparatus and to explain how he is able to act to produce electromagnetic induction being free to decide if write sentences, or draw, or both.

In the plenary discussion of the third phase teacher lists the pupils proposals reproducing each one in the exact way in which the pupil said. All pupils, reasoning on how the particular procedure works, comment it, suggest modification and specification identifying gradually the key points. Even in this phase a Roger like discussion is promoted to favorites the building of a general set of procedure able to produce induction individuating the key points needed to give an interpretation of the phenomena.

Instruments and Methods

Data were collected in each phase of the work. During the two big group discussions another researchers take note of the dialog and during the experimental phase data are collected using worksheets. In this paper, we focus our attention on the spontaneous approaches of the pupils in the analysis of the phenomena. Particularly we analyze what pupils wrote and drew on their worksheet during the exploration phase. Each pupil can write or draw what he sees and what he thinks it's important to obtain the desired effect and he had to write his conclusion on his personal worksheet.

All the 12 six years old pupil have done a picture of the experiment and 6 of these also write a short sentence about the experiment. Between the 17 eight years old pupil 4 pupils only drew a picture, 8 pupils only write a short sentence, 3 did both and 2 pupils returned a white worksheet. At last, all the 23 ten years old pupil wrote one or more sentences and only 3 of them also drew a picture.

Data and Data Analysis

To carry out a preliminary content analysis of pupils' worksheet some keywords and key-elements present in them were analyzed. Using a dictionary based approach, we look at which are the element of the experimental apparatus that are present in pupils' descriptions (Table. 1) and which are the physics entities that pupils introduce to explain the phenomena (Table 2). Moreover we look at which are the procedure to produce electromagnetic induction that they explicit on their worksheet and in which ways they recognize the effect (Table 3).

Table 1

	6 years old (12 Pupils)	8 years old (17 Pupils)	10 years old (23 Pupils)
Experimental apparatus	**12**	**15**	**23**
Magnet	11	5	10
Distance regulator	11	2	4
Ammeter	10	1	16
Index	5	7	9
Graduate scale	7	3	4
Coil/Circuit	11	12	13
Surface	2		1
Number of circumvolution	8	2	1
Connection	11	3	3
Ammeter-Circuit	10	3	3
Ammeter-Magnet	1		

Table 2

	6 years old (12 Pupils)	8 years old (17 Pupils)	10 years old (23 Pupils)
Physics entities	**6**	**8**	**21**
Magnetic poles	1	1	
Magnetic field	2	3	5
Electric Tension			12
negative and positive			12
Electric Current	2	4	1
negative and positive			1
Energy		3	6
negative and positive			5
Transient	1	3	17

Table 3

	6 years old (12 Pupils)	8 years old (17 Pupils)	10 years old (23 Pupils)
Action needed to produce electromagnetic induction	**5**	**3**	**15**
Circuit Movement	5	3	12
Circuit Rotation			1
Relative motion between circuit and magnetic field	2		5
Relative motion between circuit and magnets	2		9
Effect detection	**3**	**2**	**4**
Movement of circuit and movement of index	3	2	2
Index don't move if circuit moves between magnets			2

Data discussion

RQ1 Looking at the Table 1, it's manifestly how the six years old pupils describe each element of the experimental equipment in detail. For instance many of them represent on their worksheet the graduate scale (7/12) and the index (5/12) of the ammeter and the various number of circumvolution of each coils (8/12). Two pupils also highlight the different coils surface. This detailed description of the experimental equipment allows the six years old pupils to detect all the simple variables and parameters that characterized the experimental equipment. In this way they can highlight the presence of elements, like for instance the distance regulator of the magnets' holder (11/12), that, are related to physics quantities involved in the process, even if they are not strongly manifest due to the structure of the experimental apparatus. In addition, the six years old pupils also describe the cable connection done between the various elements (11/12). This six years old pupils naïve approach highlight how they mainly give a structural description of the apparatus that reach a degree of detail that is higher than the other groups of ages

The eight years old pupils focused their attention on elements, as the ammeter's index (7/17) and the circuits (12/17), that during the experimental exploration are in motion and that is strongly related with the generation and detection of the phenomena. Also the ten years old pupils focused their attention on some particular element of the apparatus, but beside the ammeter's index (9/27) and the circuits (13/23), they identified magnets (10/23) and ammeter as important elements (16/23) in the apparatus equipment. These selections of important elements denote the tendencies for the eight and ten years old pupils to give a functional description of the experimental apparatus: pupils focus their attention on what they consider to be related to the investigated phenomena.

RQ2 Pupils highlight the central role of the ammeter and the movement of its index as instrument useful to individuate qualitatively the presence of electromagnetic induction effects measuring the current flowing in the circuit (10/12; 9/17; 16/23; respectively for pupils of 6 – 8 – 10 years old). A small number of pupil (6/52) try to give a quantitative description using the ammeter's graduate scale. For instance a 10 years old pupil wrote: "*The circuit with 70 (circumvolutions) can also arrive to + 30. The circuit with 60 (circumvolution) can arrive to +10*". This means that pupils mainly use spontaneously a qualitative approach to the investigation; quantitative aspect are highlighted only by few pupils.

Furthermore is truly important that 2 pupils explicit that if the circuit is moved between the magnets and the index of the ammeter doesn't move. That's important because it denote the capability to understand that to analyze a phenomena is necessary to highlight also the situation in which it doesn't occur overcoming the analysis of the only elements that in the phenomenology represents elements of surprise.

All the groups performed at least a procedure able to produce electromagnetic induction and in particular the role of the movement(s) of the circuit was highlighted. In particular 2 of six years old pupil and 5 of ten years old pupil explicit that this movements are relative between circuit and magnetic field, while 2 six years old and 9 ten years old pupils explicit that the movements are relative between circuit and magnets. For instance a 6 years old pupil wrote "*index move when the circuit is inserted into the magnetic field*" and a ten years old girls explicit several procedures and also denote that an electromagnetic induction effect can occurs also when the circuit rotate between magnets. Particularly she wrote:

"*If the circuit moves to the outside vertically, index first goes in the negative then in the positive range. If you move the circuit vertically above the two magnets the index don't move too much, but if the circuit is put horizontally, index moves more. If you move the circuit more quickly and spread the magnets nothing happens. If you move the magnet* *faster the index overcome 20 instead moving the circuit slowly the index does not exceed 10. If you rotate the loop inside the magnet the index goes into the positive*"

As can be seen in this description of operative procedure, the pupil can recognize many situations suitable to product electromagnetic induction. That denote a capability to analyze methodically many single simple situation highlighting from each one of them the principal important aspects related to the phenomena that they are investigating.

RQ3 Several important physical entities were named by the pupil to describe the phenomena that they observed. But, as said in the introduction to this activity, when pupils deal with particular physics entities, like for instance magnetic field (10/52), electric current (7/52), electric tension (12/52) and energy (9/52), it doesn't mean that pupil had a physical idea of these entities, but only that they have already heard these particular words. Pupils however, approaching the analysis of the electromagnetic induction in a context like the one proposed in our activity start to associate these words to specific contexts and situations begin so to relate these words to the reality.

RQ4 Starting handling these physics concepts pupils give explanation of the single situation in which they identify that electromagnetic induction occurs. More than half of the ten years old pupils assert that one of the main important characteristic of the electromagnetic induction is that it is a transient phenomenon and wrote that related to the electromagnetic induction there is a generation of electric current (7/52) or tension (12/52) in the circuit. They deal with of electromagnetic induction in terms of movement or rotation of the circuit related to the magnet or the magnetic field. So, even if their idea of magnetic field is not structured as the physical concept, during the exploration they spontaneously link some specific situations to a change of particular physic entities. Pupils spontaneously do not achieve a vision of synthesis but that doesn't mean that pupils can't reach this synthesis by themselves, this means only that, as expected, pupils don't try spontaneously to give a global explanation of the phenomena, but they spontaneously look at the phenomena in a local way construction a set of different actions able to generate electric current.

Conclusions

From this first activity emerges that pupils of the primary school had already faced in their everyday life some electromagnetic phenomena and use terminologies that comes from physics. But, as highlighted into the data analysis, it doesn't mean that these words are related to entities defined into the physical theories. In addition, as highlight in literature, when they face a physical situation their spontaneous approaches are aimed to found a local description of the phenomenon, not to look for the construction of a more general theory. So they found and implemented a set of situations in which the phenomenon occurs relating the reliability of the induction phenomena to a set of relative movement between the coil and the magnets.

But, from the other hand, through the experimental approach pupils are able to contextualize the words that they used and for instance they begin to correlate the magnetic field to the magnet and the current as something that goes into the coil. In particular pupils indicate the magnetic field as a zone of the space surrounding the magnets giving to it a first physical meaning than even if it differs from the real physical meaning allow them to identify the magnetic field as a property of the magnet that influence the object that are put near them.

As concern the observation and the degree of detail of the description of the apparatus, it is high especially for what concern the six years old pupils, while the eight and ten year old pupils focused their attention to the functional aspect of the apparatus an also gave only the description of the components that are directly involved into the phenomena.

These two different approaches allow pupils to highlight different aspects. In particular the structural approach adopted by the six years old pupils allow them to highlight all the components of the apparatus and consequently all the parameters and variables that could be changed, while the functional approach used by the eight and ten years old pupils allow them to identify which are the main elements involved and, focusing their attention on a smaller set of variables and parameters, can provide qualitative and (sometimes) quantitative relation between the variables involved.

VII. ACTIVITY P2.

Research literature in physics education highlight as the role of experiences is pivotal in the construction of knowledge (Jonassen, 1991; Duffy & Jonassen, 1992) and some typical persistent conceptions (Driver & Erickson, 1983; Duit, 1991; McDermott & Redish, 1999) may constitute difficult barriers to overcome (Clement & Brown, 2008).
In particular, the local vision in the interlaced interpretation of the phenomena is one of the main problems in scientific education. More specifically, as concern electromagnetic induction the bridge from a local to a global vision lies in the interconnection between the different situations that are able to generate electromagnetic induction and in the gradual increasing of identification of the different aspects and perspectives. Complex phenomena, more variables dependent, require an analysis of the roles of the different quantities involved in the system representation, so, even if at the beginning a spontaneous local vision is the needed background, it has to be overcome with the construction of a wider global vision. The stop to a local vision is a huge problem in the scientific learning because the observation and the analysis of multiple situations are not enough to give a satisfying theoretical framework able to interpret the phenomenology (Bradamante et al, 2006).

Gradual process based on continuity in the construction of scientific knowledge starting from pupils' ideas and everyday knowledge, showed how the construction of scientific knowledge requires a personal involvement of the pupils and the analysis of the interpretative reference elements looking in particular at how informal learning plays an important role in conceptual change process (Vosniadou, 2008). To ensure that pupils build bridges between the local vision of common sense and the global scientific interpretation, hands-on and mind-on activities that involve pupils are needed (McDermott, 2004). It is therefore necessary to design educational interventions that help pupils to bridge from a common sense to a scientific interpretation of the

phenomena overcoming spontaneous model (Pfundt & Duit, 1993; Viennot, 2006) through predictive conceptual models (Gilbert et al, 1998; Hestens, 1987; Gentner & Stevens, 1983).
Informal situations in which pupils explore and experience directly the phenomena are a valuable starting point for the activation of reasoning related to conceptual re-elaboration (McDermott, 2004; Michelini, 2005) and knowledge building (Viennot & Raison, 1999). Research shown that pupil's involvement increase when task is given in an informal and not strictly structured situation: in this way, the assigned task can be seen by the pupils like a play, or a challenge, in which they are protagonist (Watts, 1991).

In this work three research questions were investigated: RQ1) how an operative exploration may help pupils to identified and organized electromagnetic induction; RQ2) how the exploration and the comparison between phenomena is useful to help pupils in the interpretation of artifact; RQ3) how exploratory elements are reused by pupils in the interpretation of artifacts.

Context and Sample

As the activity P1, this experimental activity was done in an informal context but, these times, in the sample were also introduces classes coming from lower secondary schools. This choice was done on the light of the previous results that highlighted how also in the primary school there were spontaneous functional analysis of the experiments and the consideration that usually in the primary school the electromagnetic phenomena are usually bypassed or treated only in a superficial and/or without using experimental approaches.

This experimental activity, activity P2, was held during a science festival – “Mediaexpo 2009” – involving 135 middle school pupils aged from eleven to fourteen years old (6^{th} to 8^{th} school grade). There were 7 classes involved: one of 6^{th} grade (20 pupils), three of 7^{th} grade (60 pupils) and three of 8^{th} grade (55 pupils).

Description of the activity

Activity is divided in two phases: 1) an inquired based experimental learning path - explorative phase; 2) a structured analysis of an artifact.

To promote cooperative learning, during the inquired based learning path pupils worked in groups of 5 but, to acquire data from each pupil involved, each pupil had his/her own personal worksheet. Communication between groups was not interdicted and after each proposed experimental exploration of a specific phenomenon there was a class discussion in which pupils organize their observation and learn how to draw conclusions, share and defend their ideas and challenge them with opposing perspectives or argumentations.

The equipment used by each group during the first was composed by: 6 compasses, 1 cardboard (A4 sheet dimension), a pair of big magnetic plates (with a surface of 10x20 cm, the ones used also during the activity P1) with their holder, analogical micro-ammeter and many coils with different surface and number of circumvolution and conducting wires to do the connection between the coils and the micro-ammeter. In this activity the setup of the classroom is also pivotal: to avoid interference with the functioning of the compasses, plastic garden tables were used and several everyday objects (Hifi, computer, mobile phone…) and some laboratory object (coils, coils carrying a current, generator…) were spread around the classroom.

The inquired base explorative phase consists of four learning macro-steps: S1) study of the compasses behavior far away from other objects; S2) study of the compasses behavior near a magnet; S3) individuation of the magnetic field source; S4) discovery and study of the electromagnetic induction.

During the macro-steps S1, we proposed to pupils a first simple exploration of the Earth magnetic field using compasses as an explorer of "a propriety" of the space (initially the use of the terms "magnetic field" was intentionally avoided because one of goals of these activity was to construct with the pupils the 'real' physical meaning of such entity). During S1 pupils used only compasses and cardboard. In this phase pupil had to answer on their personal worksheet to three specific questions:

S1.Q1 After placed the cardboard on the table with a compass upon it (Figure P2.1). Which is the direction of the compass needle?

S1.Q2 Rotate the cardboard at an arbitrary angle; wait and observe the needle. Which is the direction of the needle?

S1.Q3 If we use more than one compass, which will be the direction of their needle? Try it.

Figure P2.1: Compass

After that (and each one of the all other steps) there was a class discussion concerning these first observation.

During S2, pupil started to explore the behavior of a set of compasses when they are placed near a magnet using a set of compasses.

S2.Q1 Paste 6 compasses on the perimeter of a sheet of paper (4 on the corners and 2 on the middle of the longest side – Figure P2.2). Then put a magnet between them.

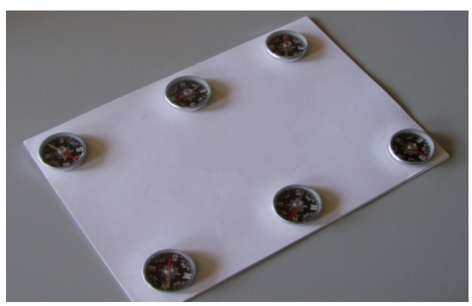


Figure P2.2: Set of compasses paste on cardboard

Which are the orientations of the needles?

In S3 pupil are free to explore all the object present in the classroom with the set of compasses built in S2 looking for other type of object that are source of magnetic field. In this phase the setup of the classroom is pivotal: pupil must be able to find a large set (as large as possible) of common everyday-life objects.

S3.Q1 Are magnets the only objects able to change the orientation of the needles? There are other objects able to do it? Explore the room and check each object using the table of compasses. Which object can do it? (Which no?).

S3.Q2 Which are the common element(s) in the objects that can orientate the needles?

S3.Q3 Put a coil between compasses. How are the directions of the needle?

S3.Q4 Leave the coils between the compasses and connect it to the generator. What's happened to the compass needles.

In S4, after that they have shown that an electric current can generate magnetic field, they explore, whit a problem solving like approach, the phenomenon of the electromagnetic induction. For this phase data were not collected on worksheet because an experimentation of this phase was already done in activity P1 (Michelini & Vercellati, 2009).

At the end of the inquired learning based path, during the second phase, artifact is offered to pupils without any introductive explanation; the only instructions gave to pupils is concerning the methodology that they had to follow in the artifact analysis: initially pupils only looking at it had to say what is it, describe it on their personal worksheet and , after that, when all group had finished the first part, they can touch experimenting its functioning and, if they think it's necessary, they can improve their first description.

In the second phase, to look at the ways in which pupils re-used in real word situation the knowledge that they had construct during the experimental learning path, was

Figure P2.3: Induction torch

proposed to them the analysis of the artifact represented in figure P2.3. This analysis was provided as a personal challenging task that had to be realized following a structured protocol. By this protocol, pupils initially can only look the artifact and describe it (writing the description on their own worksheets, and only after that they were allowed to touch and experiment it and describe it again. After that a final class discussion were promoted. The choice of this

Data and Data discussion

As concern S1.Q1: 68% answer NORD, 20% report the cardinal point that appear to be under the needle tip (as shown in the Figure 2, in the compasses used the cardinal point are painted on a fix background), 7% describe the direction of the needle using object present into the classroom (for instance one pupils wrote "*the needle of the compass points in the direction of the blackboard*") and 5% did not answer.

Concerning S1.Q2: 80% highlight that the direction is always the same, 10% say that the direction change, 5% say that the cardinal point change and 5% don't answer

At S1.Q3: 96% say that al compass needles have the same direction and 4% don't answer.

Looking at the data for the questions S1.Q1; S1.Q2 and S1.Q3 emerges how the exploration of the processes promotes an evolution of the way in which the pupils face the analysis of the phenomena. In S1.Q1, in fact, 68% of the pupils give an answer as an assertion without looking at the experiment apparatus (i.e. “compass needle point to north”) respect to 27% of them that referring their answer to the specific situation. Then, already in S1.Q2, after the first exploration, pupils’ answers are focused on the elements they think are the important ones in the description of the phenomena: compass needle 80% or compass background and needle 15%. Indeed, in S1.Q3 96% of the pupil refer their answers only to the direction of the needle.

As concern the interpretation of these observation, done during the first class discussion, pupils argued the shared opinion that whit this experiment we show that there is something, “a propriety”, in the space that oriented the compass needles.

At S2.Q1 pupils, describing what’s happened to the needles of the compasses pasted on the cardboard saying that: all needles point to the magnet (39%), needle of the compasses in the corner point to the magnet but the other two are parallel to the magnet (24%), compasses “*become crazy*” (20%), needles change their direction (6%), compasses “*lose their magnetization*” (5%), did not answer (7%).

Analysing questions S2.Q1four different approach are manifest: 39% of the pupils looking for a collective behaviour of the needles, 24% recognize the presence of a pattern, while 31% of the pupils (20% + 6% + 5%) answered to this question reporting only that there is an unspecified change in the needle directions (Figure P2.4). In particular, 5% of the pupils (included in the last 31%) highlight explicitly a casual effect.

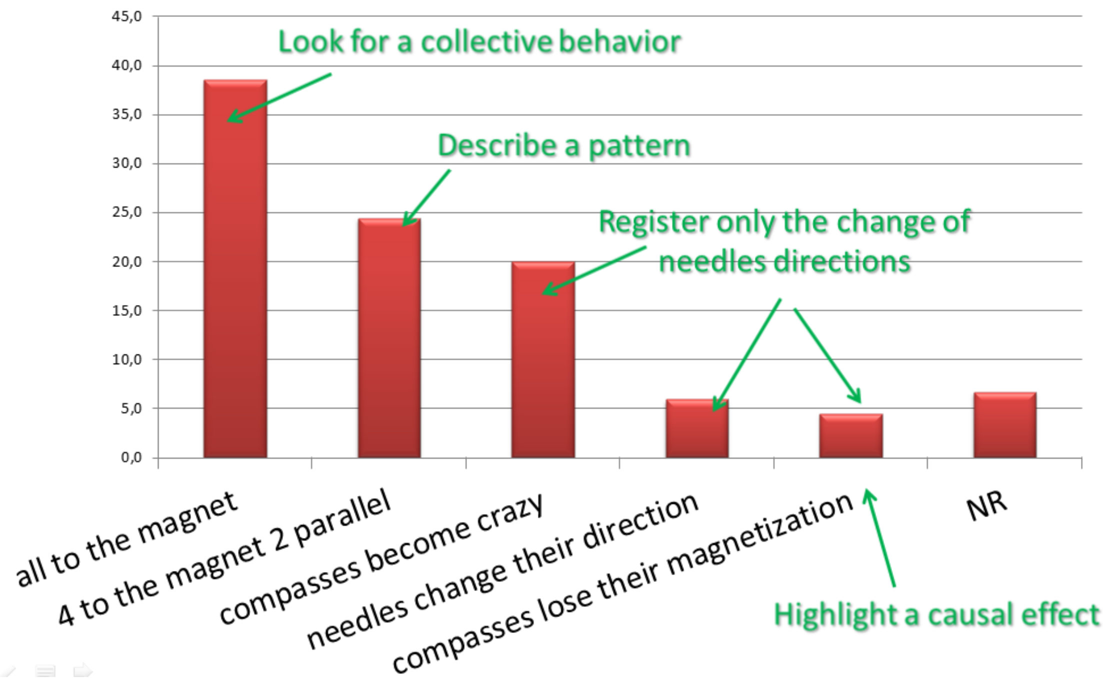


Figure P2.4 Answers to question S2.Q1

At the question S3.Q1, each pupil answer to it providing a tables in which are reported the object that he/she had tested and for each tested object the pupil reports if it affect or not the direction of the needle of the compass. All the tables compiled by the pupils are summarized in table Table P2.2 and the results are graphically represented in Figure P2.5.

As concern question S3.Q1, the more interesting part was the pupils discussions in which each object was analysed and in particular, relating to the case fire extinguisher, pupils propose a method aimed at discerning if an object that is able to change the needle orientation have or not an own magnetic field. In particular pupils argued that, while in the case of an object that has a own magnetic properties the needles of the compasses arrange themselves in a pattern, in the case of an object that influences the compasses without having an own magnetic property, all the compass needle are attracted by the object and so there is not a pattern in the needle orientation.

Tested object	Can (%)	Cannot (%)	That's strange (%)
Coils with current	32,6		
Coils	26,7	24,4	
HiFi	21,5	12,6	
Computer	20,7	15,6	
Mobile Phone	17,0	3,0	
Fire Extinguisher	15,6	34,1	8,1
Blackboard	11,9	14,1	
TV	7,4		
Windows	5,2	14,1	
Generator	3,7		
Metal pipe	1,5		
Plastic table	0,7	8,1	
Professors' head	0,7	0,7	
Blackboard eraser	0,7		

Table P2.2: Which are the objects that can change the orientation of the needle?

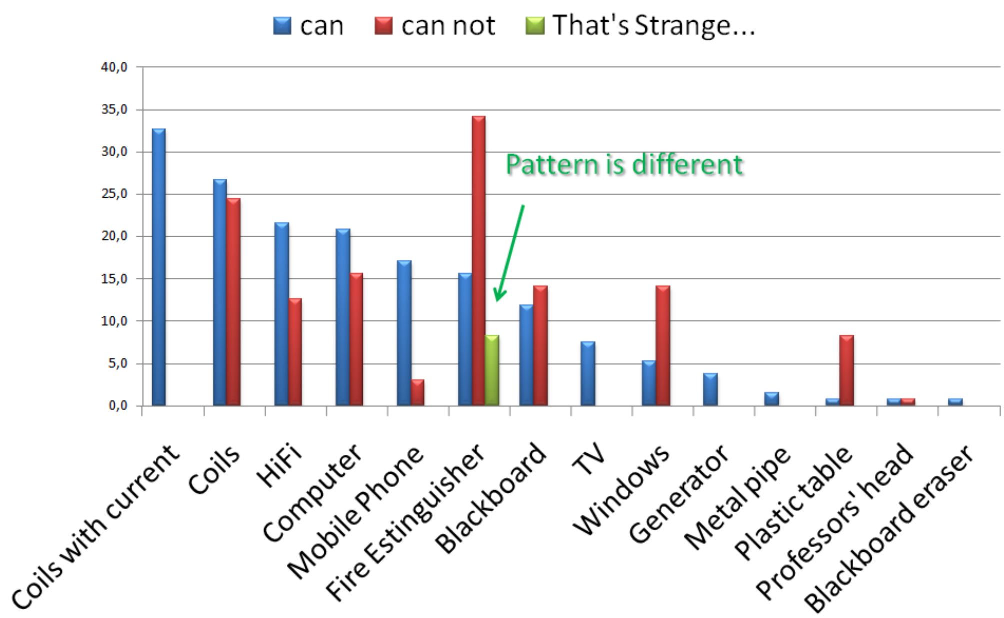


Figure P2.5: Which are the objects that can change the orientation of the needle?

Is also interesting the case of the coils: if in the case of the coils carrying an electric current there are not doubts, in the case of the coils that did not carried a current the pupils opinions is divided in half and half. Addressing this situation in the class discussion, emerges that in the compilation of the personal tables, only the pupils who had tested both the coils reported that one was connected to a generator and the other no. The other pupils that had tested only one of the two coils referred to it as "*coils*" without further specification. This observation was pivotal for the consideration of the electric current as a key factor in the determination of the object that has a own magnetic property.

Infect, in S3.Q2, pupils highlight as the common element into the object near which the compass needles change their direction is the presence of an electric current (61%); 39% don't answer.

This last conclusion done by a majority of the pupil, become a general class conclusion with the exploration proposed in S3.Q3 and S3.Q4.

Written data were not collected during the S4 phase. There were only discussions in which pupils highlight the main characteristic of the electromagnetic induction (as for instance its transient nature) and explicit the different ways in which is possible to realize it. This choice was done because detailed data on this experimental situation were already collected in activity P1 and it is not the focus of this investigation. The focus of this investigation is concerning the analysis of the description that the pupils did of the artefact.

Looking at the artefact, 56% of the pupils identified it as an electric torch, another 38% of the pupils specified that it is an electric torch with a coil that produces energy and 6% don't answer but the main interesting thinks are to look at how pupils' descriptions arise from the elements explored during the learning path and evolve from before to after that they can touch and analyse the artefact in an experimental way.

In particular in Figure P2.6 are displayed which are the element that pupils use to describe the artefact. From these data is manifest how the pure structural elements (as for instance the plastic skin) almost disappear after the experimental phase giving way to emerging functional elements (as magnet and lamp).

In addition, this aspect is more explicit when we look at the changes in the pupil explanation of the functioning of the induction torch (Figure P2.7). The percentage of pupils that give a structural description fall down from 55% to 6% and emerge two principal different approaches to the artefact analysis: one that look at the physical principles (49%) and the other that look at the technical principles (26%).

