Developing formal thinking and building conceptual knowledge as a background for formal interpretation of phenomena is one of the main challenges in teaching and learning physics. In the context of the experimental exploration of the electromagnetic phenomena, were investigated the pupils' conceptual referents and representations of the phenomena and how they identify and explore conditions to produce electromagnetic interactions. Through semi-structured interview in framework of the Conceptual Laboratories of Operative Exploration, pupils construct global interpretations of phenomena starting from local interpretations of the single experiments synthetizing formal abstract entities in a qualitative early stage.

Introduction

Developing formal thinking and building conceptual knowledge as a background for formal interpretation of phenomena is one of the main challenges in teaching and learning physics (Michelini & Cobal 2001). In particular, in the context of the investigation of the magnetic and electromagnetic phenomena, where the interpretative quantity (the magnetic field with its variation) has a formal description that is a synthesis coming out from set of several observations concerning measurable quantity, is one of the main field in which the construction of the formal thinking play a crucial role. This construction will be performed as a gradual growth of the phenomenological condition to the occurrence of the phenomena, the individuation of the quantities involved, and the phenomenological exploration at the primary and middle school levels.

Research literature review, in physics education highlights the presence of several typical conceptual knots in the students' knowledge related to the concept of field: 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 (Tornkwist et all, 1993), the relation between magnetic field and electric currents, the nature of field itself (Thong and Gunstone, 2008), the sources of field and the role of relative motion, Lorentz force and the presence of moving charges inside the conductor (Maloney et all, 2001). Indeed, students have difficulties in the determination of the verse of the induced magnetic field (Bagno, Eylon, 1997).

The pivotal role of the experiences, was highlighted by Duffy and Jonassen (1992) and Gilbert (1998) show that pupils construct spontaneously their own models to interpret the reality by observing of the world in their everyday life. It may create, in the prospective of the construction of the knowledge, the presence of persistent conceptions in pupils' knowledge that may constitute difficult barriers to overcome (Duit, 1991) So the bridging between the scientific and the everyday knowledge is one of the main problem in the scientific education (Pfundt & Duit, 1993). It is therefore necessary, to provide to pupils contexts of experimental exploration in which informal hands-on and minds-on workshop activities take place with the aim to involve them in the process of the construction of knowledge to extend pupils' experiences of the world and providing key activity strictly related to the main learning knots knowledge allowing them to address them effectively (Michelini, 2005).

With this prospective, the Cognitive Laboratories of Operative Exploration – CLOE – (Michelini, 2005) were designed and carried out by a researcher on specific topics. In particular, as concern electromagnetism, the researcher perform the lab following a semi-structured interview protocol, which represents an open work plan that allows to follow the pupils' conceptual paths on the basis of the incentives offered. Initially pupils' naïve ideas are investigated regarding the highlighted usual conceptual knots, then, by means of experimental and/or operative proposals, the phenomenology is investigated.

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 did you (operatively) 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 interact with the magnet
4) Reciprocal interaction between a ferromagnetic object and a magnet. Planning an exploration	Q4 Does the magnet attract iron or does iron attract the magnet? Propose an experiment to test it
5) Interaction between two magnets	Q5a Take two magnets. How do 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 does the hanging magnet react?. Explain Q6b How does hanging magnet react another magnet when approaches it?
7) Compass as an explorer of the magnetic field	Q7a Place a compass on the table. Rotate it. How does the needle of the compass behave? Q7b How could you 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 magnetic objects	Q9 Using a compass, can you identify which objects produce magnetic property in the space around it? 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 generate 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?

Data and Results

The audio video recording of the dialogues were analyzed as reported in Figure 2: the role of the different interventions by the researcher (first row) and the pupils (following rows) is represented with a color code which identify each category of intervention, while the bottom row indicates the key question of each intervention is referred to: red for the key questions (the ones reported in Table 2), yellow for the additional questions designed to promote further discussion, blue for the interventions that are related to experimental situations, green for answers that are based on previous knowledge without referring to a particular experimental situation, orange for the discussions, and grey if there is a waiting time before the next sentence or question.

