PRIMARY PUPILS EXPLORE THE RELATIONSHIP BETWEEN MAGNETIC FIELDS AND ELECTRICITY

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1. Introduction

The presence of conceptual knots concerning electromagnetic induction in secondary school students' ideas (Stefanel, 2008), underline the need to create vertical curricula based on a continuum learning process starting from the phenomenology of electromagnetic interactions earlier with the first exploration of the world. The connection between scientific knowledge and everyday knowledge is one of the main problems of learning in the scientific field (Pfundt & Duit, 1993). Research in learning processes shown how knowledge requires a personal involvement and analysis of the reference interpretative elements and in particular how informal learning plays an important role in building knowledge and conceptual change (Vosniadou, 2008). To ensure that students build bridges between the local vision of common sense and the global scientific interpretation, hands-on and mind-on active involvement of students is needed (McDermott, 2004). To do so informal situations in which students can explore and experience directly the phenomena can be a valuable starting point for the activation of reasoning related to conceptual re-elaboration (McDermott, 2004; Michelini, 2005) and knowledge building (Viennot & Raison, 1999). Student involvement increases when the task is given in an informal and not strictly structured situation: it can be seen by the student like play, or a challenge, in which they are a protagonist (Watts, 1991). Furthermore, cooperative learning with peers plays a key role in the process of building knowledge when it is offered for sharing ideas and reasoning, involving cognitive processes, skills and capability (Pontecorvo, 1993; Pontecorvo et al., 1991; Santi, 1995). To defend their own ideas, students have to be able to: organize their information and learn to draw conclusions, present and defend their ideas, let them be challenged with opposing perspectives or arguments, experience 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 (Comoglio & Cardoso, 1996).

The Cognitive Laboratory of Operative Exploration (CLOE), taking account of all of these aspects, provides an informal workshop that stimulates students' conceptual reasoning and offers anchors for the construction of their first steps in scientific knowledge starting from the common sense vision (Bradamante & Michelini, 2006). Previous studies (Fedele et al., 2005) show that some basic concepts of magnetic phenomena, such as the types of interaction between magnets and other materials and magnetic poles, can be addressed in this way. Furthermore, similar studies on 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).

2. Research questions

Proposing to the students an experimental activity related to the production of electromagnetic induction, our goal is to explore pupils' spontaneous approaches to the given task and their reasoning in dynamic terms. Our attention is focused not only on students' ideas, but also on the ways in which these ideas evolve and the reasoning that supports this evolution. So our research questions are the following:

RQ1 How do students spontaneously approach the exploration of phenomena describing the artifacts and experimental equipment offered?

RQ2 In what ways do they recognize and produce electromagnetic induction?

RQ3 What are the physics entities that students believe to be important to produce electromagnetic induction?

RQ4 What representation and formal entities do they introduce to explain electromagnetic induction?

With these questions we follow the process of the spontaneous approach adopted by pupils to face the task. First of all we look at how students approach spontaneously the phenomena and describe the apparatus: particularly we look if it is a simple description of the apparatus or if in their description there is a conceptual organization related to the solution of the problem (RQ1). At the same time it is truly important that they understand how to produce electromagnetic induction and how to recognize the presence of this phenomenon using the equipment offered (RQ2). After that we investigate with RQ3 and RQ4 how pupils, starting from their experimental exploration, try to formalize their results focusing their attention on some important elements and introducing some formal entities.

3. Sample and Context

The activity is carried out with 52 primary school pupils (12 six years old, 17 eight years old and 23 ten years old) visiting, in separate groups for a period of 2 hours, the annual festival of science "YOUng 2009". Our activity is based on experimental exploration carried out through group discussions, interviews, drafting of drawings and written answers in the form of interpretive challenges.

Our particular CLOE activity, focused on the relation between magnetic fields and electricity, consists of three principal phases: introduction and task assignment (30 min), group experimental exploration (1 hour) and plenary discussion (30 min).

In the first phase a semi-structured plenary discussion with the whole group is focused to attract the student attention and create resonance between some important aspect of the phenomenology and the students' common sense ideas. Only the words that students use to describe and explain the phenomena are adopted to stimulate this resonance as in the Rogersian interview.

In the second phase, the class is divided into groups and pupils are left completely free to explore and experiment as they want. The spontaneous generation of groups is allowed. The only restriction on group generation is related to the number of pupils for each apparatus: equal number of pupils for each apparatus with a minimum of 4 and a maximum of 5 pupils for each one to promote cooperative learning.

For this experimental activity, we provide the students with a pair of big magnetic plates (with a surface of 10x20 cm) with their holder, analogue micro-ammeters and many coils with different areas and numbers of windings (Fig. 1).