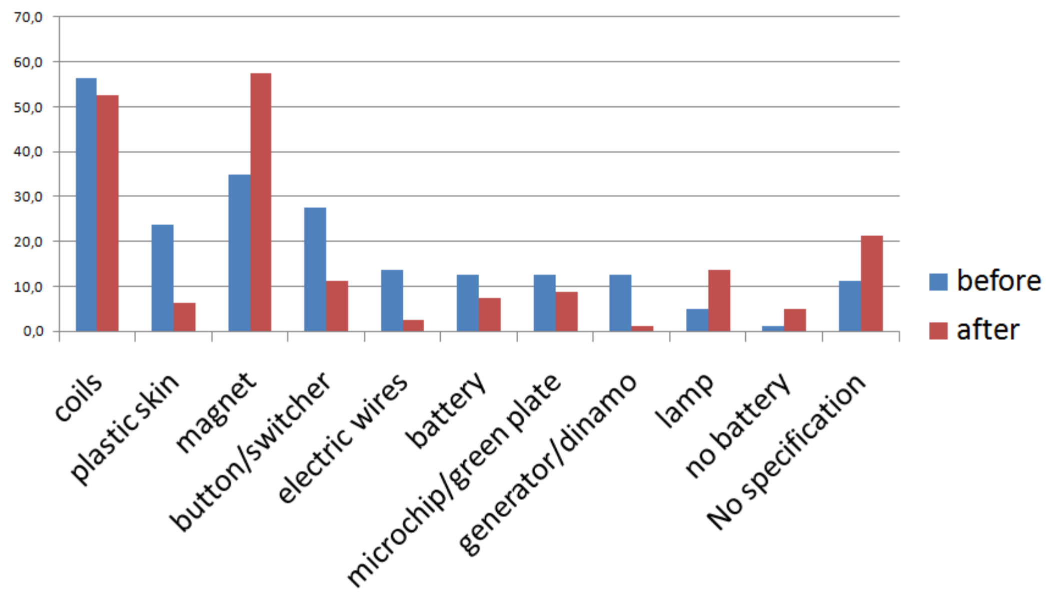


Figure P2.6. Element used by pupils to describe the artifact before and after the experimental exploration of the artifact

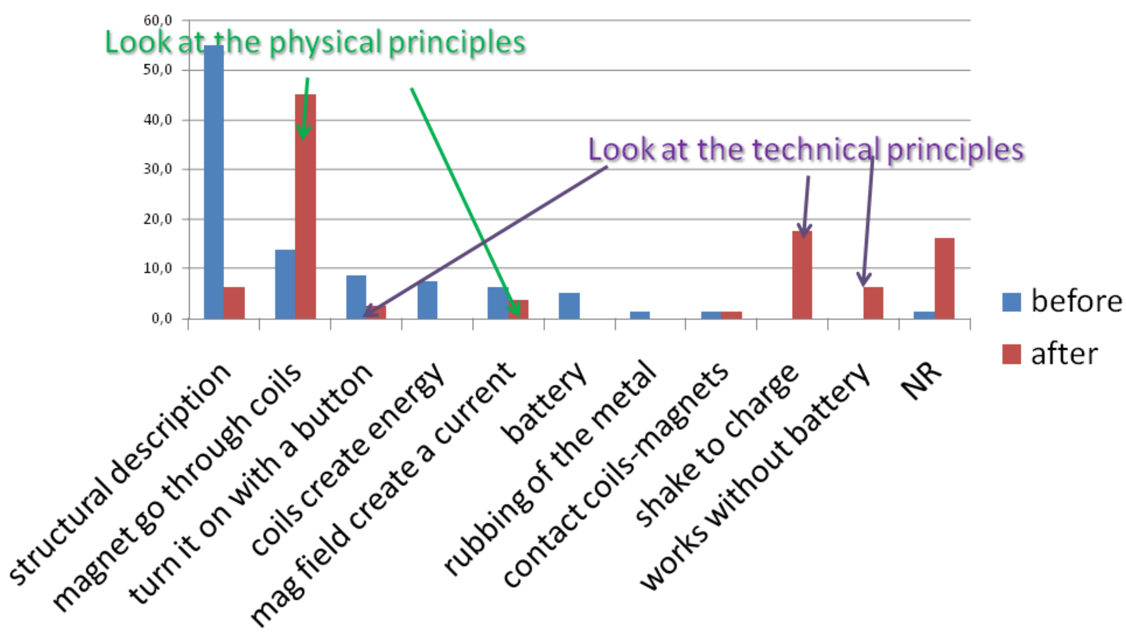


Figure P2.7: “How does the artifact work?” Pupils explanation of the functioning of the artifact

The description of the artifact done by pupils moves on the important functional parts of the artifact (in particular coils and magnet) selected after exploration (Figure P2.6) between a large number of details reported before exploration, when a structural perspective prevail on a functional one (Figure P2.7). In this process the individuation of functional element that they had already encountered during the learning path is pivotal for their description of the functioning of the artifact. In Figure P2.8 this shift is represented in a graphically ways. And in particular, in Figure P2.9 are highlighted which type of description they use splitting their description in two categories: the one that are focused on the technical functioning of the artifact and the ones that look at the physical explanation of the functioning.

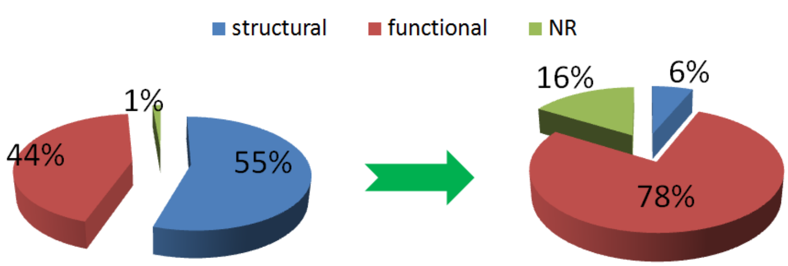


Figure P2.8: The percentage change of structural and functional description of the artifact gave by pupils before and after the experimental exploration of the artifact

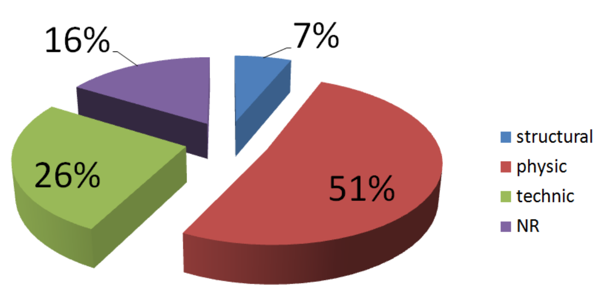


Figure P2.9: Typologies of description provided by pupils after the experimental exploration of the artifact considering the functional distinction spitted in technical and physical description of the functioning

Conclusions

From this experimentation three main results emerge: 1) an operative approach helps pupils to focus their attention on the relevant elements of apparatuses as concern the studied phenomenology; 3) the operative approach also helps pupils to bridge from a structural to a functional description of the apparatus; 3) comparison and analogies between artefacts elements and objects explored during the learning path allow pupils to re-use their previous discovers into the interpretation of the artefact.

The first results emerges during all the activity but it is more manifest looking at the questions S1.QX where the percentage of pupils who focus their attention only to the needle of the compass move from 7% of S1.Q1 to the 80% of S1.Q2 to reach 96% in S1Q3 and the analysis of the artefact where, looking at the graph reported in Figure P2.6, is manifestly how the structural elements almost disappear in the pupils' descriptions after that they had the possibility to experimented the artefact.

The second result is strictly interlaced to the previous one, but it is different because it is on another plane. The focus on the functional elements itself does not imply that the type is a functional one; for instance one could give a structural description of the apparatus taking only into account the functional elements. Give a functional description means do a description of the apparatus in which the important elements are inserted in a description that is aimed to explain the way in which the artefact works. The shift from a structural to a functional description in particularly manifest in the description of the apparatus and it is summarized in Figure P2.8. Even if 44% of the pupils gave a spontaneous functional description, the percentage raise up to 78% after that they had the possibility to experiment the artefact and consequently the percentage of pupils that gave a structural description fall down from 55% to 6%.

The third result, instead, is manifest looking at the first descriptions that pupils gave of the artefact where they identify coils and magnet also only looking at the artefact and when, in the second description, doing analogies with the experimental exploration of the electromagnetic induction they argue that are the magnet and the coils who supply current to the lamp.

VI.6 ACTIVITY P3.

Starting from the results obtained in the previous experimentation, the last experimentation was done with the aim to test a designed learning path looking at the reasoning that it activates in pupils. This learning path was designed on the base of previous research developed by the research unit in physics education of the University of Udine as concern CLOE labs (Bradamante, 2006; Viola, 2009) and the results acquired in the two previous activities (Activity P1, Activity P2).

Contex and Sample

The Activity 3 was carried out in the informal context of the GEI (*Giochi Esperimenti Idee* – Games Experiments and Ideas) exhibition held in the building of the Faculty of Science Education.. The research activity involved 19 classes: 11 of primary school (grades 1 to 5; 6 to 10 years old), 6 of lower secondary school (grades 6 to 8; 11 to 13 years old) and 2 classes of kindergarten (that will not be take into account in these analysis) for a total of 201 primary and 114 lower secondary school pupils and 19 of kindergarten. For this activity, instead than for the other two, data were collected only using audio/video recording of the activity without using worksheets. This choice was done to promote as much as possible the discussion between the components of the class promoting the sharing and the comparison of the different ideas coming from the pupils.

Description of the activity

Experimentation was structured in three phases: 1) an inquired based learning path, that starting from the pupils' naïve idea propose them several situations that hat to be interpreted and re-interpreted on the light of the different observations done; 2) a problem solving-like activity in which pupils, working in small groups (4/5 pupils for each group), has to perform and interpret a phenomenon of electromagnetic induction generating a current in a coil; 3) a big group discussion in which shared and discuss the results obtained by each group.

In Table P3.1 is represented schematically the interview protocol that the researcher used during the first phase of these activity. As manifestly in Figure P3.1, the order of the situations and the key questions that had to be proposed to the pupils is not mandatory, but the researcher had to follow the pupils reasoning deciding from time to time which order adopts and in particular in the room were available all the materials displayed in Figure P0.1.

In particular in this activity the focus of the research was on the role of the different situations proposed to the pupils and the identification of the ones that promote more discussion and result to be the main sources of comparison between pupils with the aims to reach a global vision of the phenomena explored.

The semi-structured protocol became so a guidelines that could be integrated and or modified by the research basing on the pupils needs, hypothesis and discussions.

Table P3.1 Semi-structured interview protocol.

Protocol steps	*Key question(s)*
1) Recall pupils' everyday knowledge	Q1 Which of you has a magnet at home? Illustrate some examples of magnets.
2) Recognize magnets from other objects	Q2 Having a collection of objects in a box, which one(s) are magnets? Explain how you (operatively) did to individuate the magnets
3) Ferromagnetic interaction with a magnet	Q3 Having a magnet and a series of metals, which of them interacts with the magnet? Explain how to identify which ones interacts with the magnet
4) Reciprocal interaction between a ferromagnetic object and a magnet. Planning an exploration	Q4 Is the magnet that attracts iron or the iron that attracts the magnet? Propose an experiment to test it
5) Interaction between two magnets	Q5a Take two magnets. How they interact with each other? Q5b Do magnets need to be in contact to interact?
6) Interaction between a magnet with another suspended	Q6a Hang a magnet to a pole and rotate the shaft. How react an hanging magnet?. Explain Q6b How react an hanging magnet when we approaching another magnet to it?
7) Compass as an explorer of the magnetic field	Q7a Place a compass on the table. Rotate it. How behave the needle of the compass? Q7b How could you do to turn the compass needle?
8) Compass as an explorer of the magnetic field	Q8 How does the compass needle rotate when it is placed close to a magnet. Describe what you observe.
9) A criterion to recognize the magnets	Q9 Using a compass, can you identify which objects produce magnetic property in the space around it[1]? How?
10) Identification of other magnetic field sources	Q10 Only the magnets have the property to create a magnetic property in the space around it (magnetic field)? Do you know any (other) objects able to do the same?
11) Electromagnetic induction	Q11 As we saw in the previous experiment, a wire carrying an electric current generated a magnetic field. Investigate if is possible to achieve the reverse process: can you create an electric current using a coil and a magnetic field?

[1] The magnetic property (magnetic field) is those able to orient a compass needle; being the compass the explorer on the magnetic properties into the space, its orientation describe the magnetic space property.

Data and Data Analysis

In table P3.2 are summarized the main pupils' ideas that they had before and after the explorative investigations of the singles activity. Data are collected by analyzing the audio-video recording of the little pupils' discussions.

Table P3.2 Pupils' idea before and after the experimental explorations and the discussions.

Q n°	*Naïve ideas*	*After exper. and discuss.*
Q2	- The objects that stay together are magnets	- Shake the box, take all the objects that stay together, separate them and then explore the interactions by pairs: in this way it is possible to distinguish the magnet form an "iron (or metal) object"
Q3	- magnets attract iron - magnets attract metals - magnets attract the gray metals	- magnets attract only some metals - looking at the color of the metals is not enough to said a priori if a metal will or will not be attracted by the magnet.
Q4	- magnets attract iron	- magnets and iron attract both one each other, this is clear alternating the approaching between the two. If I approach a magnet to a piece of iron, I see that iron is attracted by the magnet. And if I approach a piece of iron to a magnets I see that in this case is the iron that attract the magnet.
Q5a	- there is repulsion or attraction: depending of … …the magnet: if the magnets are equal or not …if the poles are both plus or one plus and one minus …if the poles are equal or not	- the two magnets always try to stay together, - there two cases: simple attraction or one of the two magnet rotate an then go together to the other magnets
Q5b	- they don't need to be in	- magnets feel the presence of the other magnets and

	contact they have only to be near	they can feel (albeit weekly) one each other already when they are far away one from the other.
Q6a	- rotate - it's like a compass, it always points north	- even if I rotate the shaft, its direction doesn't change
Q6b	- it feel the presence of the second magnets - the second magnet attract it	- feel the presence of the second magnets and change its direction starting to rotate even if the second magnets is still far away (15 cm) from it -the hanging magnets rotate "looking" in the direction of the second magnet
Q7a	- before the needle points to N, after to E, and then is between S and O *[pupils look ad the letter print on the background of the compasses]* - it points always in the same direction	- waiting a little time after I had rotated the compass, the needle turn back to point in the original direction - it point always in the direction of the windows of the lab
Q7b	- I can "disturb" it with another magnet	- if I put a magnet in the surrounding of the compass, its needle change direction looking in the direction of the magnet -compass behaves as the hanging magnets
Q8	- the magnet attract the compass needle - the magnet attract the compass needle or cause it to rotate in the direction in which I'm approaching with the magnet	- I can change the direction of the needle but isn't true that it always points in the direction of the magnets; they may stay parallel one to each other.
Q9	- if they can deviate the needle of the compass they are like magnets	- if they can change the direction of the compass, they may have the same magnetic propriety of the magnet
Q10	- if the needle of the compass point to the object - if they can deviate the needle of the compass they are like magnets	- if they can change the direction of the needle of the compass and if the object interacts with iron

Q11	*[no naïve idea were explicated; someone said that the electricity is produced by the battery or by power plants but they speak only in terms of source of energy and not on the process in which the current is product]*	- approaching and moving away a coil to a magnet produces a current - if I stop movement there are no more current - if we change the inclination of the coil or the speed of the movement the amount of current changes - rotating a coil near a magnet a current is produced

Dialogs were analyzed as reported in Figure P3 in which, starting from the audio-video recording of the discussions done during the first explorative phase, the role of the different interventions done by the researcher (first row) and the pupils (following rows) is highlighted by a color code which identify each category of intervention. Than in the bottom row, is highlighted to which key question each intervention is referred to.

In this figure are displayed the analysis of two learning path: the first one done with 10 years old pupils and the second one with 13 years old pupils.

The way in which pupils are inserted in this schema reflects the way in which generally the discussion evolves: in almost all the laboratory performed, especially with the younger pupils there is the emerging of some pupils (4 or 5 at least) that tend to guide the discussion and that result to be more active in the learning process than others. Looking for instance at Figure P3.1 we notice that for the 10 years old class 4 pupils (over 18) did almost one third of the interventions and the remaining part is equally divided between group (coral) answers and answer given by other pupils that did not more than two or three interventions.

The type of intervention done by the researchers and the teachers are categorized in different colors: red for the key questions (the ones reported in Table P3.1), yellow for the additional questions aimed to promote further discussion, in blue the intervention that are related to experimental situation, in green the answer that are done based on previous knowledge without being referred to a particular experimental situation in orange the discussions and in grey the waiting time that the researcher gave to further answers.

Looking at the color of the intervention reported in Figure P3.1, is manifestly how with the development of the laboratory the answers of the 10 years old pupils categorized as simple answer disappearing (color green) leaving space to pupils intervention that refers to experimental situation (blue) and discussion/argumentation (orange). This trend is less marked in 13 years where the green interventions are still remaining during almost all the learning path but emerge preponderantly in the phase of experimental exploration of the electromagnetic induction.

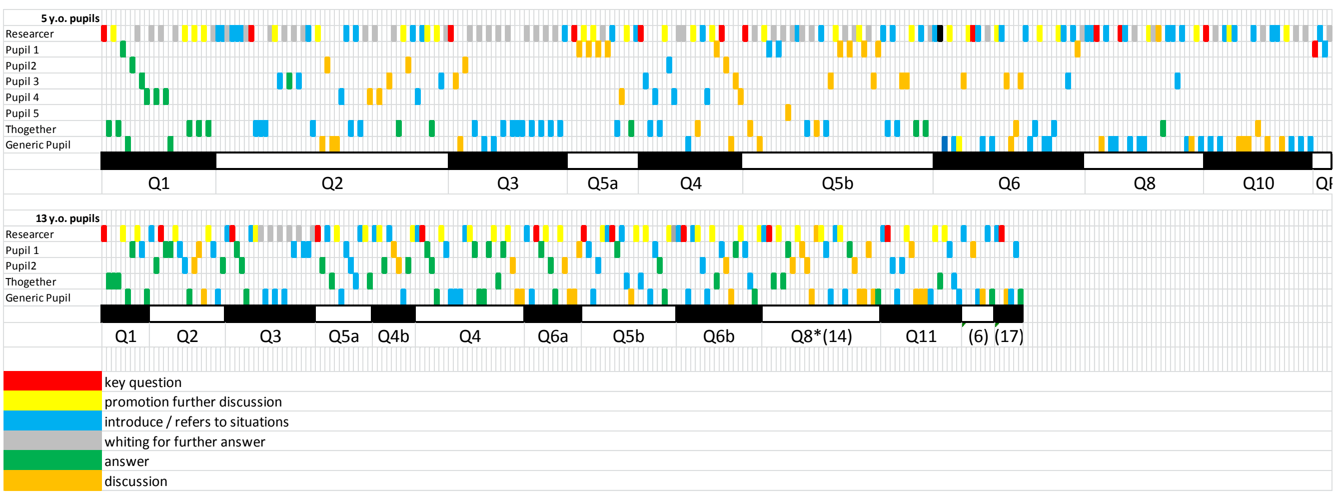


Figure P3.1 Example of analysis of a discussion

The time spent on the different situations and the number of interventions done by the pupils depends by the complexity of the proposed situations and the width of the set of the different interpretations that they proposed, but a general remark is that the lower secondary school student spent less time in the analysis of the single situation than the primary pupils.

As said, order and the typo of the activity proposed is not mandatory and in particular with different classes are followed different learning path; the learning path followed are summarized in table P3.3

Type of School	Class	
Primary	2°	Q1, Q2, Q3, Q5, Q4, Q7, Q8,Q11
Primary	2°	Q1, Q2, Q3, Q4, Q5, Q6, Q7, Q11
Primary	2°	Q1, Q2, Q3, Q5, 6, 5, Q6, Q7, Q11
Primary	4°	Q1, Q2, Q3, Q5, 5, Q6, Q7, Q11
Primary	4°	Q1, Q2, Q3, Q5, 5, Q6, Q7, Q8, Q9, Q10, Q11
Low. Sec.	2°	Q1, Q2, Q3, Q4, Q5, 5, Q6, Q8, Q10, Q11
Low. Sec.	3°	Q1, Q2, Q3, Q5, 5, 14, Q7, Q11
Low. Sec.	3°	Q1, Q2, Q3, Q4, Q5, Q6, Q10, Q11
Low. Sec.	3°	Q1, Q2, Q3, Q4, Q5, Q7, Q6, Q9, Q10, Q11
Low. Sec.	3°	Q1, Q2, Q3, Q5, 5, 6, Q6, Q7, Q10, Q11

A general trend highlighted in almost all the experimentation I relate to the introduction into the learning path of the experiment number 5 (the one in which are considered the two interacting magnets basted on floating polystyrene boats). The role of this situation was crucial for the pupils of the all levels, in particular, as concern the determination of the range of magnetic properties of the magnets, in particular pupils argue that even we are not able to detect them this do not means that the property of the magnet are only in the surrounding of the magnet, but even if it has a small entity it could be feel also far away from the magnet.

As concern the analysis of the situation Q1, pupils was able to found several different ways in which perform electromagnetic induction. All groups highlighted the transient nature of the phenomena, the whole set of the movement of the coils that were able to generate a current in the circuit (with the exception of the rotation of the coil between the magnet that was highlighted only by 2 primary and 3 lower secondary school classes) its dependence by the velocity in which the coils is moved and the role of the orientation of the coils with respect to the magnets. In particular as concern this last point, two lower secondary school classes and one primary class highlight that the orientation of the coil is relate to the "direction of the magnetic property present between the magnets" (where the direction of the magnetic property is the direction assumed by the compass needle in the considered area) and in particular, "there is more current in the circuit when the coil and the direction of the magnetic properties are perpendicular and null when are parallel".

Conclusions

The experimentation of the proposed learning path, from one side highlight the necessity to introduce a specific experiment (situation number 5 of FigureP0.1) aimed to allow pupils to explore the extension of the magnet property of the object giving them a "practical" idea of the extension of the magnetic field that goes beyond the simple observation done by the needle of the compass. From the other the experimentation highlight how the learning path provide to the pupils a set of experiences and observations that allows them to explore experimentally the phenomenology of the electromagnetic induction providing a firs explanatory model that is based on an idea that even it has not the whole structuration needed by the theory of the flux variation of the magnetic field, had its main conceptual cores and the magnetic field, even if not in a quantitative way, had already its main phenomenological characteristic.

VII RESEARCHES WITH STUDENTS

Research literature in physics education highlights the presence of several conceptual knots on electromagnetism in high school. The main learning knot that were point out are: the concepts of field as a superposition (Rainson& Viennot, 1992), the field representation (Guisasola et all, 1999), the relation between the field lines and the trajectory followed by bodies placed inside a magnetic field (Tornkwist et all, 1993), the relation between magnetic field and electric currents, the nature of the field itself (Thong & Gunstone, 2008), the sources of the field and the role of relative motion (Maloney et all, 2001), Lorenz force nature and identification of electrical and magnetic effect related to the moving charges (Maloney et all, 2001), Lentz law and the versus of the induced field (Bagno Eylon, 1997).

With the aim to introduce electromagnetism in a useful way designed specifically to addressed the learning knot highlighted in literature, a 16 hours teaching module was developed and experimented in 5 high school classes. The length of the teaching module was decided taking into account the available time that the physics teachers had in the schools and the number of different topic that they had to teach in one school year.
Two type of experimentation were done: a) in schools during the standard lessons (following the time table of the schools), b) as intensive courses for interested students coming from mixed schools and classes that were held in the common room of a schools or in the university building. For convenience in the notation, the classes will be labeled as ‘standard classes’ and ‘intensive classes’ by the work that was done with them.

VII.1 Experimentation plan

The firs experimental activity of the research work was a pilot study did in a standard class to calibrate the activities and the educational materials of the first version of the learning path. This experimentation was done with 2 high school classes coming from a technical institute of Padova [Activity SS1]. One class was grade 12^{th} and the other was grade 13^{th} (second-last and last years of the high school; 17-18 years old students); the difference in age is due to the different curricular plan that these classes have: the first one is a class of students that are studying to become chemists, and the other is a class enrolled in the technological scientific lyceum. After this first experimentation, a revised version of the learning path was experimented in 3high school classes coming from three different types of high schools: one classical lyceum, one scientific lyceum and one experimental scientific lyceum [Activity SS2] coming, respectively, from Treviso, San Daniele del Friuli (UD) and Monfalcone (GO). In this activity, the students involved are all enrolled in the 5^{th} year of the upper secondary school (13^{th} school grade).

Between these two phases of experimentation with standard classes, was done the first experimentation with an intensive class in a technological scientific lyceum located in Crema (CR) [Activity SI1] and, after the Activity SS2 other two activities with intensive classes was done in Crotone [Activity SI2] and in Udine [Activity SI3]. The last one, was the final experimentation of the learning path (as concern this thesis work) and was held in the University of Udine during the 2011 Summer School of Modern Physics in which the best Italian students coming from the all the 12^{th} and 13^{th} school grade classes of all Italy are involved.

The choice of do the final experimentation of the learning path with talented students was done to test the learning path with a sample of students that, by the results of their scholastic career, had to be some of the main skilled high school students in Italy and the goals of the activity was to go to study the reasoning of these pupils as a set of the higher type of reasoning produced by the high school students.

To give an idea of the geographical distribution of the activities done on the map below are highlighted the places in which the experimentation took place (Figure S0.1).

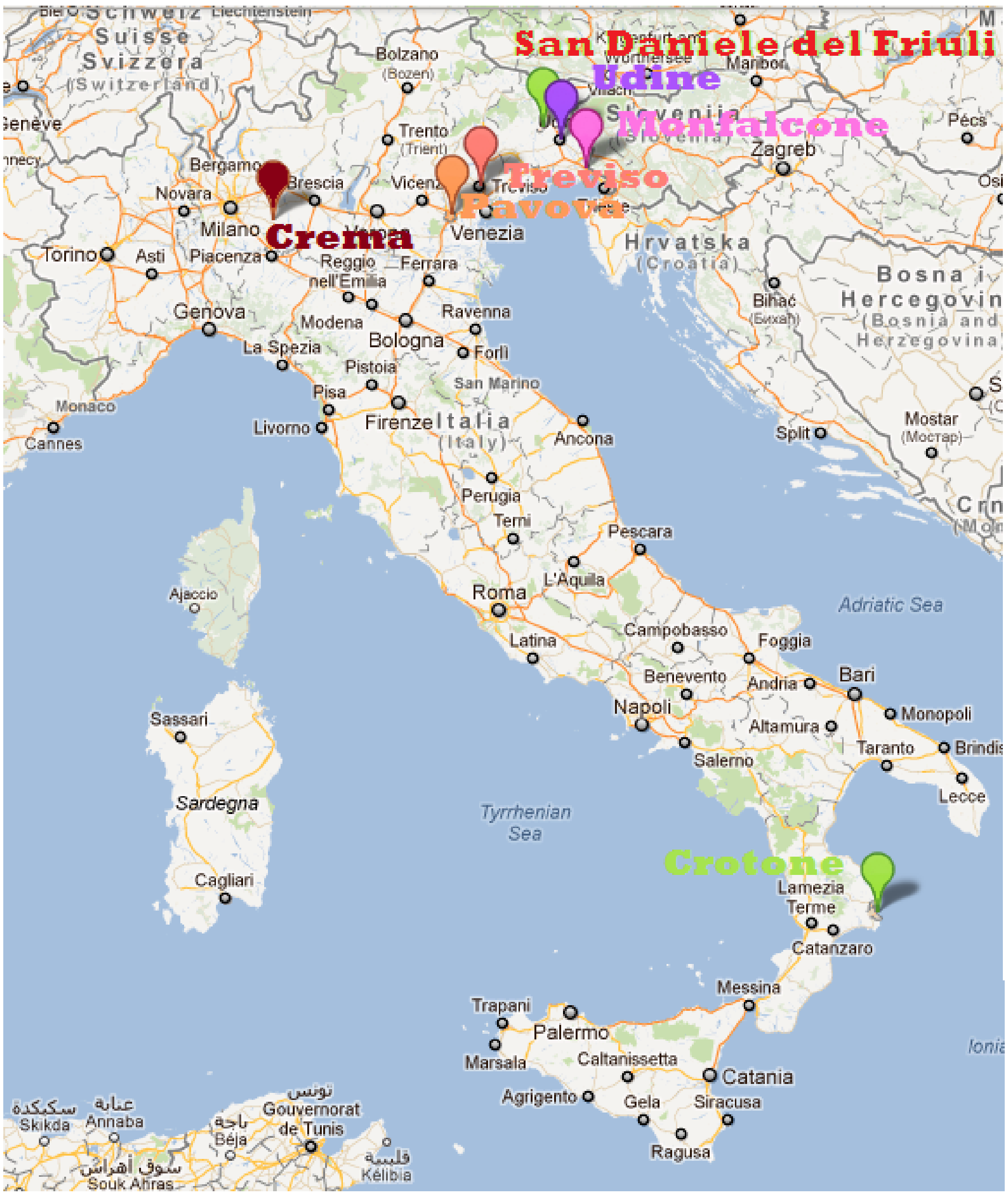


Figure S0.3: Geographical distribution of the Activity did with high school pupils

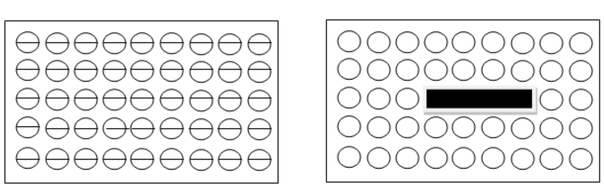
VII.2 ACTIVITY SS1

The first problem that had to be faced designing a learning path is the connection between the scientific knowledge and the students' everyday knowledge (Pfundt & Duit, 1993). For this reason, the first phase of this experimentation was focused on the investigation of the naïve students' knowledge; this investigation was done using a questionnaire with open and semi-open questions.. The second part, the learning path, was constructed using an inquired based approach (McDermott, 1996) that, through the proposal of stimulus questions contextualized on specific experimental situations, is aimed to promote the personal involvement of the students in the process of construction of the knowledge and it is aimed to the analysis of reasoning and the conceptual referent(s) that students adopt to face the learning path.

