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Building formal thinking with pupils on magnetic phenomena in conceptual laboratories

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Abstract

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, pupils' conceptual referents and representations of the phenomena and their identification and exploration of conditions to produce electro-magnetic interactions are investigated through semi-structured interview in the framework of Conceptual Laboratories of Operative Exploration. The pupils construct global interpretations of phenomena starting from local interpretations of the single experiments and synthetizing them by means of building the formal abstract entities.

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Keywords: formal thinking; electromagnetism; CLOE labs; conceptual knowledge; experimental exploration.

1. Introduction

The connection between scientific and everyday knowledge is one of the main problem of learning in scientific field (Pfundt & Duit, 1993). Pupils construct their own models to interpret the reality spontaneously, while observing the real world in everyday life (Gilbert, 1998). The role of experiences is decisive in the construction of knowledge (Duffy & Jonassen, 1992). The presence of persistent conceptions in student's knowledge may constitute difficult barriers to overcome (Duit, 1991). It is therefore necessary, to design informal hands-on and minds-on workshop activities to involve students in the knowledge building process promoting conceptual change (Michelini, 2005).

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, when a phenomenon is interpreted by means of a quantity for which formal description is not directly related to the aspects perceived (as in the case of the flux and its rate of variation in electromagnetic induction phenomena), the familiarity with and the knowledge of the phenomenology is a pre-requisite for the conceptual and formal interpretation. This is connected to a gradual growth of phenomenological condition to its occurrence, the individuation of quantity involved in the electromagnetic induction, and the phenomenological exploration at the primary and middle school levels is a must for this purpose.

Research literature review in physics education highlights the presence of several typical conceptual knots related to the concept of field. In static field, difficulties are related to: the concepts of field as a superposition (Rainson & Viennot, 1992), field representation (Guisasola et al, 1999) and the relation of the field lines with

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trajectory followed by bodies (Tornkwist et al, 1993). In dynamic field case, the relation between magnetic field and electric currents, the nature of field itself (Thong & 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 al, 2001). Indeed, students have difficulties in the determining the verse of the induced magnetic field (Bagno & Eylon, 1997).

2. Strategies and context

With the aim to investigate how pupils develop interpretative ability to explain situations and artefacts from the results of several phenomenological investigation of physic quantities, a specific activity was designed in the framework of the Cognitive Laboratory of Operative Exploration (CLOE). The CLOE labs were designed to study and then to reinterpret the single experiment in the pupils' process of creation of a global theory (Fedele et al, 2005); they are carried out by a researcher on a specific topic, and represent an open work environment aimed to follow pupils' conceptual paths through semi-structured interview protocol(s).

The first phase was carried out as a semi-structured plenary discussion in a big group. It was focused to attract the student attention and create resonance between important aspects of phenomenology and students' naive ideas describing and explaining phenomena by using only simple words. The second phase was carried out as a series of small experimental observations concerning simple example of interaction between magnet carried out by students with the support of a semi-structured inquired based discussion and it was aimed to introduce them, an early representation of the magnetic field line. The third phase was carried out in small groups; in this phase pupils had to face a real challenging task concerning the conditions needed to produce an electro-magnetic phenomenon. In this phase pupils had to interpret electromagnetic induction taking into account all the observations that they had made in the second phase. Final discussion was focused on the creation of a general set of procedure and induction cases from which recognize the key points needed to give a global interpretation of the phenomena.

An important role of the partial and local interpretations of the single experiments explored step by step emerge in building a global interpretation of the electro-magnetic induction phenomena, where interpretative aspects are recalled in an analogical way. Abstract entities are used during the learning path when inquired base hands-on and minds-on was carried out. The re-use of same quantities in a new framework is an additional gain of the coherent explorative chain in its own progress. For example, pupils refer to the property of the space surrounding the magnets, in few cases, a first representation of this magnetic property using compasses as explorer of the space, drawing a first representation of the magnetic field lines.

Table 1 represents schematically the interview protocol that the researcher used during the first phase of this activity: the order of the experimental situations and the key questions that had to be proposed to the pupils were not mandatory, but the researcher had to follow the pupils reasoning, this choosing which order to adopt.

Research focus in this activity was on the role of the different experimental situations proposed to the pupils and the identification of those that promote more discussion and produce main sources of comparisons between pupils, with the aims to reach a global vision of the phenomena explored.

The semi-structured protocol was a guideline that could be followed or modified by the researcher based on the pupils needs, hypothesis and discussions.

Experimental activity 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 primary school (grades 1 to 5; 6 to 10-year old), six lower secondary school (grades 6 to 8; 11 to 13-year old), and two classes of kindergarten (that will not be included in this analysis) for a total of 201 primary, 114 lower secondary school pupils, and 19 kindergarten pupils. For this activity, data were collected only using audio/video recording of the activity without using worksheets. This choice was done to promote as much discussion as possible between the components of the class encouraging the sharing and the comparing different ideas.