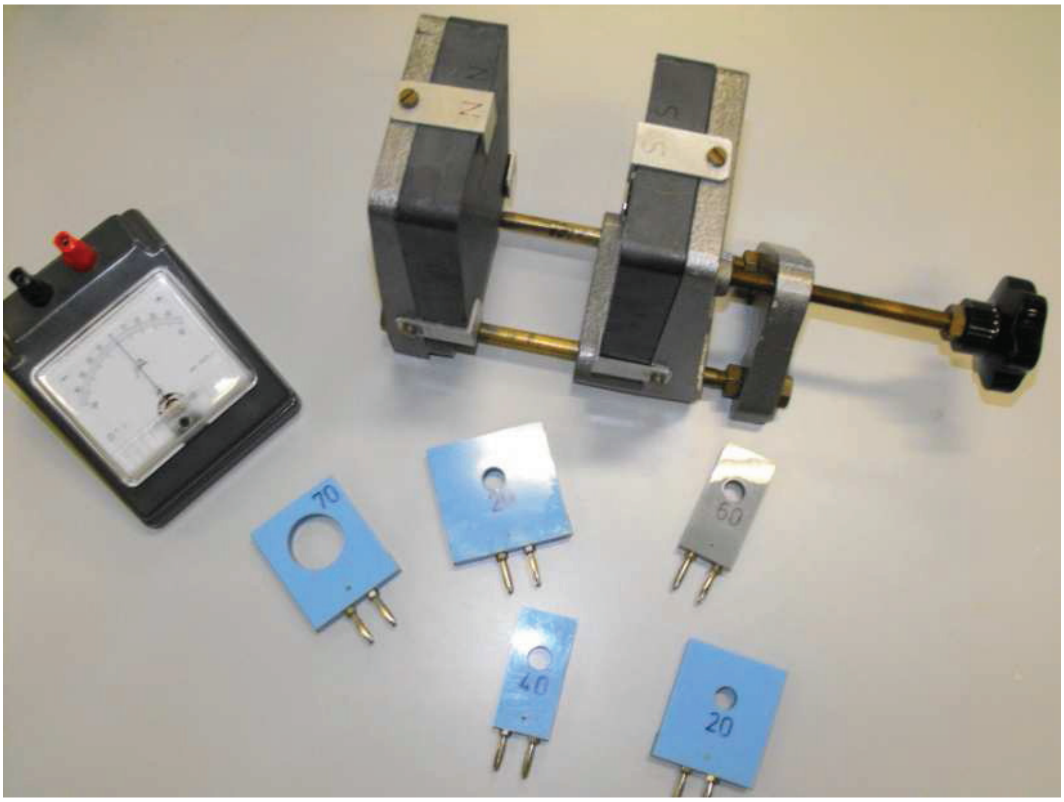

Figure 1: Experimental equipment.

The goals of the last plenary discussion (the third phase) is to look at the ways in which the comparison of pupils' ideas produce a global vision from the local one (Bradamante et al 2005) following the process of cooperative learning that pupils carry out to individuate a shared explanation of the observed phenomena.

4. Instruments and Methods

The problem of generating an electric current without a battery is placed in the context of the analysis of the magnetic effects related to a current in terms of a challenge to play with assigned resources following the popular problem solving approach (Watts, 1991). All pupils involved in this experimentation have already seen and played with magnetic toys or have used them in another section of the GEI exhibit (offered in the same context during the annual festival of science "YOUng 2009") and can describe the principal property of mutual interaction between these particular objects. The introductory phase provides a review of the phenomenological aspects related to the presence of magnetic fields and electric currents. By using a compass and creating resonance with the students' idea of the Earth's magnetic field, pupils introduce the idea to associate with each magnet a magnetic field (Fedele et al., 2006). Through an experimental approach, pupils can reach an operational definition of electrical current (Testa & Michelini, 2008). The micro-ammeter, which is not part of the everyday experience of the pupils, is recognized in an operational way as an instrument able to detect and measure the intensity of an electric current. Using a compass and an Ørsted-like GEI exhibition equipment set-up (Michelini et al, 2003), we can show them that there is a correlation between electric current and magnetic field. The assigned task is to explore if is possible carry out the reverse process and to study the principal elements needed for its realization using the instruments provided. The preliminary exploration is aimed at helping the students to localize the region of their knowledge useful to do this experimental exploration with a problem located in their zone of proximal development (Vygotskij, 1997).

In the experimental phase, pupils, working in small group, experiment themselves with the phenomena and use the experimental apparatus provided how they wish. In this phase the teacher's role is marginal: students must be free to explore the phenomena. The teacher has only to observe the student behavior and should intervene as little as possible. Communication between different groups is not forbidden, but each student has to write on his personal worksheet. Each student decides to write, draw or both to describe the apparatus and to explain how he or she is able to experimentally produce electromagnetic induction.

In the third phase, during the plenary discussion, a teacher listening to a student proposal reproduces it in the exactly the way in which the student says: all students reason how the particular procedure works, comment on it, suggest modification identifying gradually what are the key points of the procedure. Even in this phase a Roger-like discussion must be encouraged for the creation of a general set of procedures and cases from which the key points needed to give an interpretation of the phenomena arise.

5. Data Acquistion

Data were collected separately for the three classes. During the two big group discussions another researcher takes note of the dialogue and during the experimental phase data are collected using non-structured worksheets. In this paper, we focus our attention on the spontaneous approaches of the pupils in the analysis of the phenomena. Particularly we focus our attention on what students wrote and drew on their worksheet during the exploration phase. Data acquisition is done by giving each student simple worksheets on which they can write or draw what they see and what they think is important to obtain the desired effect.