The First Phase: investigation of the students' naïve ideas

To explore the students' naïve idea was construct a questionnaire constructed with open and semi-open questions. Each one of these question is related a particular goals of research. The questions proposed and the corresponding goals are listed in the next table (Table SS1.1).

QUESTIONS	RESEARCH GOAL(S)
1) Leads some examples (at least three) of everyday life situations in which magnets are involved.	Investigate the everyday experiences that students had whit magnets and which everyday object are identified by them as magnets
2) How could you proceed to identify magnet in a group of different objects?	Investigate the spontaneous way(s) in which they will operate to identify a magnet
3) Which kind of behaviours characterized the magnet when it is approaching other objects?	Investigate which are the magnets behaviours and processes that students known as concern interaction between different materials and

	magnets
4) How sort of interactions is/are possible to experiment when two magnets approaching?	Investigate which are the magnets behaviours and processes that students known as concern interaction between two magnets
5.1) Place a magnet on the table and move another magnet under the table. Do a prevision on which sort of behaviour(s) has the first magnet when the second magnet moves under its position?	Investigate which is the role that the students attributed to the medium that fill the space between two interacting magnets
5.2) How could the first magnet know that the second one is approaching him?	Investigate how students justify the interaction between two magnets
6.1) A magnet is approaching to a metal clip. How sort of behaviour(s) is/are shown by the clip?	Investigate which are the magnets behaviours and processes that students known as concern interaction between ferromagnets and magnets
6.2) How could the clips know about the approaching of the magnet?	Investigate how students justify the interaction between a magnet and a ferromagnet
6.3) Are the magnet interacting with all kinds of metals?	Investigate if students know that not all the metals are ferrmomagnet and how they justify it
7) Place a compass on a lawn. How does the needle of the compass arrange itself?	Investigate how students explain the compass behaviour
8) What is the direction of a compass needle if it is placed near a magnet?	Investigate in a general in a not structured way how students explain the effect that a magnet has on a compass
9.1) Supposed to have a board of compasses such as those one illustrated schematically in the figure below. How do you think the orient of the needles of compasses will be when you will place a magnet on it? Represent the orientation of the compass needles in the board on the right. 	Investigate in a structural way how students explain the effect that a magnet produce on compasses placed in different position respect with the magnet.

9.2) Explain your draw	
10) How sort of information is given to us by the observation of the needle of the compass?	Investigate the meaning that the students attributes to the direction assumed by the needle of the compass
11.1) Using compasses, explore the classroom observing the directions of the needles of the compasses when they are approaching different objects. What's happened? Which are the objects that interact with the compass?	Investigate how student spontaneously read the information acquired by the observation of the needle of the compasses as an explorer of the magnetic properties of the objects
11.2) If we will place a magnet near each one of these objects, what happens? Explain why.	Investigate how students, starting with the observations done with the compasses could inferred the behaviours of the object when they are placed near a magnet

Data and Data Discussion

Question 1 13th grade. First of all, is important to notice that students (mainly) did not list situations, but objects that they use and only one student provide more than 3 example of everyday objects. But, even if it is probably due to the specific request done in the question, 35% of the students provide only two examples and 20% only one (Figure SS1.1).

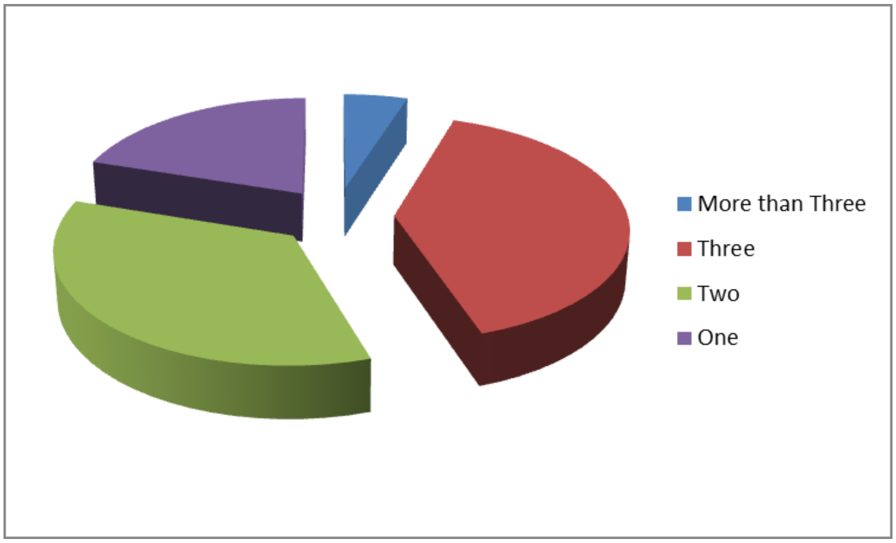


Figure SS1.1 Distribution of students by the number of magnetic object that each one proposed

The distribution of object listed by the student is reported in the following graph (Figure SS1.2).

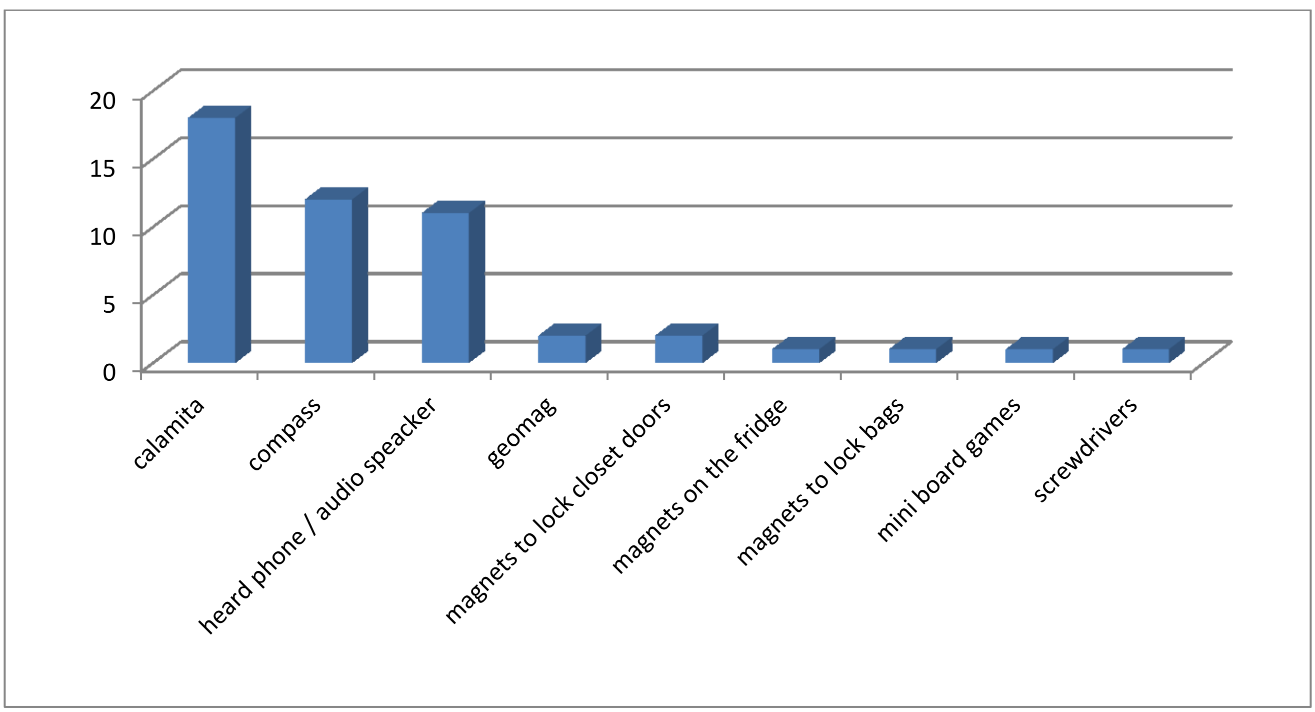


Figure SS1.2: Objects listed by 13th grade students

The first column is a typical problem related to the Italian language. In Italy there are two words to refer to magnetic objects: "magnete" and "calamita". These two words are synonymous, but the use of the terms "calamita" had a wider diffusion than the term "magnete" that is usually used only by specialist or in formal contexts. The other two main object listed by the students are the compasses and the speakers of the hi-fi or of the headphones. It is interesting compasses and speakers are included in two completely different categories of object: headphones are everyday artefacts, while compasses are not everyday objects but are object that students had already analysed during their school career especially on the science textbook of the lower secondary schools and or in movies or cartoons. Several other everyday object are instead almost neglected and named only by few students.

Question 2 13th grade. All the students propose to look at the behaviour of the magnet in relation with the other objects and in particular 52% argue that magnets attract some objects (i.e. clipboard, keys, coins…), 38% argue that magnets attract or repel the object depending by charges and the remaining 10% argue that magnets are recognizable because 'they have a positive and a negative poles'. While the first two groups identify the magnet by the ways in which it interacts with other object, the third group identify magnets by the presences of inner structures typical of the magnet. In addition, in the second and third groups, it is manifestly the influence of the students' analogies between the electrostatic and the magnetostatic phenomenology. In particular the second group highlight also the typical dichotomous approach to the description of the interaction that is represented only by attraction and repulsion.

Question 3 13th grade. 38% of the students argue that magnets attract or repel metals, while the percentage of students that argue that magnets attract metals is 48%. The remaining 10% argues that nothing happens and the remaining 4% argues that there is attraction with the metals and attraction or repulsion with other magnets. Question 3 is really similar to question 2, but it differs because it focuses the attention on the type of interactions that the magnets have. Only the 4% differentiate explicitly the interaction between magnets and between a magnet and a metal, the remaining do not highlight explicitly that magnets interact in different way with different type of objects. Indeed, as concern the group that answered "nothing appended" maybe could be a wrong interpretation of the term 'other' used into the question.

Question 4 13th grade. A big group 62% of the students argue that there is attraction or repulsion. Other two small but considerable group argue that there is only attraction (14%) or only repulsion (14%) and, at the end, only the 10% argue that there is attraction or rotation of one of the two magnets, and then attraction (as could be experimentally observed). In particular as concern the justification gave by the first group (62%): 14% illustrate the possible cases considering the interaction of the two nearest poles, while the remaining 48 argue that attraction and repulsion depends by the charges of the magnets (48%). Also in this case the analogies between the electrostatic and the magnetostatic are predominant.

Questions 5 13th grade. As concern the analysis of the proposed situation (question 5.1): 38% foresight that the first magnet moves together (or follows) the other magnet, 29% said that it is attracted by the other magnet, another 29% said that the two magnets remains stick on the table if the poles are opposite or the first one moves if the nearest poles are the same. 5% did not answer to this question. To this question there are two different approaches adopted by the students: the first group as a cinematic view of the situation, while the other two place the focus of the justification on the interaction that there is between the magnets.
As concern the justification of their foresight (question 5.2) 45% argue that this happened because the first magnet is attracted by the second one, 23% because the first one feels the charge of the approaching pole, 9% because the first magnet feel the

magnetic field of the second one and another, 9% argue that the first magnet fell the second because the force between magnets goes through the table and 9% did not replay to this question. Only few students mentioned the magnetic field, while the other answer are all related or referred to interaction between magnets or charges. In particular few of them highlight how the “force goes through the table”.

Questions 6 13th grade. As concern question 6.1: the 61% of the students argue that the clip are attracted by the magnet; 29% that magnet and clips attract reciprocally one the other; 10% argue that the clips are attracted by the ‘electric field’ of the magnet. Also in this case there are elements as concern electrostatics even if several of them highlight the reciprocal attraction between the clip and the magnets. This last is a little bit surprising results because usually the percentage of students that recognize the reciprocal attraction between magnet and a piece of iron is really low because usually the students neglected the attraction exerted by the clip to the magnet.
Question 6.2 was probably misunderstood and a large spectrum of answers was obtained several of which are not related to the specific question (33%) Example of not related question are: “also the magnet feels the force”, “only with some metals”, “between two clips there is not interaction, between one clip and one magnet there is interaction so is the magnet that attract the clip”. Between the answers 67% of answers related to the question, 24% of the students argue that magnet and clips feel a force, 5% argue that clips enter in the ‘electric field of the magnets and 5% argue that the clips enter in the ‘magnetic field’ of the magnet; the remaining 33% did not answer to this question. Looking at the data, 10% of the students give a justification in terms of field (magnetic or electrical) highlighting the presence of a mediator of the interaction while quarter of the students highlights that the clips feels a force supporting so a view related to at a distance interaction.
In question 6.3, 95% of the students argues that magnet did not interact with all metals and in particular, 52% justified this affirmation providing a list of non-interacting metals

(gold, copper, aluminium…), 24% did not justify their affirmation and the remaining 20% argued in different way (10% said that magnet interacts only with iron, 5% said that magnet interact only with metal that has an opposite charge, 5% said that magnet interacts or not with the metal depending by the direction of the magnetic field). 5% did not replay to this answer. Almost all of the class highlighted that magnets does not interact with all of the metals and half of students provide also a list of exemplificative non interacting metals.

Question 7 13th grade. A large majority of the class said that the needle of the compass points North (85%), while (5%) of the class said that the needle of the compass points in the direction of the magnetic field and another 5% said that the positive pole of the needle of the compass goes to North and the negative one goes to South.

Question 8 13th grade. Almost all the students (86%) foresight a change in the direction of the needle: 24% simply said that the needle will point North no more, 29% argue that the needle of the compass point to the magnet, 10% said that the needle rotate and lose its magnetization, 5% said that the needle of the compass rotate because it feels the magnetic field of the magnet and the last 5% argue that the there is a superposition between the magnetic field of the Earth and the one of the magnet and so the direction of the magnetic field change and the needle rotate. The remaining 14% of the class did not replay to this question. A large majority of the classes highlighted direction of the needle changes, the 29% of the students who said that the needle points to the magnets assumes that the needle point to the disturbing factor highlighting so a causal effect relationships. The fraction that said that the needle lose its magnetisation even if it highlight a causal effect relationship, the reasoning start from the idea of a ‘natural magnetization’ related to the direction in which the needle spontaneously is.

Questions 9 13th grade. Answering to this questions, 62% of students represent the needle of the compass in accord with the pattern described by the field lines, 29% of the students argued that the needles points radially from the magnet and 10% of them draw the needle in a ways that could not be understood in terms of these two models and the lacking of justifications (only 10% justified their draw) do not allow to do further explanation. Half of the ones that justified their draw argues that the needle of the compasses arrange themselves according to the magnetic field or, the other half, argues that the needle of the compasses point to the magnet. Also in the answers to this question, there is a large group that drew the orientation of the needle radially with respect to the magnet, but the more interesting thing is the real low percentage of students that justify their drawings.

Questions 10 and 11 13th grade. These question, were not took into account by the student because they consume all the available time to face the previous question.

Conclusions

The answers of the students to the proposed questionnaire highlight the presence of several conceptual knots, but in particular the main problem that they highlight is the analogies done by the student as concern electrostatics and magnetostatics. In particular in the first questions (until question 5.2) the number of students that use an electrostatic point of view to interpret magnetostatics phenomena is more than half. But, doing an analysis of the students' answers related to the approaches that they use to reply to these answers, is interesting to see how the students in the second part of the questionnaire used no more the electrostatic models in an explicit way. These analysis is represented schematically in Figure SS1.2 where for each question there is highlighted the approach used by each students (blue=electrostatic, red=magnetic field, gray= the answer do not allows to identify explicitly one of the two specific approach mentioned above, white=the student did not answer to this question).

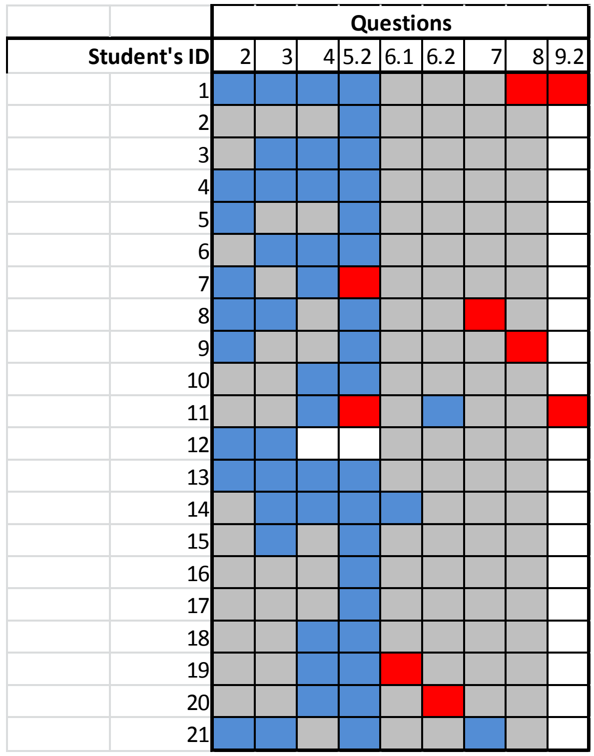


Figure SS1.4. Approaches used by the students to answer to the proposed questions

The second thing that emerges from this analysis is that the students used the magnetic field model only in few questions. It means that, even sometimes students speak in terms of magnetic field, they did not master a model constructed on that idea and they preferably use another approach that is more suitable for them. In particular, in the few cases in which they use it, students adopt the use of the magnetic field only to explain interaction when there is a distance between the interacting objects (for instance question 5.2) or when one of the two object is not manifest (the Earth with is magnetic field in question 7) or when one of the two objects is a compass (questions 8 and 9). In particular, as concern this last point, the different approaches to the description of the compass lead to the use of different model. Looking at the answer gave by the students to question 7 almost all reply that the needle of the compass points to North, but the two that gave a further justification to their answer use to different approaches and it lead them to use two different model: student number 21, arguing that the compass is a magnet and has 2 poles – one positive and one negative – apply to it an electrostatic-like model; the other (student 8), neglecting the inner structure of the needle of the compass, adopt the idea of magnetic field explain the orientation of it.On the base of these argumentations we could argue that the model that is used by the students of this class to interpret the magnetostatic interaction is an electrostatic-like model where the poles (labelled North-South or positive-negative) are considered as interacting point charge. This situation it is mainly due to the fact that the topic that student faced just before the magnetism and the electromagnetism is the electrostatic and current and so often happens that students, guided by criteria of analogy between these two topics, begin to address the magnetic phenomenology from an electrostatic-like point of view.

Phase 2

The second phase of this experimentation is the proposition of an experimental learning path that, beginning with a standard introduction on the representation of the field lines of the magnetic field as results of the envelope of the directions of the needle of the compass construct step by step (without, as done in the other experimentation, introducing a specific metric in the field lines representation), analyse several situations and several patterns of field line were and then the core of the analysis of the students' worksheets was mainly focused in the way in which the use and or not the field lines representation in the description of the induction phenomena and the range of ways that they identify as generating an induced current into the circuits.

To perform the task of individuate the situations that may produce the phenomenon of electromagnetic induction and the explanation of this phenomenon students worked in group of 4 / 5 members but each one of the components of the groups has its own worksheet and these worksheets were took into account to be analysed.

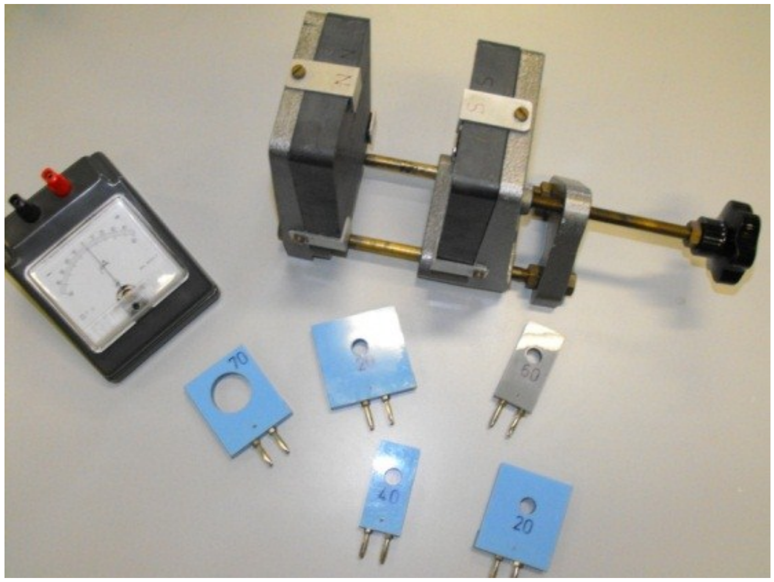
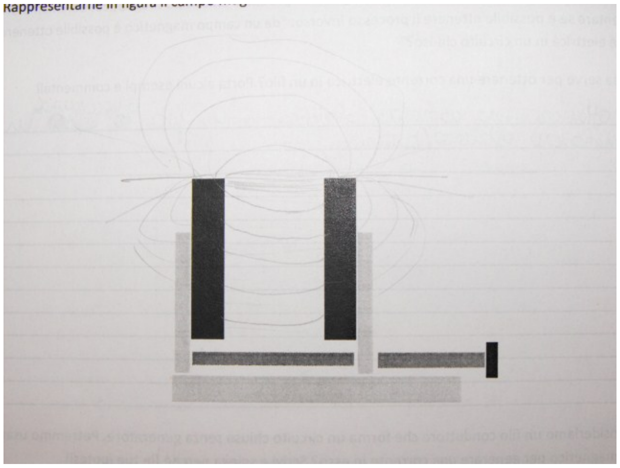


Figure SS1.3: Setup provide for the experiment concerning the exploration of the electromagnetic induction phenomena

The experimental setup provided to students is the one represented in Figure SS1.3. The firs request done to the students was to represent the magnetic field of the two magnets mounted on the holder.

Analysing the draw, 83% of the students use the field lines representation, while the remaining part represents the magnetic propriety of the space surrounding the magnets by representing the shape that a metallic chain assumes while, holding one end of the chain, it is approached to the magnets (Figure SS1.4b). 58% of the students represent the field lines between the magnet and around the magnets, but another 29% represents the field lines as if the two magnetic plates were a single bar magnet (Figure SS1.4a).



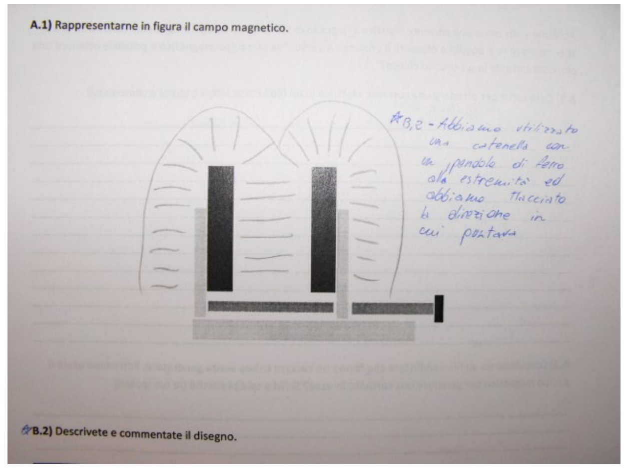


Figure SS1.4a Magnetic field of the magnetic plate represented as a bar magnets

Figure SS1.4b alternative representation

The remaining 13% did not represent field lines between the two magnets. In 71% of the draw the lines are not oriented. In only 4% of the draw there is a clear relation between density of liens and intensity of the magnetic field.

As concern the different situations that students explore to perform the electromagnetic induction: 75% argue that to perform electromagnetic induction 'you had to move (50%) or insert and extract (25%) the circuit between the poles'. The 54% of the students also argued that the orientation of the circuit respect to the field is important during the movement, and in particular when the circuit is perpendicular to the field the effect is larger. 17% also highlighted the transient nature of the phenomena, a 34% the different sign of the induced current depending by the direction of the movement and 4% the dependencies of the induced current from the number of the circumvolution of the wire of the circuit.

These facts did not allow students to use the field lines representation in an effective way. To address this problematic the following experimentation were focused on the determination of a learning path that was able to addressed effectively the construction of the field lines representation providing an effective way to introduce a metric in these representation.

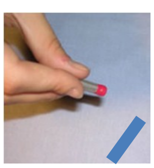
VII.3 ACTIVITIES SI1, SI2, SS2

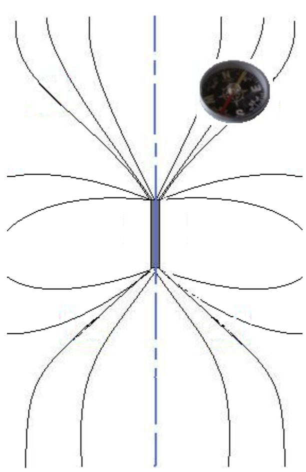
In the classes participating to this activity was performed a teaching learning formative module of 16 hours with a pre and a post- test to evaluated the development of the students' knowledge and the investigation of the same challenging situation that were proposed to the students in the control group.

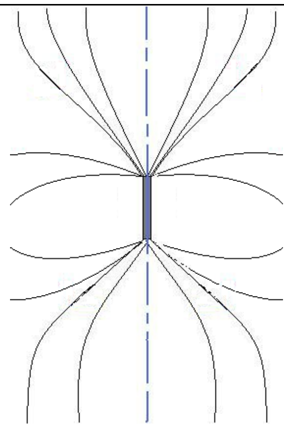
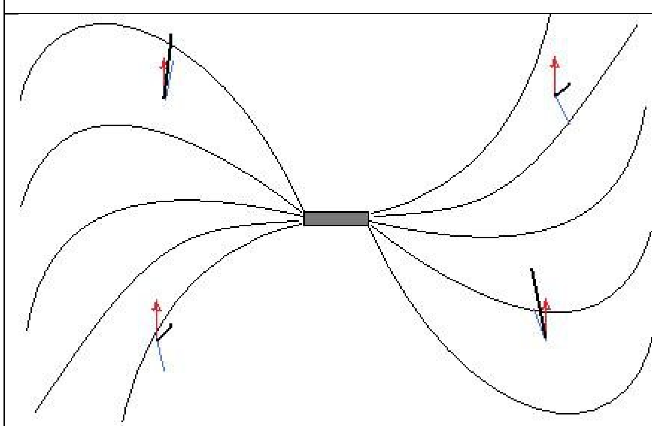
This work was done using the typical approach of the design based research in the framework of the conceptual analysis of the dynamical evolution of reasoning in content related learning research and it is based on the Model of Educational Reconstruction using an Inquired Based Learning strategy based on a sequence of stimulus questions concerning specific proposed situations.

