Exploring the sources of magnetic field and the interactions between them to interpret electromagnetic induction: a proposal of conceptual laboratory

Michelini Marisa, Vercellati Stefano
Research Unit in Physics Education, University of Udine, Italy

Introduction
Today, electromagnetic phenomena are part of everyday life, even as concern pupils’ toys. Scientific terms as “magnetic poles” and “magnetic field”, become part of the ordinary language. However, this popularization of physical terms has been obtained through a loss of accuracy of the real physical meaning of these quantities. In science education, the problem of the correlation between everyday and scientific knowledge is one of the main problems in learning (Pfundt & Duit, 1993). In the framework of the Model of Educational Reconstruction (Duit et al, 2005), it is therefore necessary, to design inquiry based learning paths (McDermott, 2004) in which students are personally involved in minds and hands-on experimental activities. With the aim to investigate how pupils develop interpretative abilities to explain situations and artefacts from the results of several phenomenological investigations of physical quantities, a specific activity was designed in the framework of the Cognitive Laboratory of Operative Exploration (CLOE). CLOE labs are experimental laboratories carried out by a researcher on a specific topic, based on a semi-structured interview protocol that represents an open work plan built through the proposal of everyday life scenarios in which everyday situations are studied following narrative reasoning by means of simple hands-on apparatus (Michelini, 2005).

Research questions
In this work, three research questions were investigated: RQ1) how do an operative exploration help students to identified and organize electromagnetic phenomena; RQ2) how is the exploration and the comparison between phenomena useful to help students in the interpretation of artefact; RQ3) how are exploratory elements reused by students in the interpretation of artefacts.

Context and Sample
The experimental activity was carried out in an informal context during a science festival – Mediaexpo 2009 – involving 135 middle school students aged from eleven to fourteen years old (6th to 8th school grade). Seven classes were involved: one of 6th grade (20 students), three of 7th grade (60 students) and three of 8th grade (55 students).
The activity was divided into two phases: 1) an inquiry based explorative phase; 2) a structured analysis of an artefact.
During the inquiry based learning path, pupils worked in groups of 5 members each, but every student had his/her own personal worksheet. Communication between groups was not interdicted and after each experimental exploration of a specific phenomenon there was a class discussion in which students organize their observations 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 this phases is composed by: 6 compasses, 1 A4 cardboard, a pair of big magnetic plates (with a surface of 10x20 cm) with their holder, an analogical micro-ammeter, many coils with different surfaces and number of circumvolutions and a couple of conducting wires to do the connection between the coils and the micro-ammeter. In the setting setup this activity, particularly attention was devoted to the setup of the classroom: garden table in plastic were used to avoid interference with the functioning of the compasses and several everyday objects.
(HiFi, computer, mobile phone…) and some laboratory object (coils, coils carrying a current, generator…) were placed around the classroom. During the structured analysis of the artefact, the analysis of a particular tool (an induction torch – Figure 1) was proposed to students. Before, being allowed only to look at it, students had to describe the artefact on a structured personal worksheet. Then they can improve their description being permitted to touch and experiment its functioning. Indeed a final class discussion was promoted.

**Instruments and methods**

The inquired base explorative phase consist 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 students a simple first exploration of the Earth magnetic field using a compass as an explorer of a propriety of the space. Students during this step used compasses and cardboard. Here students had to answer on their personal worksheets to three specific questions:

S1.Q1 After had placed the cardboard on the table with a compass upon it (Figure 2). 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 now?

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

After this first group of questions, as for each one of the all other steps, there was a class discussion concerning the observed phenomena.

During S2, students began to explore the behavior of a set of compasses when they are placed near a magnet.

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 3). Then put a magnet between them. Which are the orientations of the needles?

In S3 students were free to explore all the objects present in the classroom with the set of compasses built in S2. In particular, they looked for other types of objects that are sources of magnetic field. In this phase, the setup of the classroom is pivotal: students 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(s) can do it? (Which not?).

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

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

S3.Q4 Leave the coils between the compasses and connect it to the generator. What is happening to the compass needles?

In S4, after that students had shown that an electric current generates a magnetic field, they explore the phenomenon of the electromagnetic induction through problem solving like approach. For this phase, data were not collected on the worksheets because an experimentation of this phase was already done and described in a previous work (Michelini & Vercellati, 2009).