The way in which pupils intervention are reported in this schema reflects the way in which the discussion usually evolves in almost all the CLOE activities performed. Especially, with the younger pupils, there is an emerging group of some pupils (4 or 5 at least) that lead the discussions and are more active than other in the learning process. For example in Figure 2, we notice that for the 10-year old class, 4 pupils (over 18) did almost one third of the interventions and the remaining part is equally divided between group (coral replies, in which pupils answered all together) answers and answer given by pupils that did not do more than two or three interventions.

Looking for instance at the types of the pupils' interventions reported in Figure 2, it is manifest how, with the development of the laboratory, the answers of the 10-year old pupils categorized as simple answers decreased (color green), leaving more rooms to the ones that refers to experimental situations (blue) and discussion/argumentation (orange). This trend is less marked in the 13-year old pupils where the green interventions occur through the learning path but especially emerge in the phase of experimental exploration of electromagnetic induction.

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

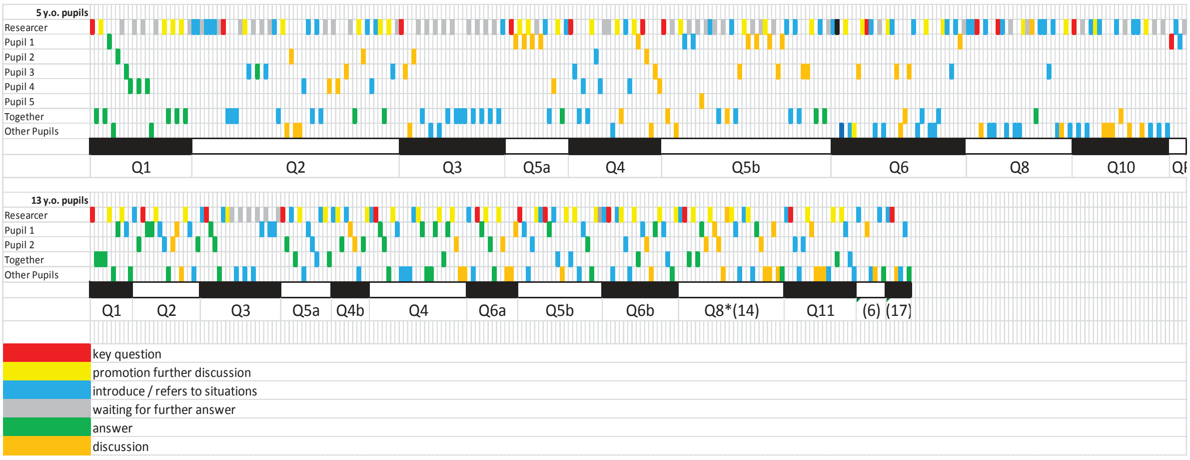

Figure 2. Example of analysis of a discussion

As previously remarked, the order and the type of activity proposed was not mandatory and in particular the different classes followed different learning paths; the learning paths followed are summarized in table P3.3

Table 2. Summary of the learning path followed by each group

Type of School	Class	Followed Learning Path
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 is the need to introduce an extra experiment into the learning path (labeled 5*) in which pupils explore the interaction between two magnets floating on the water - so they are free to rotate and rearrange themselves freely. The role of this experimental situation was crucial for the pupils of all levels, in particular, allowing them to determine the range of magnetic properties of the magnets. The pupils argued that even though we are not able to detect these properties, this does not mean that the property of the magnet are only in the surroundings of the magnet, but even if the magnet has a small entity it could be felt far away from the magnet.

Regarding Q11 (exploration of the electromagnetic induction), pupils were able to detect several different ways to produce current and all groups highlighted the transient nature of the phenomena, the set of movements of the coils that generated 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 on the velocity with which the coils moved, and the role of the orientation of the coils with