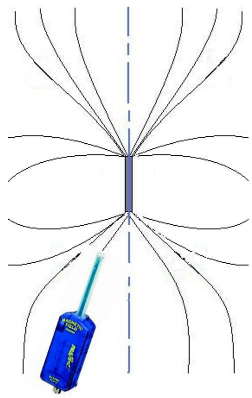
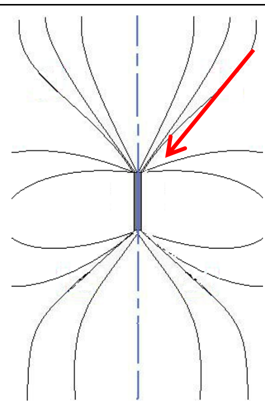
The main part of the learning path was focused on the experimental re-construction of the field lines representation and its transformation to a flux-tube representation through the use of a magnetic field sensor. The introduction of this last representation allows to introduce a metric in the field lines representation allowing students to use an graphical representational tools from which they are able to extract all the information needed to represent the field line vector in the whole considered plane and allow to address explicitly all the characteristic of the vector of the magnetic field.

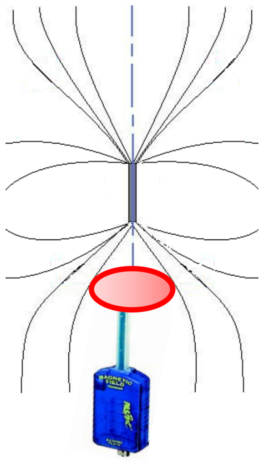
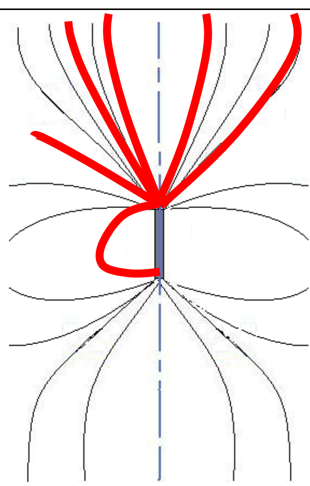
The adopted learning path was schematically represented in the next table and how could be noticed, a big work was done on the process of construction of the field line representation and the introduction in it of an effective metric that transforms the field line representation in a flux tube representation.

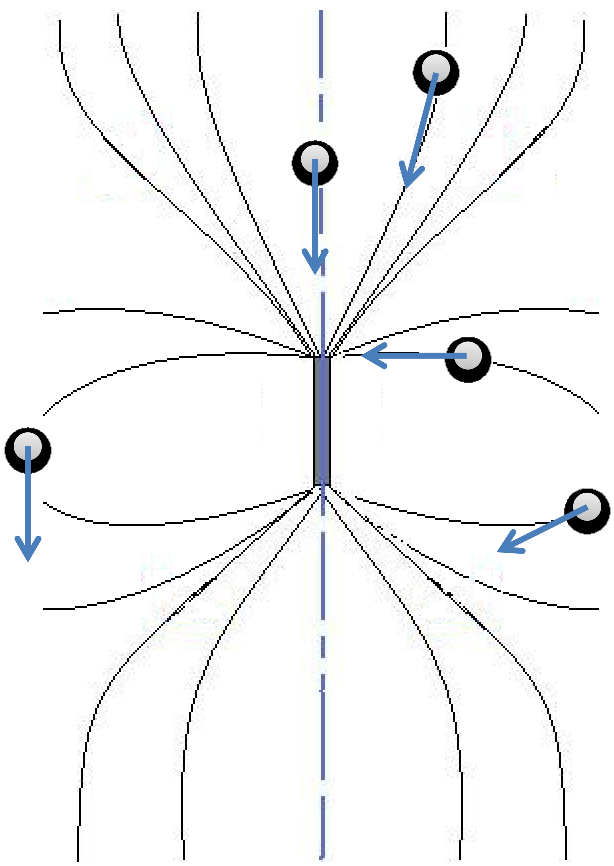
Situation(s)	Question(s)
	Magnets and their interactions How do you recognize a magnet between other objects? How does a magnets interact with other materials? Describe it and draw a sketch of the interaction Categorize the objects depending on how they interact with a magnet How two magnets interact? In which category did you put compasses
	Remove all the object from your table and put a compass on it. Observe the direction of its needle. Does it change if you rotate the compass? Thinking to the interaction previously explored, how can you change the direction of the needle of the compass?
 	Approach a magnet to a compass If I change the direction of approach, what's change? Which is the direction that the needle assumes? How can you represent formally the direction of the needle?

	Paste a sheet of paper on your desk, place the compass on it and represent the direction of the needle on the paper. Move the compass on several different points of the sheet and represent the direction of the needle in each point. Describe the directions of the needle in the different points. How are them? Chose (randomly) some of the needle that you had represent and starting to each one of them construct step by step the direction of the needle moving the compass following the direction of the needle. Describe the lines that you obtain
	Take a new sheet of paper and paste it on the desk. Paste a cylindrical magnet on it with its axis parallel to the longest side of the sheet. As done before, draw the lines of the orientation of the needle starting from several point of the paper. Take another compass and put it on one of the lines that you drown. How does the needle arrange themselves? Referring to how these lines were drown, what is represented by this lines?

	Observe the lines you drew. Do the lines intersect themselves? What does it mean? Considering two lines, is the distance between two lines constant? Where does the distance between lines change most? As we move away form the magnets, how do the lines tend to be? Interpret this behaviour.
	If we consider another plan passing for the axis of the magnet, the draw that you'll did will change? Motivate Describe and illustrate with a sketch how do you thing that are the lines around the magnet. In relation to this figure, what is the pattern that you drew on the paper?
	Place a magnet perpendicular to the spontaneous direction of the compass end draw on a sheet of paper the lines of orientation of the compass' needle Is the pattern change? Highlight similitude and differences whit the previous one. Interpret them. Your formal representation of the compass needle is useful to this interpretation? If

	not, provide a new one justifying your choose.
	Do you think that the intensity of the magnetic vector is constant or not along a line? Justify your answer Measure the intensity of the magnetic vectors along a line and compare the result with your prevision
	Which information can you acquire from the field lines representation concerning the magnetic field vector in one point? The pattern of lines gives you information concerning the intensity of the magnetic field vector?
	Looking for a correlation between the intensity of the magnetic field vector and the thickness of the stripe bounded by two successive magnetic field lines. Thinking at the tridimensional structure of

	the magnetic field, how do you figure this stripe in 3D?
	Measure the intensity of the magnetic field and the area of the tube section and check the correlation between them. Do the same measurement for several tubes. What did you notice? Can this observation be useful to extract information concerning the intensity of the magnetic field vector from the draw of the field lines?
	What do you have to do to be able to represent with field lines the intensity of the magnetic vector in each points of the space? Explain

	Place one iron sphere near the magnet in 5 different position. Which will be the starting direction of the sphere in each position? Is the same of the field lines? Do the experiment and compare them with your prediction. How do you explain the observed behavior?
	Looking for new sources of magnetic field Using a compass, how do you think is possible to identify if an object is a sources of magnetic field? Has a copper wire a source of magnetic field? Describe how do you experimental verified your answer. Connect the same copper wire to a battery. Do the magnetic properties of the wire change? How do you interpret it?

	Supposing to take a copper wire connected to a battery and a magnet. Do you think that there will be an interaction between the two object? Explain why. Experiment it. Is it consistent with your hypothesis? Exploration of Lorentz force

Data analysis

To look a t the effectiveness of the learning path proposed the analysis was focused on the particular learning knots highlighted in literature and the way in which they are faced by the student that follow these learning path.

Looking at the data, experimentation shows a sensible improvement as concern the addressing of three quarter of the highlighted conceptual knots, in particular: the concepts of field as a superposition (Rainson& Viennot, 1992), the field representation (Guisasola et all, 1999), the relation between the field lines and the trajectory followed by bodies placed inside a magnetic field (Tornkwist et all, 1993), the sources of the field and the role of relative motion (Maloney et all, 2001), Lorenz force nature and identification of electrical and magnetic effect related to the moving charges (Maloney et all, 2001). As concern the Lentz law and the versus of the induced field (Bagno Eylon, 1997) and the relation between magnetic field and electric currents, the nature of the field itself (Thong & Gunstone, 2008) further development of the learning path were needed.

In the following graphs are represented the main differences between the results obtained with the students that followed this learning path and the control group that follow a learning path less focused on the construction of the field lines representation and the introduction of a metric in that representation.

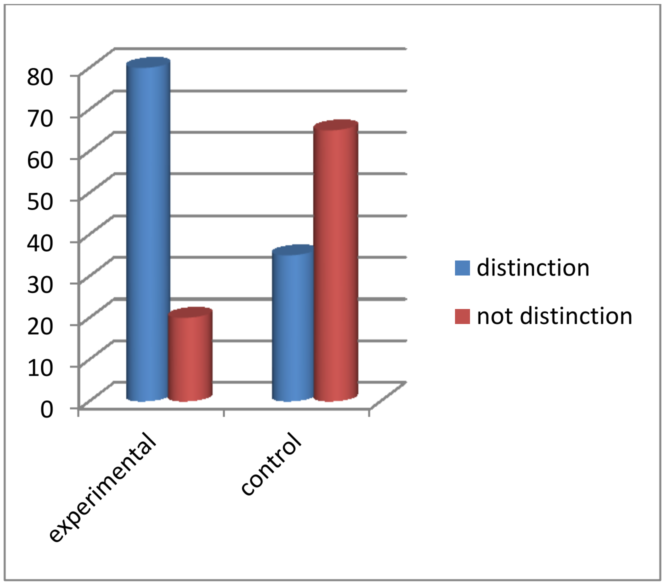


Figure SI1.1 Distinction between field lines and force lines

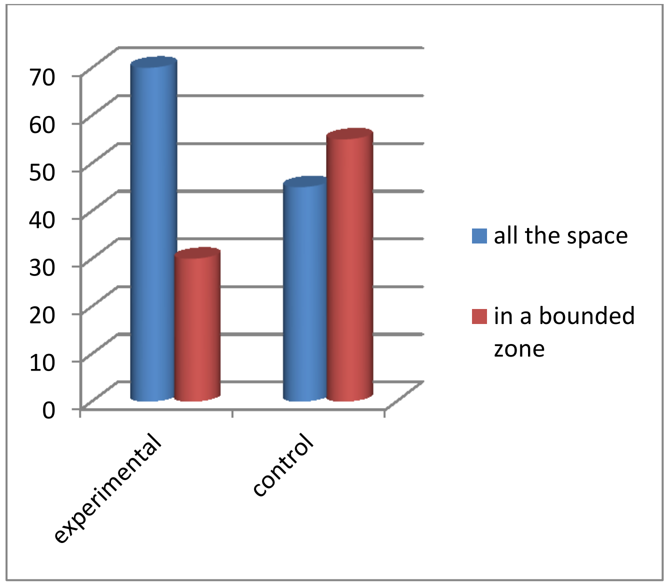


Figure SI1.2 Characterization of the magnetic field as a property of the space

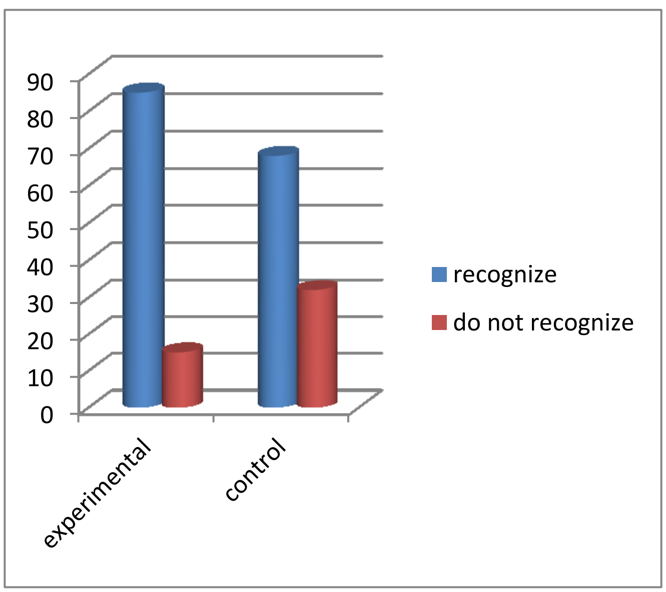


Figure SI1.3 Recognition of the constancy of the flux

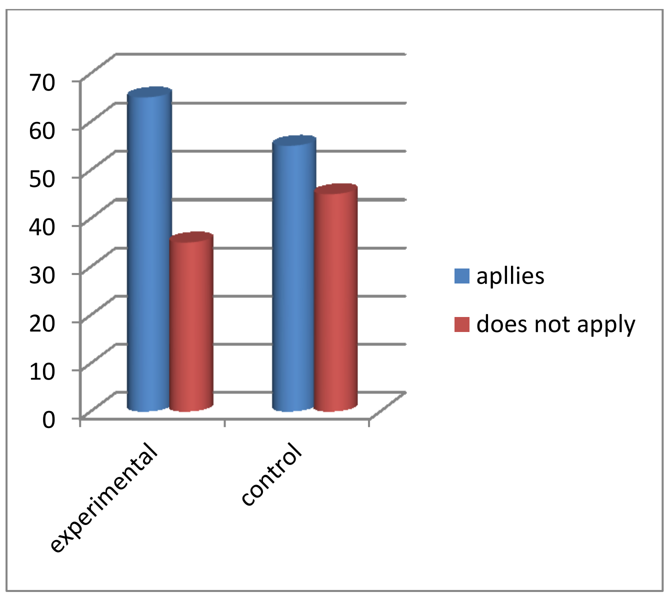


Figure SI1.4 Principle of superposition

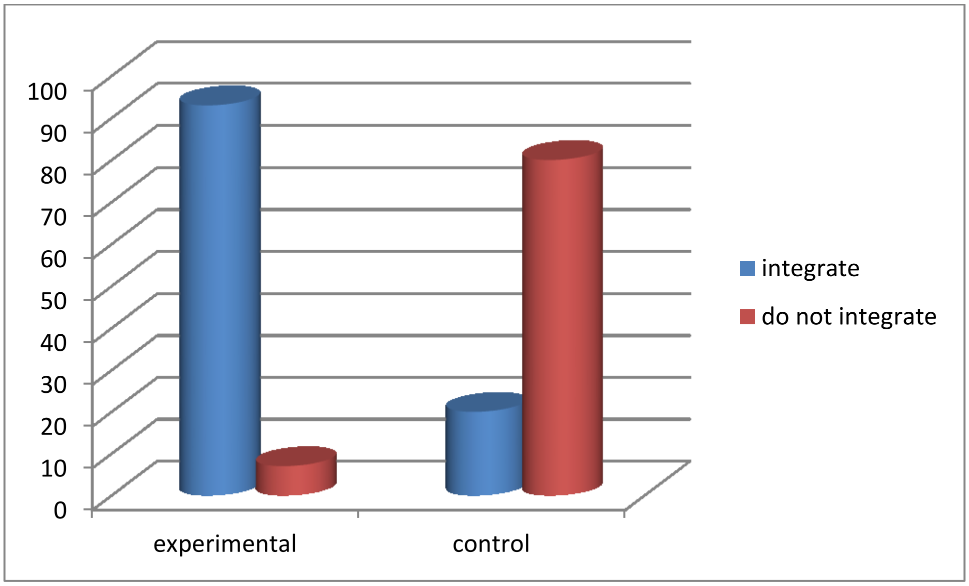


Figure SI1.5 Integration between representative elements (lines) and mathematical entities (vectors)

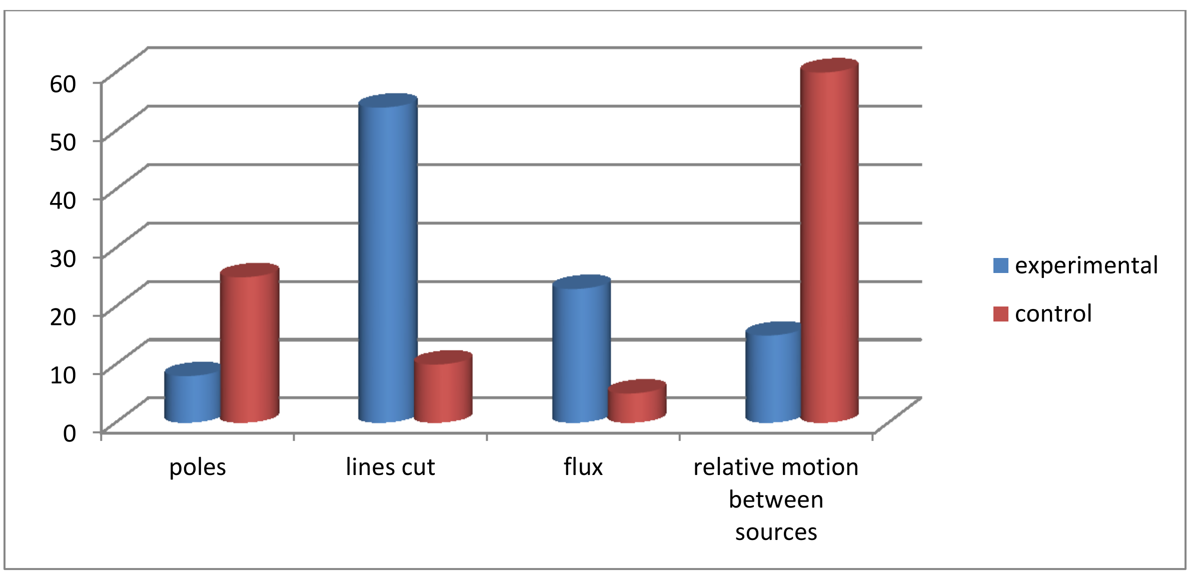


Figure SI1.6 Which are the conceptual referents that students use in the interpretation of electromagnetic induction?

As could be seen from the graph, there was a great improvement in the effectiveness of the students approach to this specific learning knots and this effect could be referred to particular work did with student on the construction of the magnetic field as formal entity starting from the experimental exploration of the phenomenology.

VII.4 MAGNETIC FIELD AS PSEUDOVECTOR

Before to illustrate the activity SI.3 there was necessary to add a paragraph as concern the idea of magnetic field as a pseudo vector because this is one of the new aspect introduced into the last version of the learning path.

Despite that mathematics is the basic language used by physicist to construct formal entities, at high school level sometimes this is poorly implemented, as the case of the naïve definitions of important entities like the pseudovector (axial vector) and the limited use of the study of the symmetries for example in the analysis of electromagnetic systems. In this paper two simple experimental contexts are proposed in which students investigate the pseudovectorial nature of electromagnetic field vector and a simple formal explanation of its nature starting from the analysis of its behavior.

Mathematics provides to physicists powerful ways to describe the phenomenological world through formal entities, with properties that constitute tools for the analysis and allows researchers to deduce important conclusions starting from the individuation of simple elements observable into the physical systems. In particular, in this framework, one of the most important theoretical tool is the Neother's first theorem (Noether et al 1918) that, in its simplest formulation, relates the presence of symmetries in a physical system to conservation laws: symmetries in classical and modern physics have a pivotal role in the description of the physical systems, so the knowledge of how formal entities are transformed by symmetry operation is crucial (Foot & Volkas, 1995; Kozlov & Valerij, 1995; Mohapatra & Senjanovi´c, 1981; Redlich, 1984).

The role of symmetries in high school physics education is often underestimated and this is due to a not so strictly definition of the formal entities, that points only to the definition of the structure of the entities and not to the way in which these entities are transformed by symmetry operations. The main example is the definition of 'vector', without stressing the difference between polar and axial vector. This distinction becomes relevant only in the higher level courses, creating so an intellectual gap between student's studies in undergraduate and graduate mathematics (Kolecki, 2002). In the student learning path, this gap seems to be a "no man's land" and represents a huge difficulty for students, so a specific activity that allows students to face the difference between axial and polar vectors has to be introduced.

To analyze the symmetries of the electromagnetic system is pivotal to know the transformation properties of the electromagnetic quantities under space inversion, charge conjugation and time reversal (Rosen, 1973). In particular Pierre Curie (1894) was one of the first scientists that demonstrate that the electric and magnetic vectors are transformed in a different ways under the space inversion highlighting the different nature of the two vectors: electric field vector transforms as a "normal vector" (as position, velocity and acceleration vectors) and the magnetic field vector (Roche, 2001) transform as an axial vector -or pseudovector- (as angular momentum vector).

In this work, that is a part of a larger work of research, we highlight the role of the formalism in the description of a quantity such as the magnetic field vector $\vec{B}$, proposing two experimental context in which its pseudovectorial nature its explored.

Experimental exploration of the pseudovectorial nature of the magnetic field vector

We propose two contexts to introduce at high school student level the idea of the magnetic field vector as a pseudovector entity: the study of the magnetic field generated by a coil and the study of the effect of the magnetic field on a moving point charge (Lorenz force).

In the case of the magnetic field generated by a coil, experimentally, we observe experimentally that a compass set in the center of the coil indicates the presence of a magnetic field having direction coincident with the axis of the loop and the versus given by the right-hand rule.

In a reference system with the *xy* plane parallel to the plane of the coil, we investigate the transformation proprieties of the formal entities describing the system.

In particular, let us consider the magnetic field vector in the center of the coils ($\vec{B}$) and a general position vector $\vec{p}$ (as shown in Figure 1a). After rotating the system around the *x* axis, the compass shows that the magnetic field vector in the centre of the coils

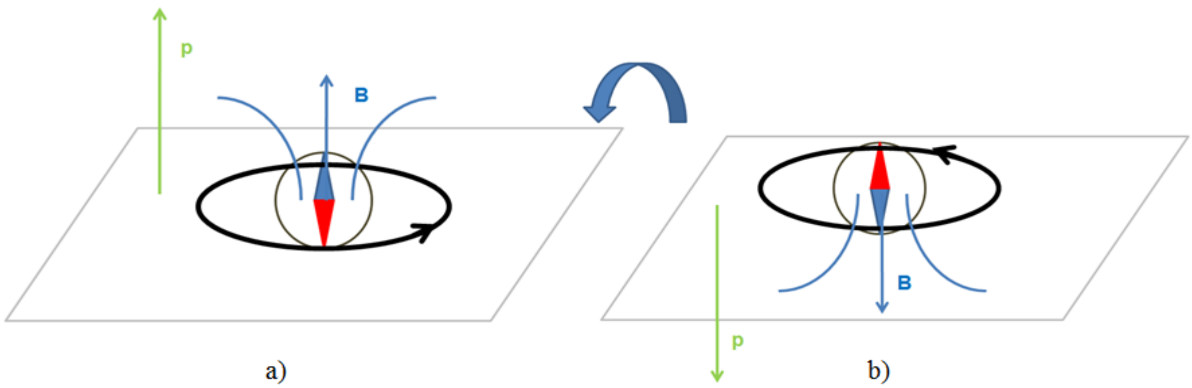


Figure 5: Rotation of a coil

transforms in the same way of the position vector (Figure 1b).

If we consider instead a specular reflection transformation of the system respect to the *xy* plane, the compass shows that the transformation rule of the magnetic field under this symmetry transformation differs from the transformation rule for the position vector (Figure 2b).

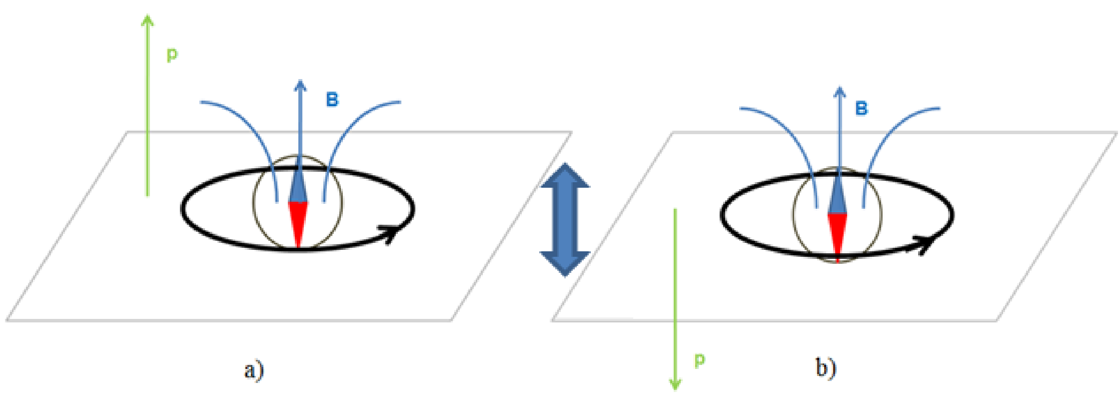


Figure 6: Symmetry transformation of coil

The case of the Lorentz force can be experimentally explored considering a moving charge between two Helmholtz coil. If any dissipation phenomena is neglected, the

motion of charge can be one of the following three types: circular uniform, helicoidally uniform (with step, radius and speed of traveling constant) or rectilinear uniform.
In each one of these types the magnitude of the charge speed is constant during the motion, while the type of trajectory depends on the orientation of the starting velocity. In addition, the examination of the phenomena leads to the conclusion that there is a force ($\vec{F}$) acting perpendicular to the velocity vector ($\vec{v}$): $\forall \vec{v} \in \mathbb{R}^3 \quad \vec{F} \perp \vec{v}$ at every point of motion.
Moreover, because of the constant step of the helix, we deduce that the force acts only in the plane perpendicular to the axis of the helix, and the parallel velocity component to the helix remains constant. Also, depending on the motion of the charge, we see that the helix axis is parallel to the axis of the uniform circular motion and coincident with the direction of the rectilinear uniform one.
These results allow to individuate a constant entity built up from the relevant vectors dynamically describing the system: $\frac{\vec{v}}{v} \times \frac{\vec{F}}{qv}$. A simple reasoning shows that this vector is essentially equivalent to the magnetic field vector.
Rotating the system around the *x* axes (Figure 3), the magnetic field vector and a general position vector transform in the same way.

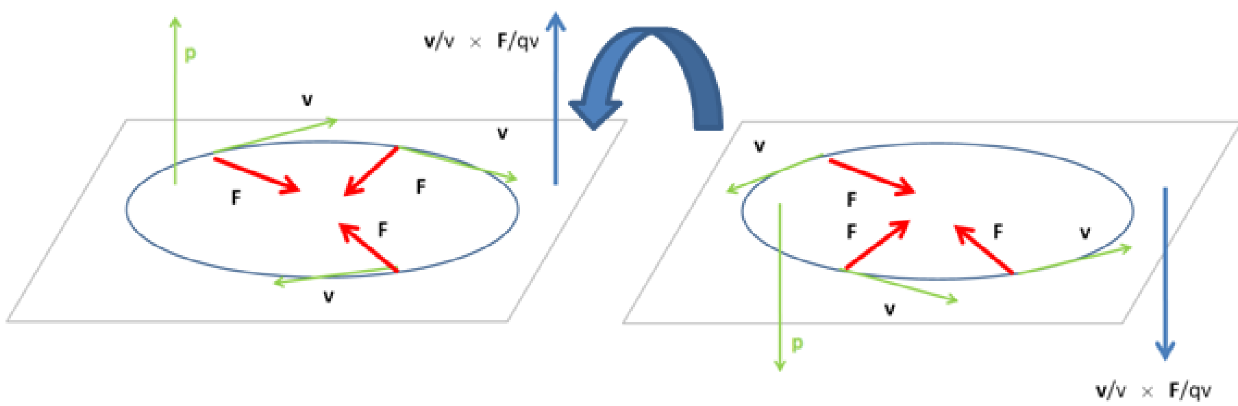


Figure 7: Rotation of a simple electromagnetic system

If we consider instead a reflection respect to the *xy* plane the two vectors transform in different ways.