Table 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 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?

3. Samples and data analysis

Dialogues were analyzed and reported in Figure 1 in which, starting from the audio-video recording of the discussions done during the first explorative phase, the role of the different interventions by the researcher (first row) and the pupils (following rows) is individuated by a color code which identify each category of intervention. The bottom row indicates to which key question each intervention is referred to.

The analysis of two learning paths: the first one done with 10-year old pupils and the second one with 13-year old pupils, is displayed in Figure 1.

The way in which pupils are inserted in this schema reflects the way in which the discussion evolves generally: in almost all the CLOE activity performed, especially with the younger pupils there is an emerging group of some pupils (4 or 5 at least) that tend to guide the discussion and tend to be more active in the learning process than others. For example in Figure 1, 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.

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 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 referred to a particular experimental situation, orange for the discussions, and grey for the waiting time that the researcher allowed before additional answers.

The color of the pupils' interventions reported in Figure 1 illustrate how with the development of the laboratory the answers of the 10-year old pupils categorized as simple answers decreased (color green), leaving more pupil interventions 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.

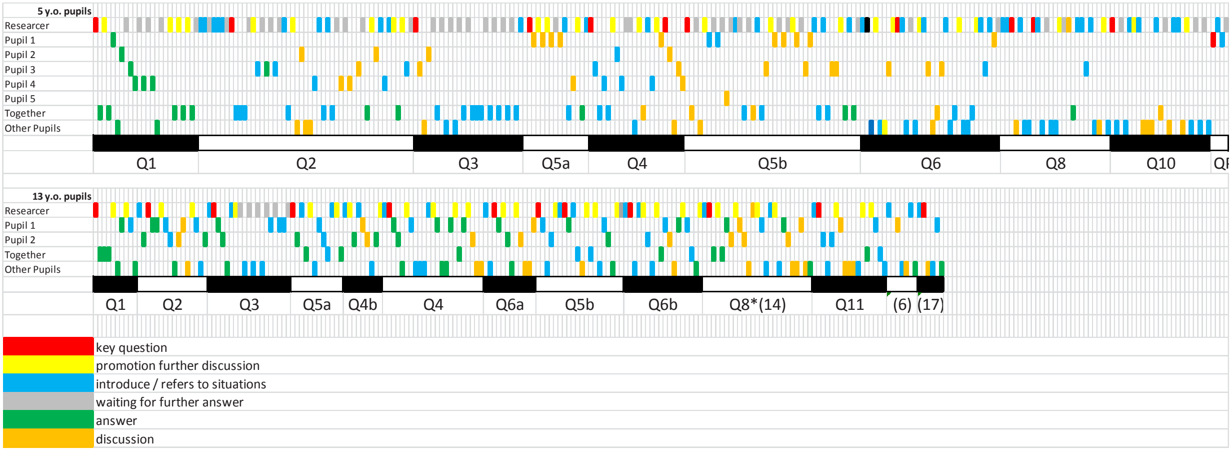

Figure 1 Example of analysis of a discussion

The time spent on the different experimental situations and the number of interventions 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.

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 2.

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, 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*, Q6, Q7, Q10, Q11

A general trend highlighted in almost all the experimentation is the need to introduce into the learning path of the situation 5* involving floating magnets on polystyrene boat. 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 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, pupils were able to find several different ways in which to perform electromagnetic induction. 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 in which the coils moved, and the role of the orientation of the coils with respect to the magnets. Regarding this last point, two lower secondary school classes and one primary class highlighted that the orientation of the coil is related 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 they are parallel".

4. Conclusions

The results from of the proposed learning path illustrate the necessity to introduce a specific experiment 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. Experiments illustrated how the learning path provides the pupils with a set of experiences and observations that allows them to explore experimentally the phenomenology of electromagnetic induction. Providing a first explanatory model based on an idea that even though it does not have the whole structuration required by the theory of the flux variation of the magnetic field, it has its main conceptual cores, and even if the pupils use magnetic field in a non-quantitative way, it has its main phenomenological characteristics.

An important role of the partial and local interpretation of single experiment explored step by step emerges in building a global interpretation of the electromagnetic induction phenomena where interpretative aspects are recalled in an analogical way. Abstract entities are used during the learning path when inquired base hands-on and minds-on was carried out. The re-use of same quantities in a new framework is an additional gain of the coherent explorative chain in its own progress. For example, pupils refer to the property of the space surrounding the magnets, in few cases, a first representation of this magnetic property using compasses as explorer of the space, drawing a first representation of the magnetic field lines.

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