All the 12 six years old student drew a picture of the experiment and 6 of these also wrote a short sentence about the experiment. Of the 17 eight years old students 4 pupils only drew a picture, 8 pupils only wrote a short sentence, 3 did both and 2 students returned a blank worksheet. Finally all the 23 ten years old student wrote one or more sentences and only 3 of them also drew a picture.

	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 1: Elements of the physical apparatus.

	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 postive			12
Electric current	2	4	1
negative and positive			1
Energy		3	6
negative and positive			5
Transient	1	3	17

Table 2: Physics entities.

To do a content analysis of students' worksheets we start focusing our attention on some key-words and key elements present in them. Using a dictionary based approach, we look at which are the element of the experimental apparatus that are present in students' 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 procedures that they explicitly write on their worksheet to produce electromagnetic induction and in which ways they recognise the effect (Table 3).

6. Data Analysis

RQ1 Looking at Table 1, it is manifest 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 numbers of windings of each coil (8/12). Two pupils also underline the different areas of the coils. This detailed description of the experimental equipment allows the six years old pupils to detect all the simple

	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

Table 3: Procedures and observations.

variables and parameters related to electromagnetic induction. In this way they can underline the presence of elements, such as the distance regulator of the magnets' holder (11/12), that, due to the structure of the experimental equipment, are related to physics quantities that are not strongly relevent here. Six year old students also describe the cable connections between the various elements (11/12).

The eight years old pupils focused their attention on elements, such as the ammeter's pointer (7/17) and the circuits (12/17), that during the experimental exploration are in motion and that are strongly related with the generation and detection of the phenomena. The ten year old pupils also focused their attention on particular elements of the apparatus, but beside the ammeter's pointer (9/27) and the circuits (13/23), they identified magnets (10/23) and ammeter as important elements (16/23). This selection of some important elements denotes tendencies 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 pointer as an instrument useful to show 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 students (6/52) try to give a quantitative description using the ammeter's graduated scale. For instance a 10 years old student wrote: "The circuit with 70 (windings) can also arrive to + 30. The circuit with 60 (windings) can arrive to +10".

Furthermore it is truly important that 2 pupils state that if the circuit is moved between the magnets the ammeter's pointer does not move. That is important because it denotes the capability to understand that to analyse a phenomenon it is necessary to highlight also the situation in which it does not occur.

To produce electromagnetic induction they underline the role of the circuit movement. Moreover 2 of six year old students and 5 of ten year old students state that this movement is relative between circuit and magnetic field, while 2 six year old and 9 ten year old pupils state that the movement is between the circuit and magnets. For instance a 6 year old pupil wrote "pointer move when circuit is insert in the magnetic field". A ten year old pupil states all these procedures and also notes that an electromagnetic induction effect can occur also when the circuit rotates. Particularly she wrote:

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

RQ3 Several important physics entities were used by the students to describe the phenomena they observed. When pupils deal with particular physics entities, such as magnetic field (10/52), electric current (7/52), electric tension (12/52) and energy (9/52), it does not mean that they have a physics idea of these entities, but only that they have already heard these particular words. However, pupils approaching the analysis of electromagnetic induction in a context like that in our activity start to associate these words with specific situations and start to handle these physics concepts.

RQ4 Starting handling these physics concepts pupils give explanations of the single situation in which they identify that electromagnetic induction occurs. More than half of the ten years old pupils asserted that one of the main important characteristics of electromagnetic induction is that it is a transient phenomena 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 do not deal with electromagnetics in terms of a variation of the electromagnetic field interlinked with the circuit, but in terms of movement or rotation of the circuit related to the magnet or the magnetic field. So they spontaneously link some specific situation to the changing of particular physics entities without achieving a vision of synthesis. To allows pupils to reach this synthesis the pupils' analysis of the phenomena had to be stimulated as in the third phase. That does not mean that pupils can not reach this synthesis by themselves, but that (referring to our data) pupils spontaneously do not try to give a global explanation, but had to be encouraged in their experimental exploration to reach it.

7. CONCLUSIONS

Our empirical research is based on operational exploration minds-on and hands-on. A situation in which primary pupils can explore electromagnetic interaction is organized in an informal environment. Asking students to identify the important elements and to explain the phenomena in each situation, the pupils' way of thinking and reasoning are analyzed. Pupils give a first meaning of some physics entities that they have already encountered in their everyday life as simple words without a precise meaning. Our data moreover show how primary school pupils can face the analysis of a situation concerning electromagnetic phenomena and can start to handle physics entities giving them a first operational definition. Primary school pupils, after a briefly introductory phase (messing phase), carry out this process spontaneously during the exploration of the phenomena. The task of describing the procedure, activates pupils' reflection on the condition to obtain the desired result (induction phenomenon) and pupils recognize many situations suitable to produce electromagnetic induction. That denotes a capability to analyze methodically many individual simple situations, extracting from them the principal important aspect related to the general phenomena that we want to investigate.

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