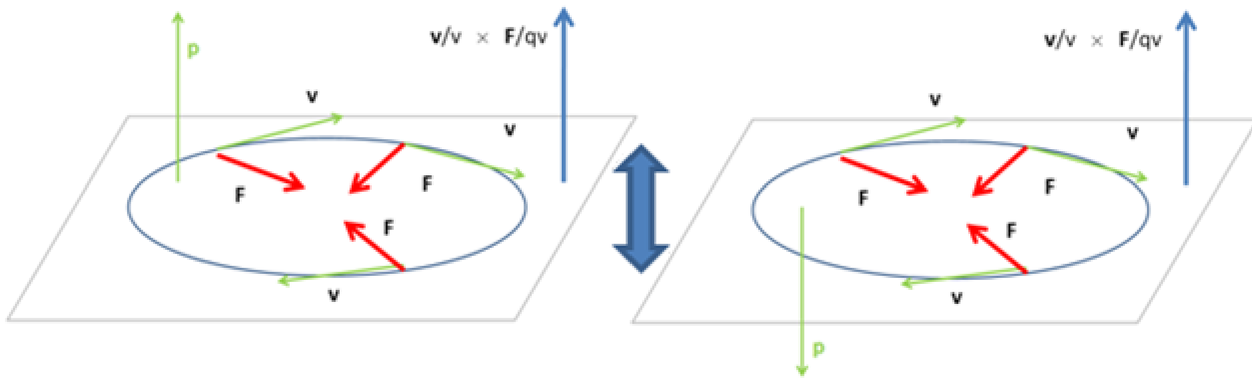


Figure 8: Symmetry transformation of a simple electromagnetic system

So, in these examples, the magnetic vector transforms "normally" under the rotations of the system, but not under reflections.

Introducing pseudovector to high school students

In low level course physics, concerning three dimensional space, vectors are defined as abstract objects that are represented and characterized by: magnitude, direction, versus and (eventually) an application point As concern operation with vectors, in particular, two external products are defined: the scalar product and the vector product. The first one associates to the two vectors a scalar quantity and the vector product associates to the two vectors a third vector (not belonging to the initial vector space) and having perpendicular direction to the plane that carries the two starting vectors and its verse is established using the right-hand rule.

More formally, a vector $\vec{v}$ is the element of a vector space, i.e. an object that can be added or subtracted to similar items and multiplied by the scalar. Given an n-dimensional Euclidean space and a set of n linearly independent vectors $(\vec{u}_1 \dots \vec{u}_n)$, any vector of the space can be written as a linear combination of these n linearly independent vectors: $\vec{v} = a_1\vec{u}_1 + \cdots + a_n\vec{u}_n$.

The $\{\vec{u}_i\}$ set is called a complete base for the vector space considered and every vector of the space may be represent as the n-tuple of the real numbers $\{\vec{a}_i\}$ so $\vec{v} \equiv (a_1, \dots, a_n)$.

From the other side, geometric transformation as rotation and symmetry rotation are formally functions that map between two vector spaces (or - as in our case- from one vector space to itself) and, if we limit our analysis to the case of a linear transformations, they preserve the properties of the linear combinations of vectors. In particular linear geometric transformations can also be seen as a base change in the vector space.

If we use a different complete base, for example $\{\vec{w}_i\}$, we would have $\vec{v}_w = b_1\vec{w}_1 + \cdots + b_n\vec{w}_n$ so $\vec{v} = (b_1, \dots, b_n)$.

In particular:

$$\vec{v}_u = b_1 \sum_{i=1}^{n} c_{1i}\vec{u}_i + \cdots + b_n \sum_{i=1}^{n} c_{ni}\vec{u}_i = \sum_{i=1}^{n} b_1 c_{1i}\vec{u}_i + \cdots + \sum_{i=1}^{n} b_n c_{ni}\vec{u}_i = \sum_{j=1}^{n}\sum_{i=1}^{n} b_j c_{ji}\vec{u}_i$$

$$= \sum_{j=1}^{n}\sum_{i=1}^{n} c_{ji}\left(b_j\vec{u}_i\right) = \sum_{j=1}^{n}\sum_{i=1}^{n} c_{ji}\vec{v}_w = \begin{pmatrix} c_{11} & \cdots & c_{1n} \\ \vdots & \ddots & \vdots \\ c_{n1} & \cdots & c_{nn} \end{pmatrix}\begin{pmatrix} b_1 \\ \vdots \\ b_n \end{pmatrix} = \vec{v}_w$$

So linear geometric transformations can also be seen as a base change in the vector space. In particular, they can be represented by a matrix in the case of a transformation that maps from a space in itself.

In the case that the two bases $\{\vec{w}_i\}$ and $\{\vec{u}_i\}$ are orthogonal, the $\{c_{ij}\}$ matrix is also orthogonal; i.e. it is a square matrix with real entries whose columns (and rows) are orthogonal unit vectors. In particular the determinant of this type of matrix is equal to ± 1

A reflection respect to a particular plane is a transformation of the vector space in itself (endofunction and isomorphism) that maps every single point of the vector space in one and only one point of the same space (bijective) without altering the distance between two starting points and the two reflex points (isometric).

So is possible to define a linear application f, representable as a matrix, that connect to each point P of the space to his transformed and result for reflection $\vec{f}(\vec{P}) = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & -1 \end{pmatrix} \begin{pmatrix} P_x \\ P_y \\ P_z \end{pmatrix} = \begin{pmatrix} P_x \\ P_y \\ -P_z \end{pmatrix}$ and for the considered rotation

$\vec{f}(\vec{P}) = \begin{pmatrix} -1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & -1 \end{pmatrix} \begin{pmatrix} P_x \\ P_y \\ P_z \end{pmatrix} = \begin{pmatrix} -P_x \\ P_y \\ -P_z \end{pmatrix}$.

We notice that the first matrix as determinant equal to -1 and the second one has determinant $+1$.

Experimentally we observe the strange behavior in the case of reflection, and in particular, considering other type of transformation, can be show that for all transformation that has a representative matrix having determinant equal to $+1$, the magnetic field vector transform as a 'normal vector', for the other (that have determinant equal to -1) the transformation rules are different. In particular, concerning the reflection respect to the *xy* plane, experimentally:

$\begin{pmatrix} B_x \\ B_y \\ B_z \end{pmatrix} \rightarrow \begin{pmatrix} -B_x \\ -B_y \\ B_z \end{pmatrix}$ while if we apply the "standard" rule: $\begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & -1 \end{pmatrix} \begin{pmatrix} B_x \\ B_y \\ B_z \end{pmatrix} = \begin{pmatrix} B_x \\ B_y \\ -B_z \end{pmatrix}$.

Since $\vec{B}$ behaves differently from $\vec{p}$ under particular transformation, they must be two different formal entities and this difference is highlighted in these particular context.

We go now to investigate the formal nature of *B*. Considering a coil carrying an uniform electric current oriented in any way in space (relative to a orthonormal reference system *xyz*), from the Biot-Savart law the magnetic field vector is defined as:

$$\vec{B} = \frac{\mu_0}{4\pi} \int \frac{I d\vec{l} \times \hat{r}}{r^2}$$

That in the case of the magnetic field generated in the center of the coil, can be rewritten as:

$$\vec{B} = \frac{\mu_0 I}{4\pi r^2}\int d\vec{l} \times \hat{r} = \frac{\mu_0 I}{4\pi r^2} 2\pi r\left(d\hat{l} \times \hat{r}\right) = \frac{\mu_0 I}{2\pi r}\left(d\hat{l} \times \hat{r}\right)$$

Posing $k \equiv \frac{\mu_0 I}{2\pi r}$, we obtain $\vec{B} = k\left(d\hat{l} \times \hat{r}\right)$.

To discover the nature of B we must then go to investigate the nature of the vector product $d\hat{l} \times \hat{r}$.

The vector product is usually defined as an application that maps from $(\mathbb{R}^3 \times \mathbb{R}^3)$ in $\mathbb{R}^3$ so at two vectors will be associated a third vector that does not belong in the starting space.

In particular the components of $\vec{B}$ are of the type $B_x = k\left(l_y r_z - l_z r_y\right)$ with cyclic permutation of the index. As can be seen the *x* component of $\vec{B}$ depends only on the *y* and *z* components of the vectors $\hat{r}$ and $\hat{l}$. To emphasize this fact we can propose a change of notation: $B_{yz} \equiv B_x$ (and similar).

Calculating all possible B_{ij} values and grouping them into a matrix we obtain:

$$B = \begin{pmatrix} B_{xx} & B_{xy} & B_{xz} \\ B_{yx} & B_{yy} & B_{yz} \\ B_{zx} & B_{zy} & B_{zz} \end{pmatrix} = \begin{pmatrix} 0 & B_z & -B_y \\ -B_z & 0 & B_x \\ B_y & -B_x & 0 \end{pmatrix}$$

This new notation allows to rewrite the magnetic field as an antisymmetric matrix with zero trace, that is uniquely associable to a set of three numbers $\{B_x, B_y, B_z\}$ that, in the three dimensional space, with an abuse of notation are usually graphically represented as a vector $\vec{B}$ having components $\begin{pmatrix} B_x \\ B_y \\ B_z \end{pmatrix}$.

The advantage given by this new representation is strictly connected to the rule of transformation. In fact matrix under basic transformation, transform according to a rule that differs from the one used for the vectors. In particular they transform following the law $B' = {}^{T}SBS$; where B' is the transformed of B and S is the usual transformation matrix for vectors and ${}^{T}S$ is the transposed matrix of the matrix S. So, in the case of reflection,

$$B' = {}^{T}SBS = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & -1 \end{pmatrix} \begin{pmatrix} 0 & B_z & -B_y \\ -B_z & 0 & B_x \\ B_y & -B_x & 0 \end{pmatrix} \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & -1 \end{pmatrix}$$

$$= \begin{pmatrix} 0 & B_z & B_y \\ -B_z & 0 & -B_x \\ -B_y & B_x & 0 \end{pmatrix} \rightarrow \begin{pmatrix} -B_x \\ -B_y \\ B_z \end{pmatrix}$$

and in the case of rotation

$$B' = {}^{T}SBS = \begin{pmatrix} -1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & -1 \end{pmatrix} \begin{pmatrix} 0 & B_z & -B_y \\ -B_z & 0 & B_x \\ B_y & -B_x & 0 \end{pmatrix} \begin{pmatrix} -1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & -1 \end{pmatrix}$$

$$= \begin{pmatrix} 0 & -B_z & -B_y \\ B_z & 0 & -B_x \\ B_y & B_x & 0 \end{pmatrix} \rightarrow \begin{pmatrix} -B_x \\ B_y \\ -B_z \end{pmatrix}$$

That are both consistent with the experimental exploration.

In the end, to find an agreement between experiment and theory, the magnetic field cannot be represented by a vector, but by a 3x3 matrix. Formally this is expressed by saying that the magnetic field is a tensor of order two.

Conclusions

In the path we proposed, starting from experimental exploration of phenomena, the students face a situation in which the “standard” representation of the magnetic field fails and, through the use of the formal description provide by mathematic, they review the definition of the formal entity. In this way the experimental framework allows students to stress the difference between vector and pseudovector (i.e. polar and axial vector) an the formal approach applied to the specific situations allow them to bridge one of the main highlighted gap in the students' studies, providing them a formal description in which they face the 'real' formal nature of the magnetic field.

VII. 5 ACTIVITY SI3

Description of the activity

As last experimental activity for the proposed learning path, it was proposed to a selection of high school students (the best students of the last two years of the Italian high schools). The students involved are 18-19 years old (school grade 12th and 13th)

Activity SI.3 was held in the building of the University of Udine during the summer school of modern physics did during the summer of the 2011.

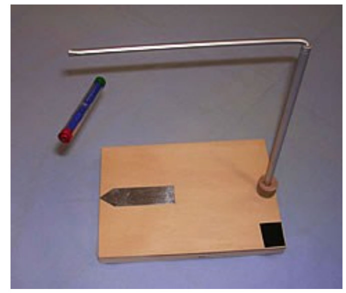
During the activity were proposed to the students individual and group works and also interactive lecture demonstration. The groups were decided by the researcher who creates homogeneous groups as concern the school level. In particular there are 4 groups of student of 12th grade and 3 groups of students of 13th grade. This division of the group was done because, while the 13th grade had already faced electromagnetism in high school, the 12th grade student did not do it and

The proposed learning path was an inquired based learning path that is represented schematically in the following table.

SITUATION AND QUESTION(S)
1) I have got a box with several different objects in it. How could I recognize the magnets between the other objects?
2) hanging a magnet in one hands, approaching it to different materials: how many and which are the interactions do you foresight to experiment?
3) Design a procedure of exploration of the several interactions.
4) Let's do the experiment together. A) write the important elements that emerges from the explorations; b) on the base of the results obtained, summarize (chategorizing) the observed interactions

5) A bar magnets lies on the table, approaching to it another magnet holding the second magnet in one hand. How do the two magnets interact?
Do a foresight, explain your foresight, represent graphically the process providing explicative comment of you representation.

6) Hang a magnet with a wire to a 'L' shaped bar.



a) Rotate the bar. Does the direction of the hanged magnet change?
b) approaching the hanged magnet with another magnet. Represents and justify the phenomenon
c) The interaction occurs even without a contact. How do you interpret this observation?
d) How do you represent it graphically?

7) The compass.
a) How do you categorize the compass, as concern the way in which it interact with a magnet? Justify your answer.
b) Design an exploration that allows understanding the nature of the compass as concern the previous classification of object that we did. Describe it and explain your proposal.

8) Discuss with your group and report the group's decision

9) Do the exploration that you design in group providing your personal critical comments as concern the way in which the exploration was held and the results obtained.

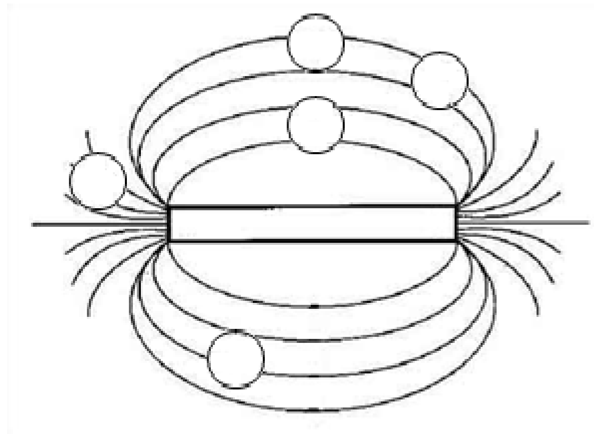
10) Every group presents its results to the class with the aim to reach a common conclusion: which is the category in which the compass had to be placed?

11) Fix a sheet of paper on the table and place a compass on it. Represent the shape of the compass and the direction of the needle.
a) rotate the compass leaving the compass on the same point. Does the direction of the needle change?
b) approaching a magnets to the compass while you are observing the needle of the compass. Describe how the needle of the compass moves and provide an explanation of it (eventually do several different experiment of approaching)
c) Paste a sheet of paper on a carton box and paste a magnet on the sheet. Using the compass as an explorer of the magnetic properties of the space, place it in several positions around the magnet. For each positions represent the direction of the needle: the choice of the position and the number of

position needed to describe the distribution of the needles around the magnet is up to you.

d) Compare our drawing with the one did by the researcher and draw the lines of orientation as envelop of the direction took by the needle of the compass.

e) Foresight the direction of the needles of the compasses placed on the different lines represented in the next figure. Justify your answer.



12) The lines of orientation in the surrounding of a cylindrical magnet. Describe the main characteristics of the pattern of lines of orientation.

a) are they symmetric?

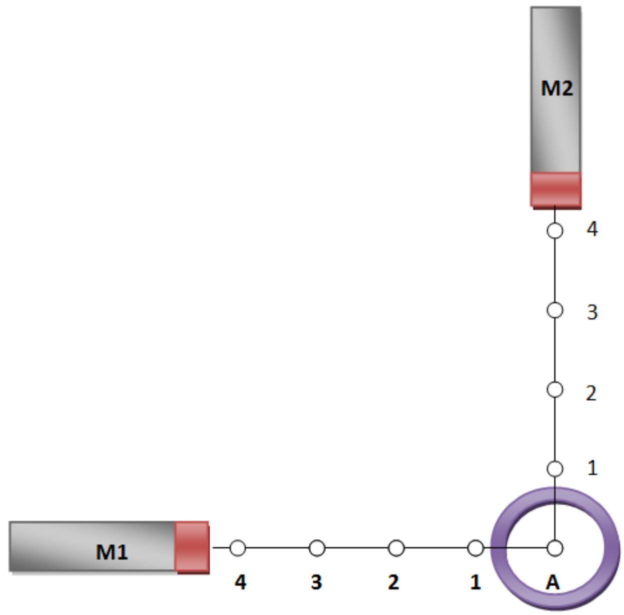
b) does them intersect one each other? What does it means from a formal point of view? (in particular as concern the uniqueness of direction at each point)

c) How does the distance between lines change? Describe, qualitatively, the trend of the distance between the lines in the points around the magnet.

d) Foresight the direction of a ferromagnetic needle placed in the same point in which the compasses were placed in the figure of the question 11.e.

e) Observe a table of compass and a table of ferromagnetic needles. Describe similarities and differences between the two cases.

13) In the figure below, are represented 2 identic magnets M1 and M2 placed orthogonally one to the other with the same pole at the same distance to the point A.



a) represent the direction assumed by the needle of the compass in the point A.

b) explain the reasoning that you did to foresight the direction of the needle in the point A

Let's do some experimentations with the table of compasses to study the orientation of the needle changing the distance of one of the two magnet from the point A

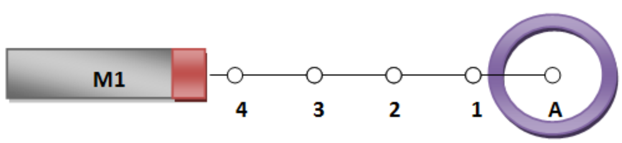
c) Use a different color to represent in the previous figure the direction of the needle of the compass plased in the point A when the magnet M1 is placed in position 4,3,2 and 1.

d) How do you explain the changes in the needle direction at the approaching of the magnet M1 to the point A?

e) looking at the results obtained, which are the characteristic of the property (the physic quantity) that we explored in the space around the magnet in terms of orientation of the needle of the compass?

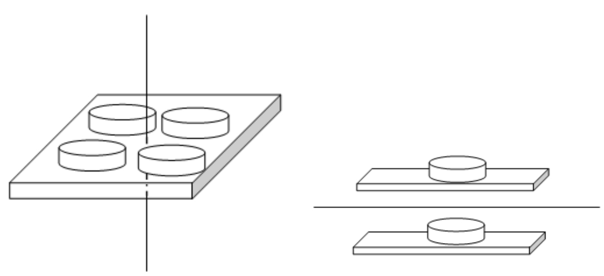
f) which formal (mathematical) entity you will use to represent this property of the space? Justify your answer.

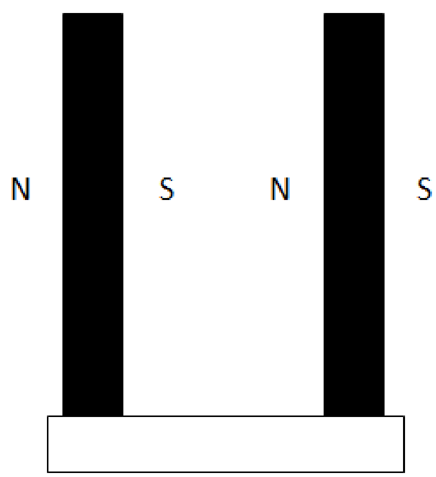
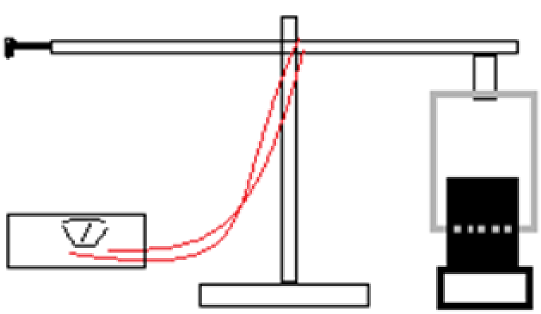
g) Represent whit the formal entity that you choose the magnetic propriety of the space / the physical quantity that we had explored in terms of orientation of the needle of the compass.



h) describe your representation, justifying it

i) the points 1,2,3 and 4 lies on a line of orientation coincident with the axes of the magnet. Do you think that the physical quantity that represents the magnetic property of the space is constant along the lines of orientation of the needles? Justify your answer.

14) a) what type of physical quantity is the one that represents the magnetic property in the points of the space? Justify how could you investigate the nature of the quantity that we represent using the lines b) Place an iron ball on a line. Leave the ball; which one will be the direction of starting of the ball? c) Do the experiment. Looking at the results of the experiment, could you said that the property of the field is a force?
16) a) Do you think that changing the plane of observation the shape of the lines representation change? b) observe the shape that the iron filling takes around the magnets. Describe if comparing its shape with the one that you drew. How do you interpret in 3-Dimensional terms the relation between the intensity of the magnetic field and the distances between the lines?
17) magnetic effects related to electric currents a) we saw that approaching a magnet to copper object there are no visible interaction. What's happen if we approach a compass to a copper wire? b) connect the copper wire to a generator so that an electric current flow in it. Approaching a compass to it, does the direction of the needle of the compass change? c) Using a compass, explore the space around the wire and complete the following picture drawing the needle of the compasses in according with the experimental exploration.  d) observe a simulation that allows to see the direction of a table of compasses place perpendicular to the wire carrying the current. Looking at the simulation, represent the field lines around the wire that carries a current. e) On the base of the observations that we did, could we argue that a wire carrying a current generate magnetic field? Justify your answer. f) describe the field lines that you just drew highlighting similarities and differences respect with the one of the cylindrical magnet

g) Using the simulation, observe the field lines of a coil and a solenoid. Describe the field lines highlighting similarities and differences respect with the one of the cylindrical magnet
18) Interaction between fires carrying a current a) two magnets are sources of magnetic field and interact one with the other. Do you think the two wires will do the same? (Being also them sources of magnetic field) b) Do the experiment and describe the observed phenomena c) how do you explain the observed phenomena?
19) Exploration of the effect produced by a magnetic field on a wire carrying a current a) The following figure represent two magnets that has the opposite poles facing. Represent the field lines of the two magnets  b) Do the following experiment. Place between the two magnets a wire connected to one of the two arms of a balance. Connect the wire to a generator and let the current flow before in one verse and then in the other.  c) describe the phenomenon that you observe and interpret it d) discuss your hypothesis in group. Write the shared idea of the group and comment it from your point of view

I.1) Paste a magnet on a sheet, placing it in the north-south direction (so the axis of the magnet coincides with a field line. Draw the axis of the magnet and represents, helping with a compass needle, a field line near field that passes from the axis of the magnet

a) measure the height of the stripes (r) in function to the distance from the nearest ends of the magnets (x). Import the data in Excel and create the graph of r^2 in function of x. Ad a trend line showing the its representative formula (to do the fit use a power-like formula).

b) Place the Pasco track in the same direction of the magnet, paste the magnet on the cart and measure with a magnetic field sensor the intensity of the magnetic field (B) in function of the distance between the magnet (x). Use Data Studio to collect data and then export the data in a .txt file, so you can import it in Excel. Represent the graph B vs. x and add a power trend line as done before.

c) draw and the worksheet the two graph writing also the two representative formulae.

d) working with the obtained formula, check if there is the hypnotized relation between B and r^2. Comment the results explaining the physical meaning.

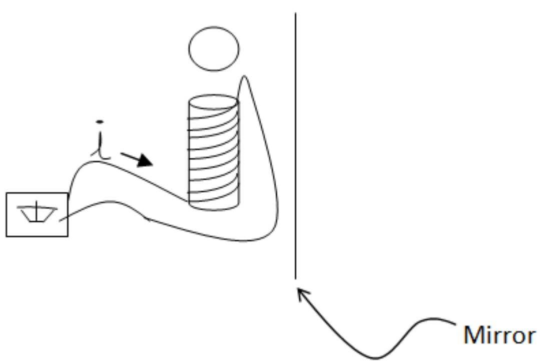
e) Looking at this relation, could be it used to acquire information starting from the field line representation as concern the intensity of the magnetic field inside the considered stripe?

f) Looking at this relation, could it be used to improve the field lines representation with the goals to represents also the intensity of the magnetic field in each point of the sheet?

g) group discussion as concern the answer to question e) and f). Write the group's opinion and comment it from your personal point of view

h) Compare the ideas of the different groups and report the idea that the class share.

I.2) Let consider a solenoid carrying a current placed vertically in front of a mirror and a compass (the circle represented above the solenoid)



a) Draw the direction of the needle in the proposed situation and in the mirrored situation (represent also the mirrored situation)

b) Realize experimentally the prosed situation and its mirrored situation c) looking at the experimental results, do you think that the magnetic field is a vector or not?
II.1) In previous explorations we saw how an electric current produces a change in the magnetic field lines. Explore now, with the available materials, if a variation of the magnetic field could produce a current in a circuit. Explore the phenomenon individuating parameters and variables a) in how many way could you generate a current? Describe all of them carefully b) which action instead did not produce current? c) which are the parameters involved into the process? d) Do a group discussion and write the shared opinion reporting your personal comments
II.2) a) which is the type of motion of the magnet? b) taking into account all that you had discovered during the first phase of this activity, how do you think that the tension-time graph will be? Represent it qualitatively c) do the experiment. Draw the graph obtained on your worksheet d) compare it with your previous foresight and comment similitude and differences between the two graphs. e) has the tension always the same sign? What does it means? How do you explain it? f) Which phase are the phase that you recognize into the graph? g) Looking at the graph, when the magnets is approaching to the coils? h) when does the magnet go through the coil? i) compare the absolute value of the height of the two pick. Are them equal? How do you explain it? j) measure form the graph the width ad half height of the pick. Are them equal? How do you explain it? k) Using Data Studio, measure the area of the two pick. How are these two areas? l) what does it means from a physical point of view?
III) Taking into account all what you saw and experimented during the learning path, answer in the best way that you can, to the following questions: 1) why can I use iron filling instead of compasses to visualize the magnetic field lines? 2) Describe the proposed artifact [induction toarch] 3) take two magnet and an iron ball and place them as in the next figure. Remove a magnet, reverse it and then approach it to the iron ball. Does the magnet stick with the ball? Using a draw explain the

observed phenomena 4) Draw the field lines of a magnet when it is placed parallel to the Earth magnetic field. Then place the magnet perpendicular to the Earth magnetic field and draw again its field lines. Compare the two drawings. Are them equal? Explain why. 5) Observe the experiment of the falling magnet in a copper pipe. Why the fall of the magnet is slower?

Data and Data Discussion

Here will be discussed the more interesting question as concern this learning path with an analysis of their results.

Question 1. The students gave several different answers that are summarized in the following table (Table SI3.2). Answers, obviously, are not mutual exclusive because one student could provide more than one strategy to solve the proposed problem. A large majority of the students propose to use a known object as a probe to explore the other objects; in particular they propose to use a piece of iron (53%), a compass (26%) or a

Table SI3.2. Student's answers to question 1. The percentages reported in the three columns are relative to the whole number of students, and the 12th and the 13th grade students separately.

STUDENTS' ANSWERS	**%TOT**	**%12th Grade**	**%13th Grade**
Shake the box and…	7	8	6
…look if some object attracts or repel others	2	4	0
…look which object will stick together	5	4	6
Look at the direction of a compass needle…	**26**	**28**	**24**
Take the compass, put it far away from the box and approach one abject at a time; if compass needle is not toward North ,it is a magnet	24	24	24
…because its needle is influenced by the presence of magnetic and ferromagnetic objects	2	4	0
Approaching an iron/ferromagnetic object to the box and…	**53**	**44**	**65**
…if there is a magnet, the magnet will move	5	8	0
…look for abject that will be attracted	48	36	65

Use a magnet…	**14**	**12**	**18**
…and look if some objects are influenced by it	10	4	18
and look for abject that will be attracted by the charged magnet	2	4	0
and look if some object is attracted becouse equal charges repel themselves, while opposit charges attrac themselves	2	4	0
Approach the objects two by two…	**24**	**24**	**24**
…and after that I had individuated a couple that stick together , I will separate them and I will check with other objects each one of the two object with other objects	19	24	12
…and look if they attract themselves	2	0	6
…it means that someone of them is a magnets	2	0	6
Using Iron Filling:	**5**	**4**	**6**
throw it in the box and look around which objects it will be attracted	5	4	6
Using a fluxmeter	**2**	**0**	**6**

magnet (14%). There is also a considerable group of proposed strategies that do not need the use of a known object (31%) and are based on the observation of the interaction between the objects that are inside the box. In particular 7% proposes to shake the box and look, while 24% propose a more systematical exploration taking into account only two abject at time. At least, only one student (2%) of 13th grade propose to use an instrument, a measure of flux to identify the magnet(s). No relevant differences are noticeable related to the difference in school grade.

Question 2. Two not negligible groups (12% each one) argue respectively that the possible interactions are: attraction repulsion or rotation (group 1) and attraction or nothing (group 2). But, answering to this question, the majority of the students (71%) highlighted three type of interactions: attraction, repulsion or nothing. In particular, as concern to the repulsion is interesting to notice that 16% of the whole students argued that there is always repulsion between two magnets, while the remaining 55% speak about interaction between the poles of the magnet saying that if two equal poles are approached there is repulsion and if two opposite poles are approached there is attraction. Indeed there is a very small group (5%) that instead speaks in terms of attraction and/or repulsion, speak in terms of movement: magnets and object approach one each other or go away one from the other. As concern this question almost all the students (95%) speak in terms of interaction between the magnet and the other objects or magnets, in addition the other important results id that three quarter of the students argue that there is repulsion between the magnets referring spontaneously to an approach that considered only the interaction between the two nearest poles or that referred to a situation in which the magnet are constrained on a line.

Question 3. After a discussion, half of the students did not reply to this question, while 17% propose to check two by two the interaction between the objects and then, looking at the type of interaction, identify the magnets. 29% propose to use a magnet and try it with each object and look at the type of interaction. The large number of students that did not reply to this question, as them confirm orally, is mainly due to fact that the answer to question 3 was the same that they wrote for the question 1 before the discussion, and so they do not fells the need to rewrite the same answers but even they did not explicit this fact on the worksheet and so the data concerning question 3 are not to be considered valid.

Question 4a. For the same reasons of the question 3 it did not give relevant results.

Question 4b. This question instead was faced effectively. 7% categorized the object by their type of interactions: no interaction, always attraction and attraction after the rotation. A 50% use instead another categorization that is also based on the type of interaction: attraction between opposite poles, always attraction and paramagnetic and diamagnetic interaction. 5% use a categoriazation based on the cinematic description of the phenomena: no movement, approaching, stick together after rotation. 33% used a categorization based on the typo of materials: ferromagnets, paramagnets and diamagnets that interact in different ways. In particular, as concern this last group, 3 students provide models of the inner structure of the different materials: 2 in terms of Wise domain and one in terms of Ampèrian elements of current. Indeed 2 students represent the different shape that the field lines assume while they go through these different materials. Looking at the data emerges the importance of the experiment done with the pyrolytic graphite that allows highlighting the presence in the box of paramagnetic and diamagnetic objects. It's also interesting to notice how the categorization related to the objects with which there are no interactions, disappears leaving its place to the two categories related to the paramagnetic and diamagnetic.

Question 5a. As concern this question, 38% of the students foresight that there will be attraction or repulsion depending by the pole that we approach. 28% said that there is approaching with eventually a rotation of the free magnet. 14% said that there is attraction or rotation and attraction. 12% foresight attractions until the two magnets stick together. Indeed 5% argue that the magnet on the table aligns itself to the other magnet and 2% argue that the magnet is always repelled. Looking at these data emerges that, despite all the previous observations, more than one third foresights that two magnets attract or repel themselves as said during the exploration of their naïve knowledge. But more than half (28%+14%+12%), looking at the previous experimentation, overcome this dichotomous approach to the description of the interactions between magnets highlighting that there is not a simple repulsion.

Question 6. All the students highlight that the direction of the magnet does not change arguing in particular that: the hanging magnets is like a compass (29%), the hanging magnet is influenced by the Earth magnetic field (29%), the magnet is always attracted by the same point (21%) or only highlighting that the direction does not change. The percentage of students is almost the same for each type of answer. In particular more than one quarter of the students highlight spontaneously the analogies between the hanging magnet and the needle of the compass.

Question 6.c. The spectrum of the answers to this question is really wide: 21% of the students said that there is at a distance interaction, 17% that there is a modification of the space, 12% said that there is attraction and repulsion between the poles, 10% said that it is due to the presence of a magnetic field and 8% that it is due to the line of force of the magnet. The other 45% gave a series of answers that are so different that could not be categorized in category that are larger than 5%. In addition in this question there is a substantial differences between the two groups of ages, in particular the 32% of the 12^{th} grade assert that there is at a distance interaction when the corresponding group of the 13^{th} grade students is 6%; and the opposite happened to the ones that argue that this type of interaction is due to a modification of the space: 8% of the 12^{th} grade and 28% of the 13^{th} grade. So in this question the role of the prior education is preponderant.

Questions 13. In these set of question will be addressed the problem of the representation of the magnetic field in a point as a vector (instead of a versor as done until before this question in the learning path). This represents a change in the standard learning path experimented before.

Question 13b. All the students highlight that moving the magnet M1 there is a change in the direction of the needle of the compass and in particular they argue that we have to consider also the intensity of the magnetic field (46%) we have to use the rule of the parallelogram (10%), because change the angle between the needle and the straight line of the position 1, 2, 3, 4 (15%) or because there is a composition of field.

Question 13d. There are ….. main ways in which the students explain it: approaching one of the two magnets there is no more balance between the two force exerted by the magnet and so the direction of the needle changes (33%), approaching one of the two magnets the square become a rectangle and so the direction changes (23%), the distance influence the force with which the magnet attract the needle (16%); it is a manifestation of the superposition of the fields (5%); the remaining part gave other justifications (11%) or did not reply (17%).

Question 13.f. almost all of the students propose as representative formal entity a vector (93%) because we need to represent direction verse and orientation (69%) or because it can take into account the principle of superposition or the parallelogram rules (22%).

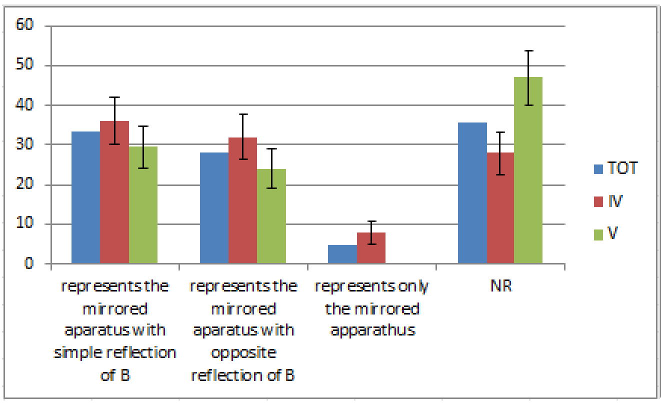
This formulation of these part of the learning path allow student to address the problem of the formal representation of the magnetic field as a vector in an experimental way that is more suitable that the one used in the previous learning path based of on the drawing of the field lines of the magnet when it is perpendicular and parallel to the field lines. This formulation with respect to the previous one is better because it works in only one point and not on the entire plane and so it is better founded as regard the representation in one point of the magnetic field.

The problem of the representation will be address and extended to the idea of pseudovector using the description of a situation and its mirrored situation proposed at the end of the learning path (Part I.2)

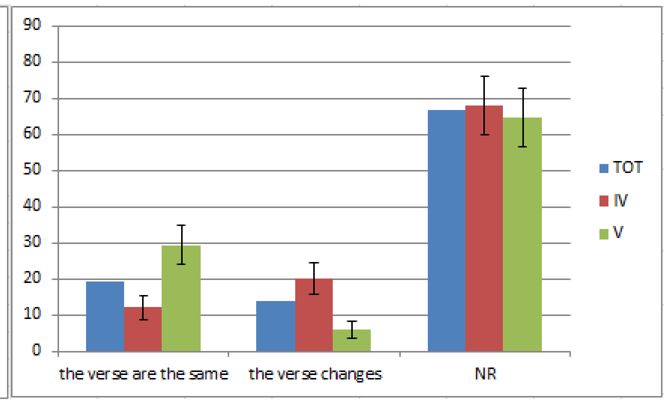
As concern this part of the experimentation, in the provisional phase, 36% of the students represent the mirrored image of the needle as simple reflection, 28% represents the needle of the compass with opposite verse, 5% represent only the mirrored apparatus and 36% did not replay to this task (Graph SI3.1).

At the second phase, 19% of the students highlighted that the verse of the mirrored image of the needle is the same without justify it, while 14% highlights that the verse is different justifying their answers saying that the verse is different due to the right hand rule (2%), because the verse of rotation of the coils change (2%), because there is a change in the direction of the magnetic field (Graph SI3.2).

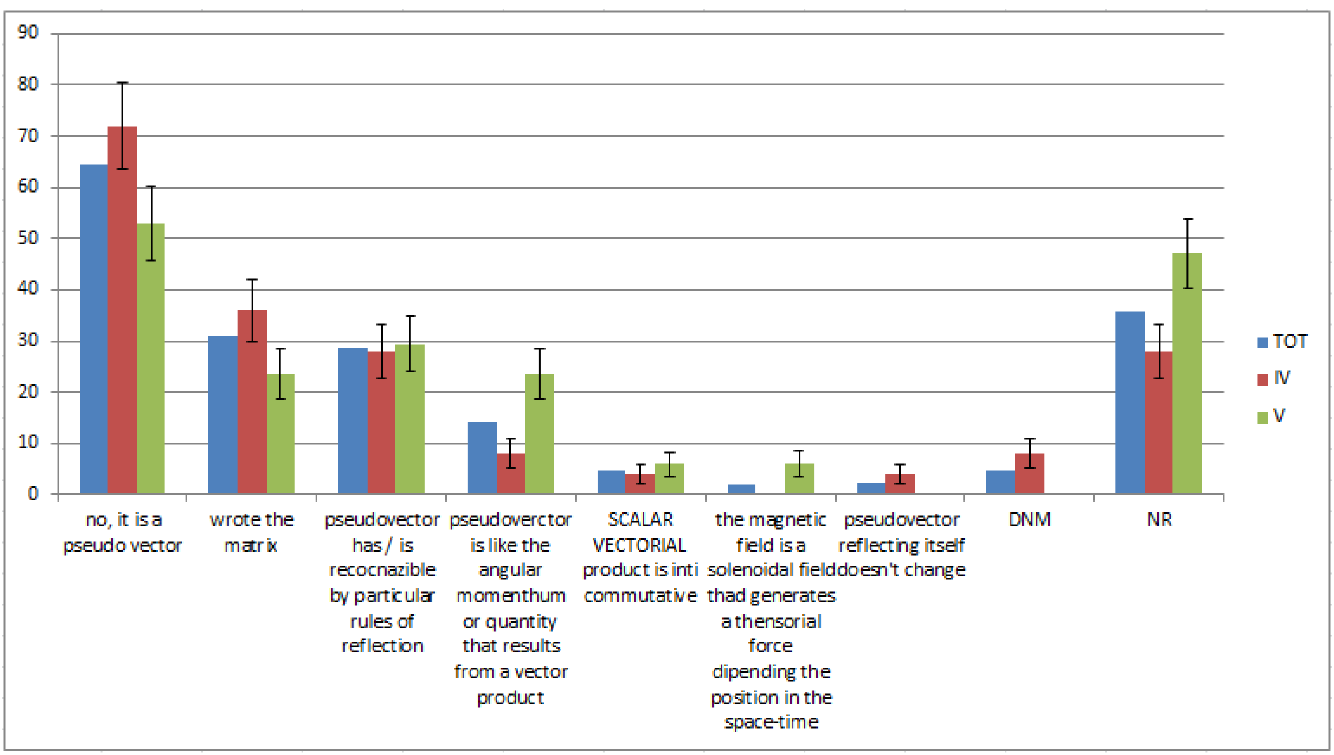
In phase three, 64% of the student highlight that the magnetic field is not a vector reporting only the representative matrix wrote by the teacher on the blackboard 31%, highlighting the rule in the recognition of the nature by the different rule of reflection 29%, pseudo magnetic vector is like the angular momentum or quantities that are defined through a vector product, 14% because the scalar product is anti-commutative 5%, or give other argumentation 4%, 5% did not motivate and the remaining 36% did not reply (Graph SI3.3).



Graph SI3.1: Representation of the mirrored image of the needle done by the students



Graph SI3.2: Observation done by the students of the experimental results



Graph SI3.3: Consideration done by the students on the nature of vector of the magnetic field

Neglecting the students who did not replay and the ones that represented only the mirrored apparatus, students' spontaneous approaches to the analysis of the mirrored situation are almost distributed equally on two different way of analysis: the first one is the representation of the needle of the compass as a simple reflection of it and the other is the drawing of the compass needle starting from physical consideration of the mirrored apparatus. No significant differences were highlighted between the 13th and 12th grade students.

In phase two, the analysis of the experimental situation, could be noticed how decrease the number of students that thought that the compass needle (i.e. the magnetic field) is reflected in the standard way, but not to a negligible percentage highlighting two main approaches. The first approach followed, by that the students of 13th grade (that had already faced the magnetic field description during the previous school year), is to look at the experiment as a confirmation of their ideas and not as an investigation opened to new findings, do not allowing them to notice keys elements that are in opposite with their thesis. The second approach, followed mainly by the 12th grade students is more open to the acceptance of eventually discording results respect to their prevision and so they can noticed and highlighted these discrepancies.

After the discussion, in the third phase, no one of the students recognize the magnetic field as a 'standard' vector, but the motivations that they gave are distributed on a wide spectrum that is reported in graph 3. Interesting to be noticed is that, even almost one third of the students justified this aspect reporting only the formal structure wrote on the blackboard by the teacher, the remaining part highlights experimental evidences to support this inference. In addition the data also highlight how mainly the 13th grade students propose comparisons and analogies with other quantities that they had already faced during their previous study (as for instance the angular momentum).

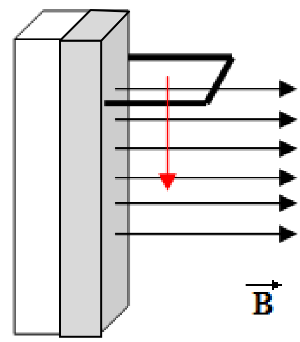
Indeed this experimentation, done on the introduction to high school students of the nature of pseudovector of the magnetic field, highlight how through a simple experiment student could face this formal characteristic, recognize it and do comparison between this characteristic and analogous previous physic entity that they already know. In addition, looking data concerning question two, were highlighted how the standard way of teaching used in the high school represent an obstacle to the acceptation of this 'new' property by the student in they further studies.

VII.6 ACTIVITY U1

In the perspective of future developments of a teaching learning path realized at university level, a first investigation of the learning knot related to electromagnetic induction is developed and early experimented through the use of the following questionnaire.

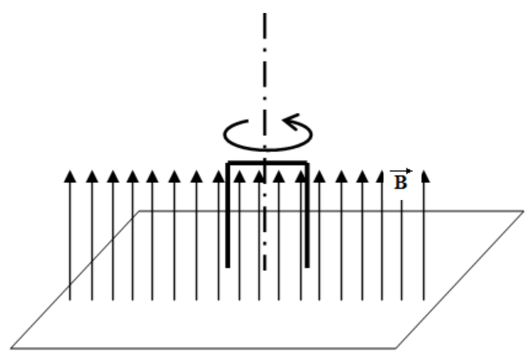
Exercise 1

A U-shaped conducting wire slides with a constant speed along the pole of a magnet, which magnetic field is constant, as shown in figure. Do you think there exists an induced current circulating inside the wire? Justify your answer and explain how you argue it



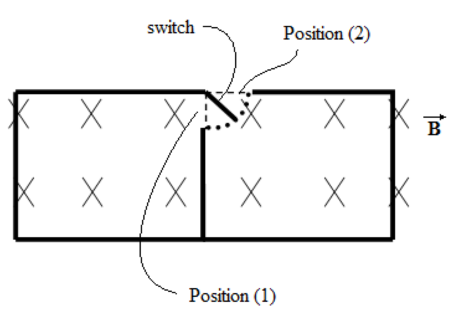
Exercise 2

A U-shaped conducting wire rotates on a conducting plane (being in contact with it) surrounded by a uniform magnetic field as shown in figure. Do you think there is an induced current circulating into the wire? Justify your answer and tell how you discriminate if an induced current circulates into the wire or not.



Exercise 3

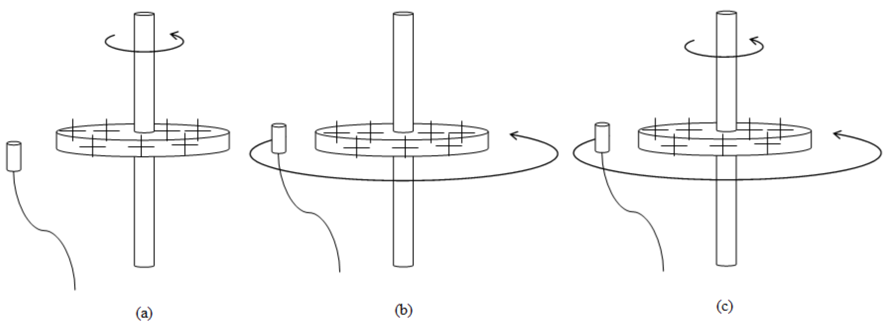
A conducting circuit is placed inside an uniform magnetic field **B** entering into the sheet, as shown in figure. Changing the



switch position from (1) to (2), does it generate an induced electromotive force? Justify your answer. If the experiment will be repeated with a switch that is longer than the one used before, do you think that the induced electromotive force is reduced, increased or remain the same? Justify your answer.

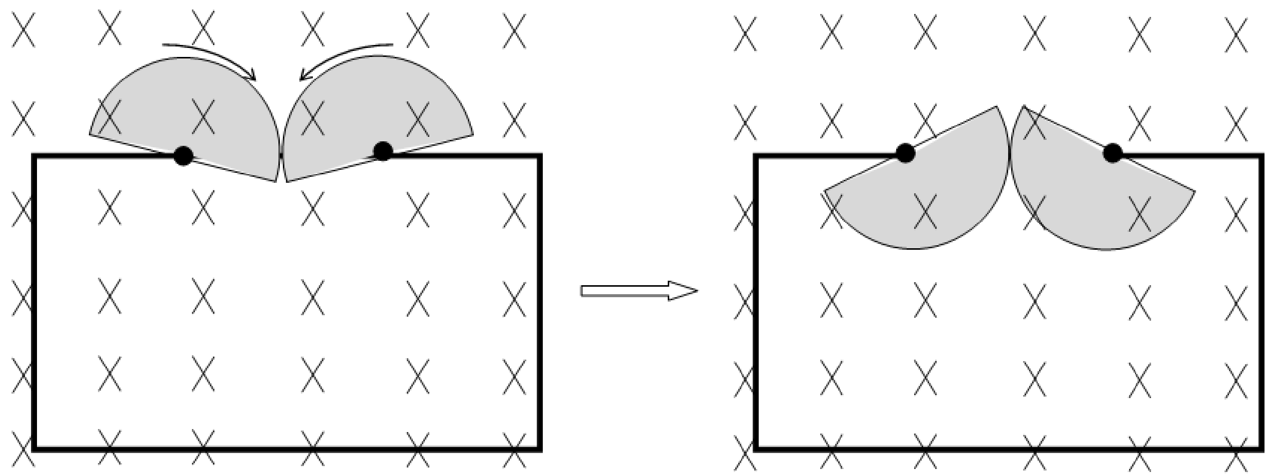
Exercise 4

Les us consider a charged disk and a magnetic field sensor in the three different situations shown in figure: (a) sensor is at rest and the disk rotates on its axis; (b) the disk is at rest and the sensor rotates around the disk; (c) both the disk and the sensor rotate with the same angular velocity. Explain in which of these situations the sensor reveal the presence of a magnetic field. Justify your answer.



Exercise 5

Considering the situation proposed in the next figure, where the connecting wires and the rotating half circular are all conductors, do you think the displayed process can produce a current into the circuit? Justify your answer.



This simple-like situation are real challenging problems in which solutions could be perform only through the use of high level reasoning that highlight the use that students do of their own knowledge in the interpretation of these exotic challenging situations.

As one can find in many physics exercises, there are several ways to solve the proposed problems. In particular concerning electromagnetic induction problems two are the main ways in which we expect that students will solve these exercise: one is using a Faraday-like approach looking and analyzing the changing in time of the flux interlaced to the circuit; the other one is related to the analysis of the Lorenz force acting to the electrical charges that are inside the conductor. The equivalence of these two approaches is simple mathematically demonstrable by the use of the Stokes' theorem that allow to move from an interpretation to the other.

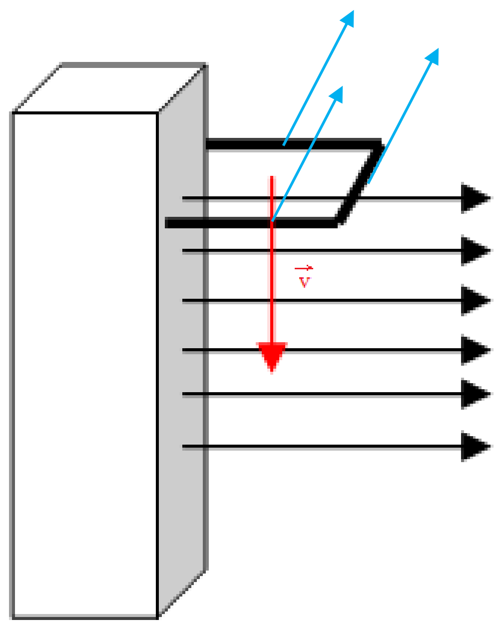
As concern the first approach, from an educational point of view the main conceptual knot that is involved is the definition of the area swept by the circuit, in particular when there are sliding contact between the elements of the circuits. In the second approach, instead, the main learning knots knot is related to the role (and the definition) of relative motion between charges and magnetic field.

For each one of the proposed exercises there will be introduced the both type of solutions.

Exercise 1: Solution

Faraday-like approach: The area enclosed by the conducting wire while it is moving, includes also the lateral areas swiped by it. So, the outermost part of wire generates a swiped area normal to the B field and therefore there is a not null flux concatenated, which varies while the wire falls. Therefore, there is an induced electromotive force (emf) in the circuit.

Lorentz like approach: (in this and next figure, force acting on each side of the circuit are displayed in blue).

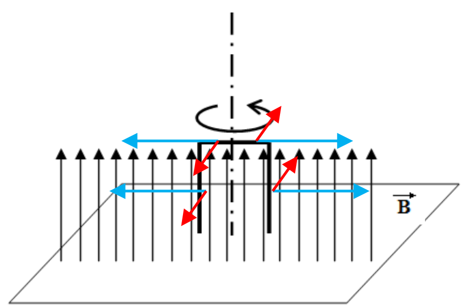


In this analysis will be considered only the negative charges. As usually done for metals, we suppose that only the negative charges are able to move through the circuit. So the two forces acting on the lateral side are perpendicular to the side of the circuit, so they haven't got an effective effect related to the induced electromotive force. Instead, on the central segment of the circuit, there is a net force that moves charges generating a current.

Exercise 2, solution

Faraday-like approach: Also in this case, the surface closed by the wire is formed also by the surfaces swept by the different parts of the wire. While the lateral one, generated by the vertical tracts of the wire, has associated a null flux, the circular sectors defined by the movement of the topmost part of the wire has associated a not null flux, varying in time and therefore, there is an induced emf.

Lorentz like approach: (Lorentz force in blue, velocity of the wire in red)

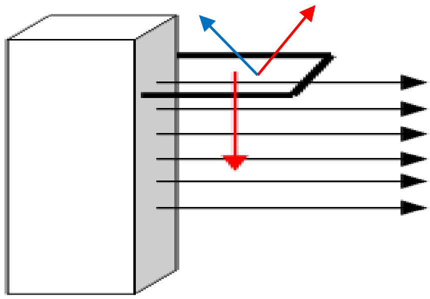


Force on the lateral sides can be neglected as in exercise one because force is perpendicular to wire. As concern the central side of the wire, for each point on an half of this side, there is a point symmetric to it (respect the center) in which there is an opposite force acting on it. So, in the circuit there is not a current flowing in it, but there is an induced emf between the edge of this segment of wire and its center.

Exercise 3, solution

Faraday-like approach: The surface “closed” by the circuit varies while the switch is moving, sweeping the circular sector shown in the figure. So there is an induced emf, with an intensity depending on the amount of the area swiped by the switch: the longer the switch is, the greater is the induced emf. The magnitude of the second area is not important.

Lorentz like approach: (Lorentz force in blue, velocity of the wire in red)



The only part of the circuit moving is the switch, so the force Lorentz fore is acting only on the switch and then the emf depends on the length of the switch.

In this case, in addition, also an approach that looks at the energetic considerations on the system, is truly fruitful because is strictly related to the principle of conservation of energy and if one assume the all the “new area” is involved in the calculus flux variation (instead of the area swept by the switcher) it could be easily connected to a situation of violation of the principle of the conservation of energy.

Exercise 4, solution

From an analytically point of view this is truly a challenging problem. The solution to this problem is that the sensor measures a field in all of the proposed situations.

But, even if the analytical solution of this problem is probably out of the range for these students it could provide extremely interesting consideration as concern the approach that the students adopted to face it.

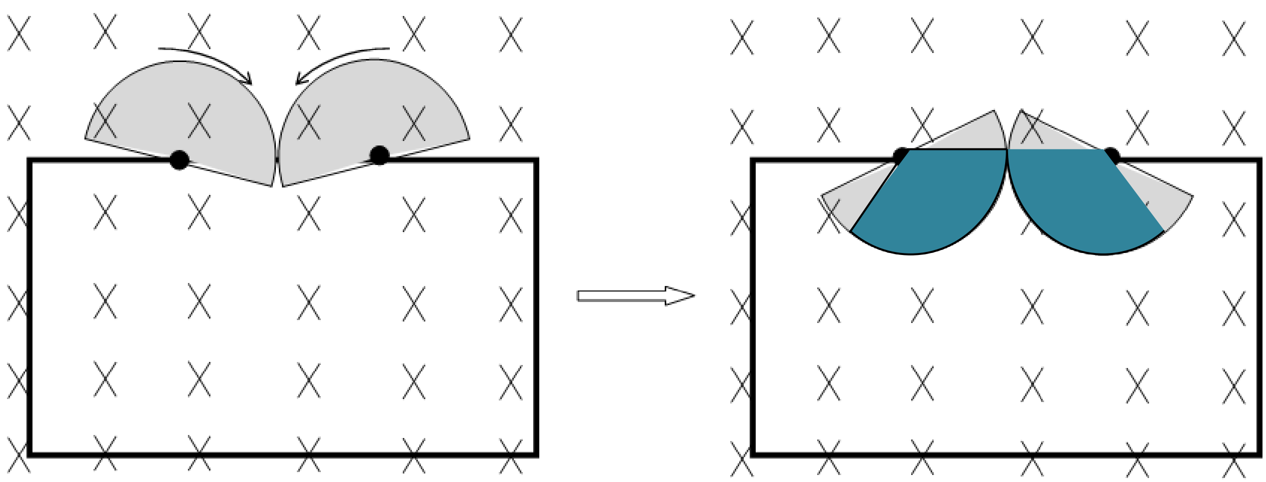
In particular looking at the different ways of reasoning that students use to face it:

- if they take into account the relative motion between detector and charges, the field sensor detects a magnetic field in two of the cases (a) and (b).

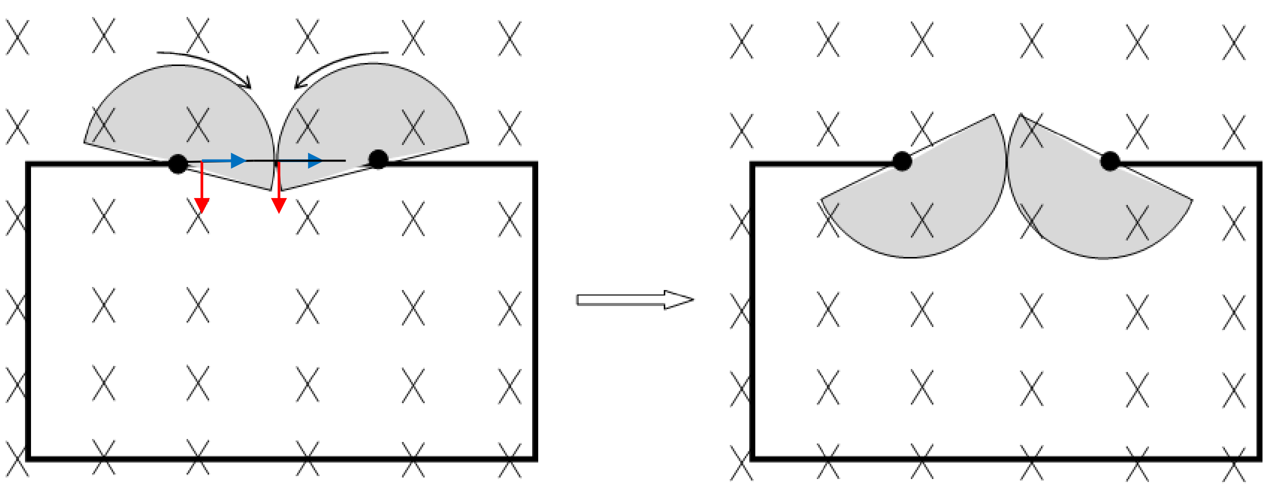
- if they take into account the charges in motion with respect to an inertial frame produce a magnetic field, the field sensor detects a magnetic field in two of the cases: (a) and (c).
- if they take into account the relative motion between charge and the detector also considering the fact that the system in case (c) is not inertial, they deduce that the detector detects a magnetic field in all the three cases.

Exercise 5, solution

Faraday-like approach: the swept areas are the two colored in blue



Lorentz like approach: (Lorentz force in blue, velocity of the wire in red)



In this case a quantitative Lorentz approach isn't so smart with respect the Faraday one, but it avoid the need to considered swiped areas. In particular, using the right hand rule for the charges that are on the line that connects the two center of the half circles, the Lorentz force acting on these charges is in the same direction and it could (qualitatively) suggest that this process generate an electromotive force in the cirduit.

Data of the pilot study

As pilot study, this test was proposed to university students coming from the University of Pavia (Italy) that had already followed the course of electromagnetism in the previous semester. There were 11 students that participated to this pilot study: 8 of them had already passed the final examination of the course, and 3 no.

As concern exercise one only 2 students argued that there was an induced electromotive force in the circuit. One justifying his answer with the use of the vector formulation of the Lorentz force applied to the circuit side that is perpendicular to the magnetic field; the other, instead, misunderstood the problem saying that there is a generation of current while the circuit enter and exit from the magnetic field. The other 9 student argued that there is no induced current in the circuit using exclusively a Faraday approach (6), a mixed approach (2) or arguing that there is not an induced emf because B is constant (1). For mixed approach was identified an approach that was based on a double analysis of the problem done before with a Faraday like approach and then by a Lorentz like approach used as support for the results of the first one. Between the 6 students that use a Faraday approach, 5 lead to the conclusion that there is not an induced emf because there is no flux variation and 1 because the magnetic field is perpendicular to the surface of the circuit.

As concern exercise two all the students agreed that there is not induced current: 7 of them used a Farady like approach, 2 a Lorentz like approach, 1 look at the constancy of the magnetic field (the same student of the previous question), and one did not answer.

The argumentation was almost the same of the previous exercise: who used the Farady like approach argue that it was because there is not flux variation (5) or because B is perpendicular to the wire (2); who uses the Lorenz approach or use the vector formulation of the Lorentz force as done before (1), or doing argumentation on the symmetry of the system (1) arguing that because the system has a central symmetry the net force of the all Lorentz force acting had to be 0. The student who use the vector approach of the Lorentz force, also highlight the presence of a difference of potential between the center and the side of the horizontal part of the circuit.

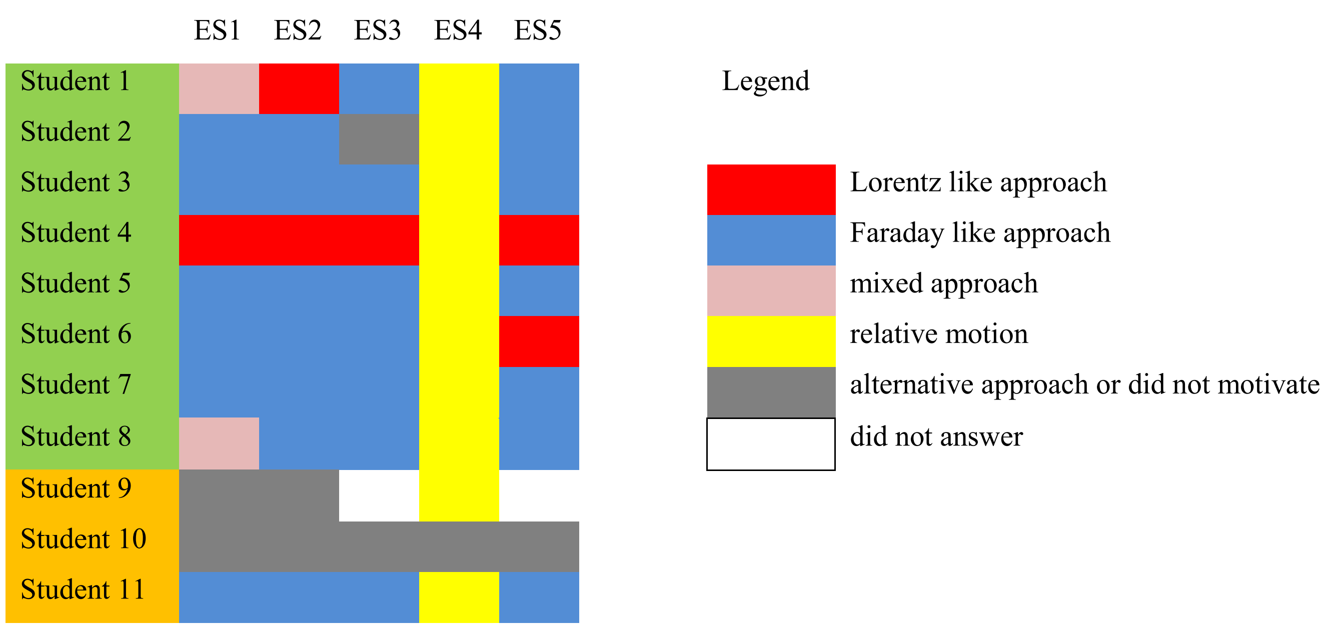
As concern exercise three, 10 students said that there is an induced current, one said no, and one did not reply. The one who said no, argued that if the switching is instantaneous the classical electromagnetism is not applicable and if the switching takes some times we do not have an induced current but only an initial and a final situation. From the 10 that said that there was an induced emf, 9 of them, considered as related to the change of flux the all new area (not only the one swapped by the switch). Only one, reasoning in a Lorentz like way highlights the importance of the length of the switch.

In exercise four, all student (but one who did not motivate his answers) replied that the magnet field sensor measures a magnetic field in situation (a) an (b) justifieng their answer by the relative motion that there is between the two abject. The only one student that gave a different answer did not provide any explanation for it, but he argues that the sensor measures a magnetic field in case (a) and (c) that are the situation in which the disc is in motion respect with an inertial frame.

In exercise five, 3 student said that there is an induced emf using a Faraday like approach and arguing that it happens because the final area of the circuit is smaller than the initial one. One student did not replay and the other (7) said that there is not an induced emf because: there is not variation in flux (2) – if we consider the ‘effective’ circuits it is always rectangular; doesn’t matter what the disk did; the contribution of the integral of $\vec{B} \times \vec{s}$ is opposite for the two half disk and so there isn't a net contribution (2); the disk generate opposite emf (1); being the apparatus symmetric there isn't a favorite way for the circulation of the current (1) and one did not explain his answer.

Data analysis

What emerges from this pilot investigation is that the student's most used approach is a Faraday like approach even, in some cases the Lorentz approach seems to be more useful. A table of synthesis of the model that the student used is reported here (if the background color of the student's code is green it means that this student had already passed the examination of electromagnetism, if it is orange, no):



What emerges from this table is that each student has his own favorite way to approach to the problems (i.e. is almost always the same student who uses the Lorentz like model. A double interpretation, using mixed approach was only performed for the first exercise and the use of the second model was only seen as a support of the first one.

The most used model is the Farady-like model even if in the argumentation of the exercises no one of the students uses the idea of swapped area and/or address the presence of sliding contacts into the situation proposed.

Conclusion

As expected, the proposed problems results to be truly challenging situations for the students, but the main important results of these experimentation is that what emerges from the data is that each student uses almost always the same model to approach to the different situations and only in rare cases they tray to apply a different model to the same situation to check their prevision. This is a crucial things because if with pupils and high school students reach a global vision of the phenomenology is a great goal, with future specialist (university student enrolled in the bachelor degree of physics) the goals had to be much wider. It has to be the acquisition of the skills needed to master multiple global vision of the phenomenology individuating which is the best one to address the particular situation.

And, moreover, a consideration for further development is the role of the symmetry in the electromagnetic situation. As shown by the data, some students try to take advantage in the interpretation of the phenomena by finding symmetry into the system. This approach extremely useful in physic had although the problem of the different rules of symmetry of the different elements involved in the system. For instance, being the magnetic field a pseudovector, compared to a vector, it has different rules of reflection that had to be taken into account also in the analysis of the symmetry of the system.

VIII RESEARCHES WITH TEACHERS

VIII.1 Overview of the activity of research as concern teachers formation

The formation was done with in-service e pre-service teachers. The teachers formation was realize also by means at distance courses using blended modality with the in-service teachers. The blended activities were done using the IDIFO2 and IDIFO3 platforms that were developed by the Research Unit in Physics Education in the framework of a pluriannual work on at distance in-role teachers formation (Activity T1).

As concern instead the pre-service teachers formations, the work was held with the students enrolled at the second year of the Faculty of Education in the University of Udine. In this case the strategy adopted was done through an experiential modality in which the teachers had to face the same learning path proposed to the pupils analysing and discussing each steps of the proposed learning path. In addition, pre-service teacher had to design a learning path starting from the one that we proposed and experiment with a class of pupils under the supervision of a researcher.

VIII.2 ACTIVITY T1.

Research literature highlights the importance of a revisiting of disciplinary content in a didactic perspective starting from students reasoning and learning processes. A research-based on these aims, concerning in-service teacher formation, was done treating electromagnetism and superconductivity in the framework of the national project PLS and the European MOSEM Project to realize a research-based in-service teacher training based on PCK.

In the framework of the national project, "Progetto Lauree Scientifiche" – PLS – in which the Research Unit in Physics Education of University of Udine leads 15 Italian research groups, was activated a teacher training institutional course ("Corso di Perfezionamento IDIFO2 - Innovazione Didattica in Fisica e Orientamento 2" - of 15 CTS) at national level on modern physics teaching. This national project, financed by Ministry for Education and University (MIUR) and promoted by the Science Faculties of Italian Universities, is implemented to face the fall of students' interest and motivation concerning the study of scientific subjects. The goals of this project are the promotion of students' interest in physics subjects and the popularization of research activities promoting lab work in schools and producing a cooperation between schools and universities having teachers as referents. In this framework particular attention was given to in-service teacher training, scientific education in school curricula and learning processes focusing on which are the main important conceptual knots related to each subject.

Figure 1 Universities involved in PLS project

For what concern electromagnetism research literature highlight the presence of some typical conceptual knots in the students' knowledge related to the concept of field both in static and dynamic situations. In static field students' difficulties related to the concept of electromagnetic field are concerning: 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). Related to the interpretation of Lorenz law there are two main knots because students do not distinguish electrical and magnetic effect and they do not recognize Lorentz force or that there are moving charges inside the conductor (Maloney et all, 2001) and, 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).
Moreover, for what concern in-service teachers training, recent researches showed how teachers had to acquire competence as in subjects mastering as in pedagogical skills and a PCK analysis [Shulman, 1986] on particular situation allows teacher to face directly the conceptual knots; in this way teachers can study how to face in classroom these main learning problems and avoiding so the creation of misconceptions.

To do so, looking into the literature (Galili & Kaplan, 1997) and in the framework of a collaboration between the University of Udine and the University of Basque Country (Guisasola J. private communication), a set of problematic situations is identified and some of these are take into account to be proposed to teachers analysis in the context of the Master IDIFO2 .

Master IDIFO2

Master IDIFO2 was responsible for the training of in-service teachers on issues of modern physics. To do so a blended at-distance course was activated at the University of Udine for two year. The goals of the Master were: training teachers on issues of modern

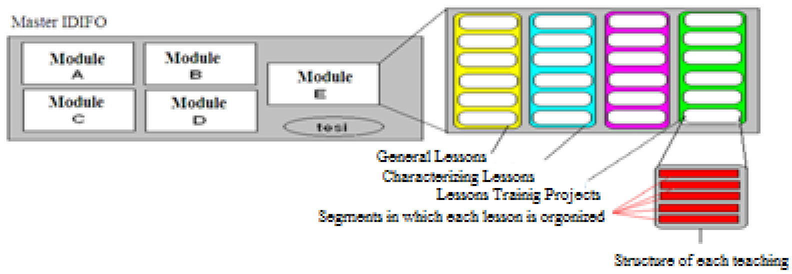


Figure 2: Structure of Master IDIFO2

physics, increase the depth of teachers' skills concerning the mastering of subjects and pedagogical aspects, promote innovation in teaching strategies in secondary school, preparation and testing of teaching materials with blended strategy and development of proposals for orientation training. Project was structured into four formative areas (general, characterizing, design and located) and was divided into seven modules: 1) quantum physic, 2) relativity, 3) superconductivity, 4) time, 5) energy, 6) physic and art, 7) orientation and problem solving. All modules were organized into activity sections. The activities of the master include: training in communication network, experimental activities in laboratory, intensive workshops, design activities and experimental teaching activities.

An important role was reserved for on-line discussion on teaching strategies stimulating so a process of cooperative learning among the participants of the Master.

PCK activity

Into the superconductivity teaching module, developed at the same time in the both frameworks (MOSEM European project and PLS national project), particular attention was given on the study of particular conceptual knots related to electromagnetism trough the development of a PCK analysis..

The PCK analysis performed was structured in three phases: in the first one teacher had to analyze the situation, master it and answer to a particular question, in the second phase teachers had to analyze a set of typical students' wrong answer (each one is related to a particular conceptual knot) identifying the errors and in, the third phase, they had to plan how to face each one of these knot in classroom.

Teachers so have to analyze:

1) The situation itself

2) Which are the situations that may be submitted to discuss the thesis incurred by each student?

3) Which are the models of interpretation and the types of reasoning that students show in the cases listed?

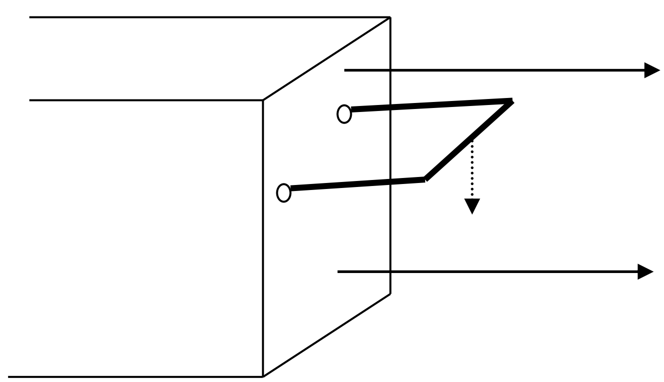
4) Which are the knots behind each answer?

5) How to deal these situations in classroom.

In this way, starting from the analysis of specific physics situations, teachers can investigate their knowledge and the pedagogical aspect facing directly the main important conceptual knots.

Furthermore, the comparison between teacher's answer can be a source of interesting discussion on the conceptual knots present in the teacher knowledge establishing a peer-cooperative environment in which teacher help one each other to reach the formulation of a formal complete answer for this challenging situations.

For instance, analyzing the situation proposed in Figure 3, one teacher wrote: *"Charges (electrons) of the conductor A'A'' are subject to the Lorentz force and are pushed towards the point A''. If the loop was complete (closed) even the charges of the side conductor AA''' would be pushed towards the point A'''. In this case there would not be induced current, but only a potential difference due to the Hall effect. The fact that the loop is not complete, but closes on the contact AA''' of the magnet may be suspected that the induced current circulating in the loop conductor, closing the circuit on the magnet"*. Other teachers, for the same situation, uses the idea of magnetic line cut by the circuit to explain electromagnetic induction: *"The conducting wire of Figure 3 moves with velocity* ***v*** *perpendicular to the lines of force of magnetic field B. The movement of electrons in the conductor develops the Lorentz force that is an electric motor field. We can therefore say that whenever a circuit cuts the lines of force of a magnetic field, due to the relative motion to it, it creates an electromotive field, if the circuit is closed and the electric motor circuit of the field is different from zero, you build a circuit emf responsible for the induced current flow in the circuit"*.



After that, in the second phase, analyzing fake students' answers, teacher can recognize the presence of the various conceptual knots that sometimes are also present in the answer that they wrote in the first phase and facing it they can recognize some knots as the role of the relative motion between circuits and magnets, the idea that electromagnetic induction is related to the line cut by the circuits and the acknowledgement that electromagnetic induction accurse only when there is the presence of an induced current. In the third phase, to face these particular conceptual knots, teachers proposed methods that are focused on theoretical or experimental activity producing interesting teaching proposal concerning for instance the use of cooperative learning as a possible way to address the knots making comparisons between the students' ideas. Between the experimental procedures proposed by the teachers, particularly interesting is the one which suggest to use a solenoid connected to the oscilloscope with a galvanometer in series with it (ie open circuit) to see if you have the formation of a potential difference across solenoid even when the circuit is open, but do not have the formation of current.

Conclusions

During the PCK activity teachers directly address the conceptual knots that characterize particular topics. In this way teachers can propose and discuss among themselves which are the best methods to face in a specific way the occurrence of specific conceptual knots. Particularly in our activity teachers address the knots related to the role of relative motion in electromagnetic induction, the role of the magnetic lines and the ways in which is possible to recognize the electromagnetic induction. The use of a web based platform allows teachers to compare their ideas and, reach a well-structured proposal of invention to face some of the most important conceptual knots.

VIII.3 ACTIVITY T2

A wide literature underline how a scientific education very early in the curriculum create the conditions to face the documented difficulties in interpreting phenomena with a scientific point of view (Cobal 2002, Viennot 2003, Grayson 2004). Explorative experiences are in particular relevant in primary school, when the basic reasoning bridge the spontaneous common sense ideas with the scientific ones. Some topics appear to be in particular crucial in growing scientific approach in interpreting phenomena and develop formal thinking (Niedderer 2001, Michelini 2010). Electromagnetism is one of them. In spite of its wide and relevant applications in everyday life, many conceptual knots are presents in secondary school students, facing at this level the related concepts (IPN 1985, Galili 1997, Guisasola 1999, 2003, 2004, Maloney 2001, Salverberg 2002, Stefanel 2008, Thong 2008). For this reason, the construction of basic concepts on electromagnetic phenomena at primary level is now a research goal (Michelini 2006). To have well prepared primary teachers to implement this material is the parallel need (Tiberghien 1998). One of the main problems in perspective primary teacher (PPT) formation is the lack of a basic culture in the scientific field and the need of a relative professional preparation. Metacultural and Experiencial models (Michelini 2004) have therefore to be integrated to offer a reconstruction of the contents in educational perspective. Curricular materials for this aim had to be studied, having Pedagogical Content Knowledge (PCK – Schulman 1986) as theoretical background (Vercellati 2010 a, b). Design research (Hake 2004) is therefore carried out in the framework of Model of Educational Reconstruction (Duit 2005, 2008) to produce a teaching/learning proposal (TLP) on electromagnetic phenomena in vertical perspective (Viola 2009, Vercellati 2010). The TLP was experimented for six year with primary school pupils (Michelini 2010). An inquiry based Formative Intervention Module (FIM) for PPT on electromagnetic phenomena was than designed having TLP results in primary school as reference framework. Tutorial supported PCK activities of the FIM were than experimented with 120 Perspective Primary Teachers (second years of university – age 20 year old) in the framework of a didactic laboratory held in the Faculty of Science of Education of the Udine University. The FIM was based on interactive demonstrations on the main phenomena of the electromagnetic interactions and are offered with the strategy of the Inquiry Learning. The conceptual knots related to the educational path TLP were discussed step by steps on the light of the answers of PPT on some crucial questions posed on the context of the investigated phenomena. The analysis of this data and of PPT discussions during the cooperative learning activities and in large group offered an interesting spectra of the formation need and produce indications on the model for primary teachers formation.

Phase 1: learning path

A wide literature underline how a scientific education very early in the curriculum create the conditions to face the documented difficulties in interpreting phenomena with a scientific point of view (Cobal 2002, Viennot 2003, Grayson 2004). Explorative experiences are in particular relevant in primary school, when the basic reasoning bridge the spontaneous common sense ideas with the scientific ones. Some topics appear to be in particular crucial in growing scientific approach in interpreting phenomena and develop formal thinking (Niedderer 2001, Michelini 2010). Electromagnetism is one of them. In spite of its wide and relevant applications in everyday life, many conceptual knots are presents in secondary school students, facing at this level the related concepts (IPN 1985, Galili 1997, Guisasola 1999, 2003, 2004, Maloney 2001, Salverberg 2002, Stefanel 2008, Thong 2008). For this reason, the construction of basic concepts on electromagnetic phenomena at primary level is now a research goal (Michelini 2006). To have well prepared primary teachers to implement this material is the parallel need (Tiberghien 1998). One of the main problems in perspective primary teacher (PPT) formation is the lack of a basic culture in the scientific field and the need of a relative professional preparation. Metacultural and Experiencial models (Michelini 2004) have therefore to be integrated to offer a reconstruction of the contents in educational perspective. Curricular materials for this aim had to be studied, having Pedagogical Content Knowledge (PCK – Schulman 1986) as theoretical background (Vercellati 2010 a, b). Design research (Hake 2004) is therefore carried out in the framework of Model of Educational Reconstruction (Duit 2005, 2008) to produce a teaching/learning proposal (TLP) on electromagnetic phenomena in vertical perspective (Viola 2009, Vercellati 2010). The TLP was experimented for six year with primary school pupils (Michelini 2010). An inquiry based Formative Intervention Module (FIM) for PPT on electromagnetic phenomena was than designed having TLP results in primary school as reference framework. Tutorial supported PCK activities of the FIM were than experimented with 120 Perspective Primary Teachers (second years of university – age 20 year old) in the framework of a didactic laboratory held in the Faculty of Science of Education of the Udine University. The FIM was based on interactive demonstrations on the main phenomena of the electromagnetic interactions and are offered with the strategy of the Inquiry Learning. The conceptual knots related to the educational path TLP were discussed step by steps on the light of the answers of PPT on some crucial questions posed on the context of the investigated phenomena. The analysis of this data and of PPT discussions during the cooperative learning activities and in large group offered an interesting spectrum of the formation need and produce indications on the model for primary teachers' formation.

This activity was divided in three phases.

The first one was a Module of Formative Intervention in which the content knowledge formation is offered to in the form of an experimental model in which the learners go through the contents of a research based didactic proposal experimented with primary school pupils. A walkthrough by means of interactive demonstrations using personal worksheets to collect the answers prevision, comments on experiments and their comparison by prospective teachers in accordance with the PEC strategy.
The experimental explorations were visualized by means of a webcam on a wide screen and interactive discussions were done after personal analysis on the stimuli worksheets

In the second phase conceptual microstep activities with primary pupils was done in an informal context. During the GEI exhibition, held in the Faculty of Education of the University of Udine for pupils of local schools and local primary teachers, a part of the participating prospective primary teachers are personally involved in carrying out microsteps activities with pupils. Under the supervision of a researcher, 4 group composed of prospective primary teachers worked with pupils. There were 4 prospective primary teachers for each group each one of them had the responsibility to introduce and discuss a particular situation with pupils (each teacher was able to choose the situation that s/he prefers).

In the third phase, the prospective primary teachers that had participated to the second phase did a group discussion concerning their experience and on the base of their observations they had to design a learning path and present it to the whole class.

Here will be reported the text of the worksheet that prospective primary teachers used during the first phase.

1) RECOGNIZE A MAGNET

1.1) Having a variety of materials, how could I know if among them there is a magnet?

1.2) I have a magnet in a hand and I approach it to objects of different materials: how many and which interactions did you expect to experience?

1.3) DO THE EXPERIMENTS. How many and what behaviors did you see by testing them?

1.4) Take two magnets, past them on two polystyrene boats and see how they interact with each other. How did the two magnets interact with each other?

1.5) In which category of behavior should we put the compass? Explain

2) Approach a magnet to a paperclip.

2.1) Is the magnet that attracts the paperclip or is the paperclip that attracts the magnet?

2.2) How can we determine who attracts whom? (Design and describe an experiment)

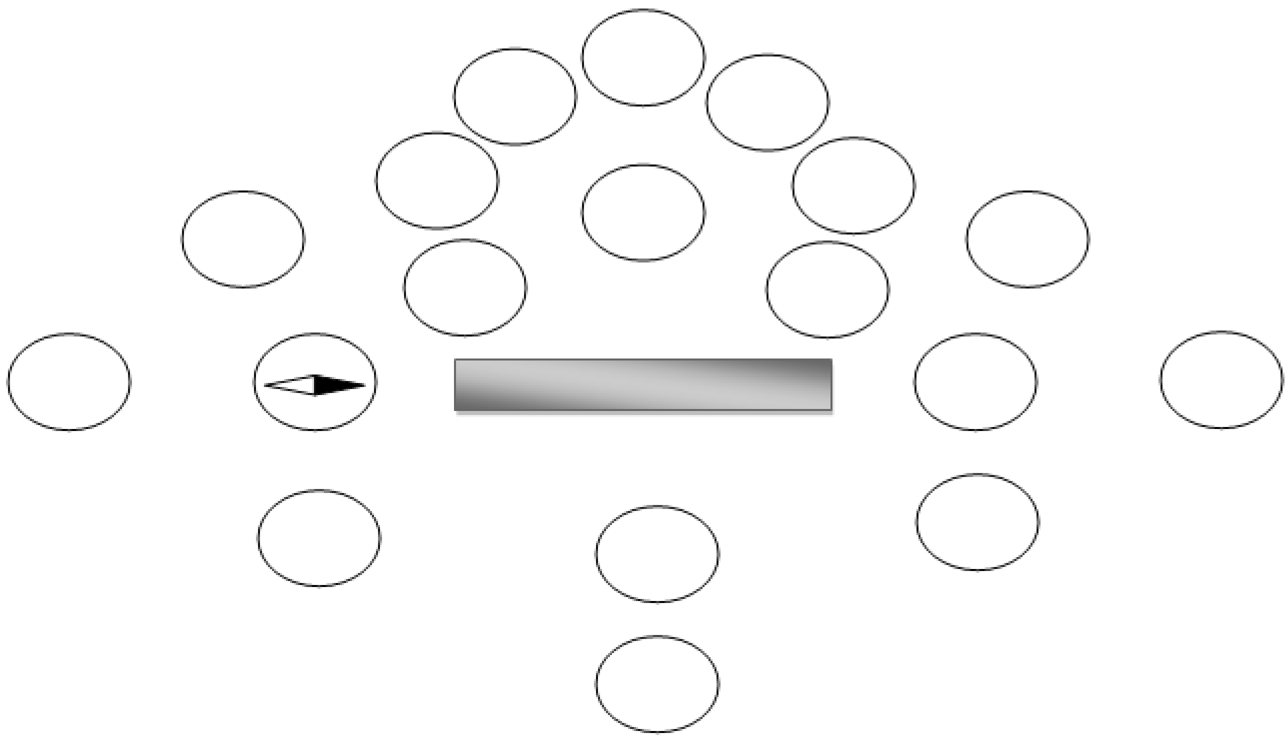
3) The compass

3.1) Take a compass and put it on a table. Observe the direction in which the compass needle is. Rotate the compass leaving it at the same point. Does the direction of the compass needle change? Explain

3.2) How could you change the direction of the needle of the compass?

3.3) Approach a magnet to a compass. What is the effect?

3.4) Explore with the compass the space around a magnet and draw below the directions of the needle of the compasses in the different places.



3.5) Draw the lines of orientation of the needles on a platform with a compass and visualize them using a simulation. Describe the main characteristics of the figure

3.6) Do the lines intersect with each other? Explain

3.7) In your opinion, the configuration of the lines is concerning only that plan of the desk or involves all the space around the magnet? Explain your answer

Let's look a simulation

4) INETRACTION BETWEEN WIRE CARRING A CURRENT AND COMPASSES?

4.1) Approach a copper wire with a compass. Do you expect to see anything? Motivate

Experiment it. Are the results the expected ones?

4.2) Connect the copper wire to a generator. Does the direction of the needle change? Explain

4.3) Using a compass explore the space around the wire: how are the lines of orientation of the needles? Explain how did you recognized it and draw it.

4.4) Draw the lines of orientation that you would expect to be around a current-loop.

4.5) See now the representation of the orientation of a platform of compasses around a current loop. Draw the lines of orientation in this case.

4.6) Draw the lines of orientation around a series of turns (a solenoid or coil)

4.7) Identify similarities and differences with the situations that produce the lines of orientation of the compass needle in space.

Compasses help us to explore a magnetic property of the space. They show us that this property can be displayed with the line of orientation of the compass needle and that this propriety comes from magnets and wire carried by an electric current.

5.1) Two magnets are each one source of magnetic properties in the surrounding space and interact one with each other. Considering two wires carrying a current, seen that each one of them generates in space a property that orients the compass, do you think that they will interact? Hypothesis

Experiment it

5.2) Describe the observed phenomenon:

Now let's see if a wire carrying a current interacts also with a magnet.

5.3) sketch the lines of orientation produced by the magnets, and explain the observed phenomenon

(LORENTZ FORCE EXPERIMENT)

Place a coil between the two magnets, and balance the scales

5.4) Let to circulate a current into the coil. Does the position of equilibrium change? How do you explain that?

5.5 Which are the variables that affect the equilibrium?

5.6 Change the intensity of the field, the amount of the currying current and the length of the coil. How did these parameters influence the equilibrium?

6.1 By moving the wire in the neighborhood of the magnets I realize that there is a variation of the circulating current in the circuit and now I wonder to check if will be possible to rise a current in a circuit in which the current is not circulating.

6.2. I approach the magnets with a coil connected only to an ammeter. There is the revelation of a current in the wire? Explain

10. Design what you should do to better understand the phenomenon

ACTION: What do I do? PURPOSE: To look for what?

###HOMEWORK ###

Answer to the following questions

11) Illustrate and explain the guided exploration done [10] highlighting the aspects that you had learnt.

1.2) How do you plan to teach to a child the last phenomenon?

2) How does the torch?

3) How does the dynamo work?

4) How does the magnetic pendulum work when I use with the aluminum bar?

5) How do you explain the fall of the magnet into the copper pipe?

Data collected

Question 1.1

The prospective teachers interpreted the question in two ways: 82% propose to use a known object to find the magnets, while the remaining 18% addressed the situation in which there are no known objects. Between the 82%, 52% propose to use a ferromagnetic object and look to which abject will be attract (40%) or will be stick to the magnet (12%) or to use a magnets looking for the objects will be attracted (12), will be stick (12%) or will be repelled (6%). Between the 18%, 8% said that an object is a magnet if attract other objects or if stick other object (10%). Looking a t the data, the main approach adopted by the pre-service teachers was the one to use a known object and 52% of them propose effectively the use of a ferromagnetic object as explorer of the presence of magnet. Instead, the ones that proposed to use a magnet did not address the problems of the discrimination between ferromagnet and magnet while they are attracted by the magnet; only a 6% look for a different type of interaction that is not characteristic of the ferromagnets and that the students identify as the repulsion.

Question 1.2

In this question 44% argued that the possible behaviors are attraction, repulsion or nothing; 36% attraction or nothing; 18% attraction or repulsion or speck about interaction in general (2%). Between the ones who argued that the possible behaviors are attraction, repulsion or nothing 22% said that the different behaviors depends by the materials involved, while 10% by the object involved. The same difference in the motivation of the different behavior was given by the ones who said attraction or nothing (22% by materials, 8% by objects) and attraction and repulsion (6% by materials and 8% by objects). More than half of the students use the shared dichotomous approach to the interactions between magnets describing them as attraction and repulsion, but also one third highlights that there is always attraction in every situation. No one speaks explicitly about rotations of the magnets.

Question 1.3

The answers to this question are: attraction or nothing (60%), attraction or nothing or rotation to attract (16%), nothing, attraction or repulsion (8%) attraction or rotation (2%) and 4% did not replay to these question. In this question, the answer that treated the elements of the rotation of the magnet arise from one quarter of the pre-service teachers, the experimental exploration of the interactions between the magnets and the other objects allow them to stress explicitly this situation noticing this unexpected behaviors. But is interesting to notice how this aspect was not highlighted by all of the pre-service teachers, but only by one fraction of them even if the experiment that implies a rotation of the magnets was shown to the whole class.

Question 1.4

The distribution of the answers was the following: 58% said attraction or rotation, 12% attraction or repulsion and rotation to attract, 10% attraction or repulsion, 10% attraction, 4% rotation, 6% other answers or did not replay (2%). Addressing a specific question on the situation of interaction in which are involved two magnets, the aspect of the rotation appear in three quarter of the pre-service teachers' answers and moreover a 4% of them referred their answer only to rotations.

Looking at the questions 1.2, 1.3, 1.4 it can be see the development of the change in the prospective teachers' opinions as concern the ways in which two magnets interact. In particular looking at the following graph can be seen how their spontaneous ideas (1.2) evolves after the experiment (1.3) and the discussion (1.4). To highlight more this trend, the distribution of the answers to this question are reported in Figure T2.1.

The experiment causes a breakdown of the percentage of the prospective teachers that thinks that two magnets attract or repels them, produce reinforcement of the idea that two magnets attract always themselves and in the same time "born" a group of teachers who focus their attention on the rotation of one of the two magnets. Physically both of these answers are right but, while the first groups looks only at the final results (the magnets stick together) another group looks instead at the way in which the interaction happens (one of the magnet rotate and then them stick together). Instead after the discussion the pick is located on the teachers who think that there is attraction or rotation focusing so the attention on the way in which the process develops while the number of the students who speak only about attraction decrease to a percentage that is lower than the one expressed before the experiment.

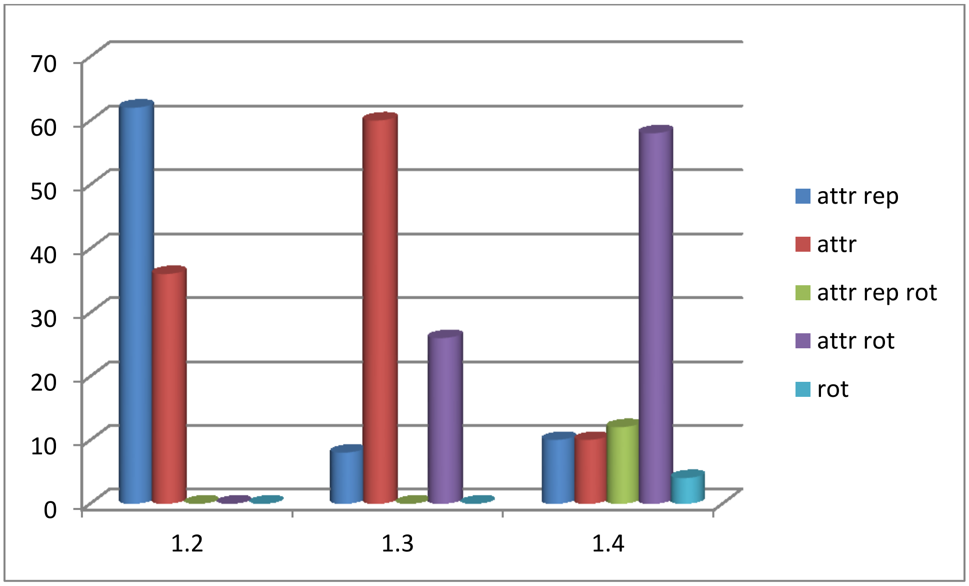


Figure T2.1 Distribution of the answer for question 1.2 1.3 1.4: before the experiment, after the experiment and after the discussion.

Question 2.1

66% of the prospective teachers argued that the magnets attracts the paperclip, 32% said the magnet and the paperclip attract both each other and the 2% said that is the paperclip that attract the magnet. In this question, the learning knot of the reciprocal interaction is well highlighted: only one third highlight that there is a mutual interaction and two third of them attribute the capability to exert forces only at the object that they identify as the source of the interaction (in this case the magnet).

Question 2.2

To check experimentally who attracts whom, the prospective teachers propose to place the magnets and the clip at a certain distance, leave them and see which one moves first (14%), to approach the magnet with the clip and vice versa (56%); approach magnet to clip (14%) or approach clip to magnet (6%); 8% did not replay to this question. Even if the hypothesis did in the foresight, half of the pre-service teachers are able to design an experimental exploration that was able to address effectively the question proposed before. In addition another 14% was able to propose an experiment, that even was not experimentally realizable with the provided materials, it was theoretically effective.

In question 2 are highlighted the teachers' naïve idea to attributes the cause of the interaction to the elements that they retain to be the owner of the magnetic proprieties (i.e. being the magnet the object that causes the interaction it's him that exerted the force). But, in the same question they show to be able, at the same time, to design experimental situation in which test their assertion and on the base of them (eventually) change their mind.

Question 3.1. Almost all said that the direction of the needle of the compass did not change (70%) or is always the same (24%), a 2% said that the direction change and 4% did not replay to this question. A 2% also highlight that it happened because the position of the compass wasn't change and a 6% point out that the compass pints always to North. The approach of the pre-service teachers to this question is almost only descriptive, only few of them propose an explanation of it. It is probably due to two possible factors: the pre-service teachers assume to be this observation obvious or they had not idea about the motivation. From the worksheets does not emerge evidences pro or contra one of the two, but, looking at the recording of the general discussion during the activity, seems to be that the first hypothesis the right one.

Question 3.2

The spectrum of the answer is wide but picked: 70% proposes to approach a magnet to the compass (in different directions 10% or moving it 10%); 14% proposed to change the compass position and the remaining proposal are approach the compass with another compass or a ferromagnetic object (6%), move the Earth or change the Earth magnetic poles (4%), change the force that oriented the needle (2%). A large majority of the pre-service teachers highlights the dependences of the direction of the needle of the compass by magnetic factors, being them the approaching a magnet or a magnetic property of the Earth and, also in the previous questions, pre-service teacher could provide experimental situations in which explored their hypothesis.

Question 3.3

In the answers to this question the prospective teachers observe several behaviors that they had reported in question 1.4. In particular 70% said that there is attraction or rotation, 12% said that the white/red part of the needle of the compass is attracted by the magnet, 4% said that the direction on the needle changes, rotates 4% or gave other answers 4% or did not reply to this question. The main part of the pre-service teachers describes the interaction as done when they are exploring the different interaction between the magnet and the other objects. The remaining part describes instead the needle as two part one of the two is attracted by the magnet or simply reported the change in the needle direction without providing further explanations.

Question 3.4 - 3.5

Grouping the answer in exclusive: 16% said that the lines are symmetric and make loops, 14% said that lines are circular or makes loops, 10% the lines are symmetric and go from North to South, 6% all the line are oriented toward the magnet, 4% the lines are symmetric, 4% the lines do not intersect themselves, 2% lines are symmetric and at arc near the magnets, 2% lines near the magnet are curves and far away are rectilinear, 2% gave other answer or did not replay 38%. The spectrum of the possible answer is wide, but if we look at the elements present in the answer we noticed that: 32% of the prospective teacher highlighted that the lines are symmetric, 34% that these lines makes loops (or circles) and 4% said that these lines did not intersect themselves. So in one third of the descriptions was highlighted the symmetry of the pattern and the idea that the lines make loops around the magnet from one poles to the other, but only in a very few number of description the prospective teachers highlights that the lines do not intersect one each other.

Question 3.6

Almost all said no 92% highlighting also that the lines are symmetric 28% and do circles around the magnet 8%. How could be seen by this question, the fact that the prospective teachers neglected in their description that the lines does not intersect, is because they did not feel that this aspect is important and so they spontaneously did not look at it as something to that had to be highlighted.

Question 3.7

90% of the prospective primary teachers foresight that the configuration of lines is related to the whole space around because the magnet distributes its properties (10%), use a compass to explorer it (8%), magnet create a magnetic field (6%), magnets acts as an attractive point (4%), magnet attract in all verse (2%), magnet interact in every direction (2%). The remaining 10% did not replay to this question. Almost all the teacher foresight that the property of the magnet involves all the space around the magnet, and not only the plane of the sheet considered for the drawing, but only one third of them feels the need to justify their foresight.

Question 4.1

Also before the experiment, almost all the prospective teachers (98%) said no because, during the learning path we had already experimented it (48%), there is not interaction with copper (42%). Only a 2% said yes, without arguing the answer. The almost unanimous answer to this question highlights the capability of the pre-service teachers to re-use the explored situations into the learning path to approach the analysis of new situation. Obviously it is only a simple example of this type, but is also interesting because this aspect will be involved particular in the description of the artifact and the exotic situation proposed as homework.

Question 4.2

All the prospective teachers observes that the needle of the compass arrange themselves perpendicular to the current (100%) and some of them (46%) also notice that, placing the wire horizontally, over the wire the needle has one verse, above the wire another. In these question the prospective teachers explore in an effective direction that the needle of the compass assumes, even if they did not try to explain what they did or how they interpret these direction.

Question 4.3

88% said that the lines are around and some specify that they are in circle (38%) or concentric (40%). A 2% said that the lines are spirals, and the remaining 10% or gave other answers or did not replay (4%). Also in this case there is a descriptive approach to the situation without providing justification or explanation of the work done.

Question 4.7

In this question, 78% of the prospective teachers highlight that the lines of the coils are similar to the ones of the magnet but (6%) have got a circular orientation, or (4%) can go through the solenoid, or (2%) have got a spiral orientation. The remaining 22% gave other answer or did not replay (20%). Almost all of the teachers in their spontaneous personal descriptions highlight the similarities of the field lines of the solenoid and the ones of the magnets, but only few of them highlight also the differences.

Question 5.1

66% aspect an interaction between the wires and in particular 8% said that the wires attract themselves or go away, 8% approach or go away depending by the currents, 8%

interact (generically), 4% wires move (generically), 2% go away, 2% said that wires act as magnets, and 4 % said that the wires interact because around them they had the same property of the magnet 4%. Two third of the pre-service teachers foresight en interaction between doing an analogy between the interactions between two magnets and interaction between objects that have a magnetic field.

Question 5.2

Observing the experiment the 96% said that the wires approach themselves or go away depending by the current if they are equal or opposite (48%), or different (20%), or perpendicular (4%). The remaining 4% did not replay. Almost all of the teachers describe the experiment recognizing that there is an interaction between the two wires and highlighting the role of the direction of the currents.

Question 5.4

The three main observations done by the pre-service teachers as concern this question are: the balance loses its equilibrium (44%), the coil 'became heavier' (44%), the coil goes down (12%). No one did not replay. The justification for the first group are: current is perpendicular to field lines 14%, it is due to the magnetic field (2%), because a force is born (2%), field lines change while there is current (2%). To argue the third category 12% said that current, magnetic field and force are perpendicular 6%, current is perpendicular to field lines and interact with them 4%, there are three perpendicular fields 2%. At least, to justify the affirmation the coil became heavier, 22% said that is because there is a current in it, 16% current is perpendicular to field lines, 2% current acts with a perpendicular force, 2% current interacts with magnets. Instead of the first and the third category, that gave only a description of the situation, the second group of answers provides an interpretative explanation of the phenomena and in particular they justify the loss of balance as an increasing of the weight of the coils. This statement highlights a learning knot that is not related to electromagnetism but to the interpretation of the equilibrium of a balance that is seen as an instrument that measure the weight of the corps without taking into account the eventually forces that acts on their arms. It's also interesting how 22% of the teacher said that the coils become heavier because there is a current in it, as the cause that changes the equilibrium of the balance was the weight of the current.

Question 5.5

Using mutual exclusive categories, the quantities that are important fort the equilibrium of the balance are individuated by the 56% of the prospective teachers as current, force and magnet; for 14% as current, force and intensity of the field lines; for 10% as current force and the distance between magnets; for 10% as force and the intensity of the current; for 4% as force and magnet and for 6% as current and force acting on the coil. As concern instead the quantities: the force is highlighted by 94% of the pre-service teachers; current by the 96% of the prospective teachers; magnet/magnetic field by the 74% plus a 10% that express the dependence with by the magnetic field in terms of the distance between the pair of big magnets. Almost all of the teachers highlight the three main physical quantities involved into the process: current, force and magnetic field. Even if no one of them look for parameters related to the geometry of the system.

Question 6.2

Almost all (94%) said that there is current in the wire and they justified it saying that: it happens when coils enter and exit from the magnetic zone (74%); because if I enter in the lines, they change they pattern (36%); because I go through the field lines. And in addition, 12% of them noticed that if the coil is at rest between the magnets there is no current, the amount of produced current depend by the velocity (6%) or the number of line that I go through (2%); if I rotate the coil between the magnet there is a current and 33% highlights the different sign of the current. Almost all could perform at least one way to produce electromagnetic induction. The explanation proposed are coherent with the situation proposed and in particular is interesting that one third explicit that the inserting a coils into the magnetic field it change the pattern of the lines. Also high was the number of pre-service teachers who could found the rotation of the coils between the magnets as a way to produce an electric current.

Conclusions

Pre-service teacher following the proposed learning path addressed some of the main learning knots that are related to electromagnetism and electromagnetic induction. Looking at the pre-service teacher answer in interesting to notice how their naïve knowledge and spontaneous approach to the addressing of some situation drove them to consideration that are really similar with the alternative conception highlighted by the pupils. For this reason a PCK formation of the pre-service teachers is pivotal: they had to be able to interpret pupils' models and design the best strategy to address situation with a particular angle of attack that will allow pupils to improve their mental models in a scientific direction. In this framework is so crucial the experimental approach in the addressing of the proposed situations and the teachers experimental experiences in the choice of the situation that had to be proposed.

Phase 2: activity with students

A part of the pre-service teachers that participated to the first phase, were also involved in conceptual micro-steps activity with primary pupils in an informal context. The activities, of the length of one hour, were held under the supervisor of a researcher. In this activity the prospective teachers work in small group with pupil. Each one of the prospective teachers had the responsibility to introduce and discuss a particular situation with pupils (each prospective teacher chose his own situation). The activity were held in the informal environment of the Games Experiments Ideas (GEI) exhibit held in the Faculty of Education of the University of Udine. Prospective teachers are personal involve in carrying out micro steps of activity with pupils. Participate to this activity 16 prospective teachers divided in 4 small groups. After working with pupils and each of four small groups of prospective teachers discuss their experiences and later they had to design a specific learning path starting from the one that we proposed in the first phase. At least their projects were presented in a plenary session to the other prospective teacher that, being enrolled in their same university course, had worked with pupils on different topics. The analysis that is proposed here is focused on the analysis of the presentation held by the teachers and the relation that there is between their proposal and our learning path.

Data and data analysis

The learning paths followed by the four groups of teachers are represented schematically in Figure T2.1 in relation with our proposed learning path.

The firs group propose situations 1, 2, 4, 5, 6, 7, 8, 9, 6 and 10; the second group proposes situations 1, 2, 3, 4, 5, 6, 9, 10 and 11; the third group propose instead situation 1, 2, 3, 4, 5, 7, 9 and 11 and the fourth group propose situations 1,2 and 5.

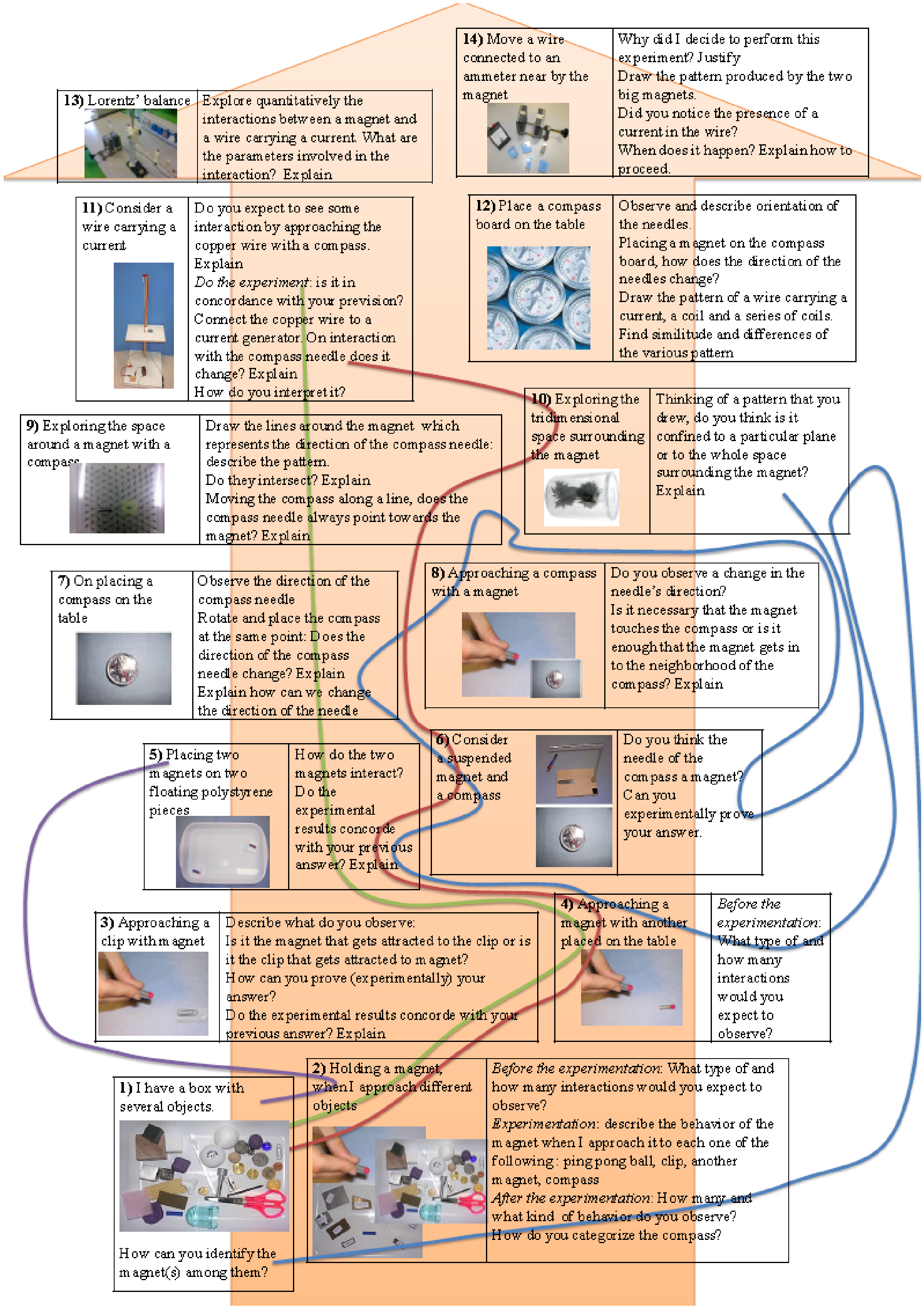


Figure T2.9: Learning path proposed by the four groups to the pupils

All the groups adopt the first two situations as starting point of their learning path and the situation 5. The success of this last particular situation is due two main factors: the first one is that it highlights a behavior that was surprising for the teachers when they faced the learning path (the rotation of the magnet) and second, is an emotional point of view because pre-service teachers like a lot this experiments.

Another situation that was proposed by the teachers is the number 4. Also this is related to a surprising result with respect to the pre-service teachers' foresights. This is a general trend as concern the early observation that the group proposes: the pre-service teacher spontaneously addressed more often with the pupils the situation that result to by surprising for them while they faced the learning path.

Instead, from situation 6 and after, the selection was done in a way in which the pre-service teacher neglected the situations that they think that are obvious. For instance one group did not address the comparison between the hanging magnet and the needle of the compass.

Conclusions

Prospective teachers, working with pupils, were able to reconstruct and adapt the proposed learning path in their personal way even if this reconstruction is often driven by the pre-service teachers' interest for the particular situation and or assumptions that some of them are obvious. Even if in almost all of the cases they can adapt their designed learning path to the pupils need. In only one of the cases, group four, pre-service teachers try to follow strictly their predesigned learning path and that produce a slowdown of the rhythm of the lecture that cause the possibility to face effectively only three situations in one hour.

XI. CONCLUSIONS

This research work on vertical learning path as concern electromagnetism from primary to high school was one of the first attempt aimed to address from a point of view of research the main learning knot problems inside a structured and organic learning path, and not as a series of single learning interventions. The key concept that lies on the bases of the all construction of the learning path is the idea of field seen as a property of the space that could be explored with a compass.

The construction of the formalization of this property by means experimental investigations is the key aspect of development of the proposed learning path. As concern instead the particular ages of pupils, the main goals was to provide, even to pupils, elements to construct explanatory model that are based on experimental observation without the introduction of surrogate model (overcoming for instance the dichotomous approach that often were used in the description of the interaction between magnets and the importance of addressed with the student complex phenomena as the exploration of the electromagnetic induction).

As concern the research in high school a big work was also devoted to the construction of a representation by means field lines that was able to represent quantitatively the magnetic property of the in each point through the introduction of a metric based on the idea of tube of flux and the right interpretation of the nature of these property (in particular the difference that there is between magnetic field and force acting on an object placed in a magnetic field.

Main results and further development

What emerges from this work as concern the implication for teaching are:

- the correlation between everyday knowledge and the early steps of the learning path is crucial especially for two different reasons: for pupils the correlation with their everyday experiences allows them to re-interpret situation that they had already faced in they life, and for student because, in addition to a larger set of experiences, there is also an approach due to the previous argument that they address at school, in particular the electrostatic and the idea of electrostatic field that the student tent to extend through analogies to the magnetic phenomenology
- the role of the representations of the magnetic field is crucial in the interpretation and in the facing of situation in which electromagnetic phenomena of induction are involved: for the students, have a representation that took into account all the formal property of the field is useful to understand also the properties of the field and use the field itself as a conceptual referent in the exploration of exotic situations.
- The importance of the experimental exploration by means person involvement of the student in a process of the construction of knowledge interlaced with the process of construction of formal entities.

As concern instead of the limitation and further development:

- The research works with primary pupils were always held in informal context to promote pupils communication and promote an everyday approach. Could be interesting to study what changes while the teachers will proposing the same learning path in classroom.
- The duration of the PhD course is not comparable with the vertical development of the classes and so was not possible to follow the evolution of the same class in

different type of school (primary lower secondary and high school) the research work was held with different classes coming from school of different level (it means for instance that the high school classes had not faced the learning path that we propose for the lower secondary school, but, students had faced a standard learning path. Could be interesting to study the vertical development of the same classes during the all vertical path.

- An element of further development of the proposed learning path could be the use of interactive whiteboard and new simulation.

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