At the end of the inquired learning based path, during the second phase, the artefact was offered to students without any introductive explanation. The only instructions gave to students were concerning the methodology that they had to follow in the artefact analysis. Initially, only looking at it, students had to say what is it, describe it and, after that, when all group had finished the first part, they can touch the artefact experimenting its functioning and, if they think it is necessary, they can improve their first description.

Data

To S1.Q1: 68% answered NORD, 20% reported the cardinal point that appear to be under the needle tip (as shown in the Figure 2, in the used compasses the cardinal point are painted on a fix background), 7% direction described it by referring to objects present into the classroom and 5% did not answer. Concerning S1.Q2: 80% highlighted that the direction is always the same, 10% said that the direction change, 5% say that the cardinal point change and 5% did not answer. At S1Q3: 96% said that all compass needles have the same direction and 4% did not answer.

During the first class discussion, the shared opinion was that with this experiment we show that there is a propriety in the space, which oriented the compass needles.

S2.Q1: describing what is happening to the needle of the compasses pasted on the cardboard, students said that: all needles point toward the magnet (39%), the needles of the compasses placed into 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%).

Replying at the question “Which are the object(s) that can change the orientation of the needles?” (S3.Q1) students answered reporting a series of tables that are summarized in Table 1 and graphically represented in Figure 4.

Table 1: Which object can change the orientation of the needle?

<table>
<thead>
<tr>
<th>Tested object</th>
<th>Can (%)</th>
<th>Cannot (%)</th>
<th>That’s strange (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coils with current</td>
<td>32,6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coils</td>
<td>26,7</td>
<td>24,4</td>
<td></td>
</tr>
<tr>
<td>HiFi</td>
<td>21,5</td>
<td>12,6</td>
<td></td>
</tr>
<tr>
<td>Computer</td>
<td>20,7</td>
<td>15,6</td>
<td></td>
</tr>
<tr>
<td>Mobile Phone</td>
<td>17,0</td>
<td>3,0</td>
<td></td>
</tr>
<tr>
<td>Fire Extinguisher</td>
<td>15,6</td>
<td>34,1</td>
<td>8,1</td>
</tr>
</tbody>
</table>
In S3.Q2 students highlighted as common element into the objects able to change the direction of the compass needles, the presence of an electric current (61%), while 39% did not answer. This last conclusion, done by a majority of the students, become a general class conclusion with the exploration proposed with S3.Q3 and S3.Q4.

During S3 discussion, the discussion about the fire extinguisher as an object that have or not an own magnetic field was a point of particular interest (please note that during the activity, the ‘magnetic field’ was introduced by the researcher only as label for the discovered that can reoriented the compass needles). In particular students highlight that, when they go near the fire extinguisher with the table of compasses, all of them point to the object, but there are not needle that lies parallel to it, so they argue that it has not got an own magnetic field.

As said before, during the S4 phase was not collected written data. There was only a discussion in which students highlighted the main characteristic of the electromagnetic induction (as for instance its transient nature) and explicated the different ways in which is possible to realize it.

<table>
<thead>
<tr>
<th>Tested object</th>
<th>Can (%)</th>
<th>Cannot (%)</th>
<th>That's strange (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blackboard</td>
<td>11,9</td>
<td>14,1</td>
<td></td>
</tr>
<tr>
<td>TV</td>
<td>7,4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Windows</td>
<td>5,2</td>
<td>14,1</td>
<td></td>
</tr>
<tr>
<td>Generator</td>
<td>3,7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Metal pipe</td>
<td>1,5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plastic table</td>
<td>0,7</td>
<td>8,1</td>
<td></td>
</tr>
<tr>
<td>Professors’ head</td>
<td>0,7</td>
<td>0,7</td>
<td></td>
</tr>
<tr>
<td>Blackboard eraser</td>
<td>0,7</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Concerning the analysis of the artefact, 56% of the students said that it is an electric torch, another 38% of the students said specifying that it is an electric torch with a coil that produces energy and 6% did not reply.

**Data analysis**

Looking at the question S1.Q1; S1.Q2 and S1.Q3 is manifest how the experimental approach promotes an evolution of the ways in which students face the analysis of the phenomena. In S1.Q1, in fact, 68% of the student gave as answer as assertion without looking at the experimental apparatus (i.e. “compass needle point to North”) respect to a 27% of them that referred their answers to the specific situation. Already in S1.Q2 students focused their answers on what they think as important elements in the description of the phenomena: compass needle 80%, compass background and needle 15%. In S1.Q3 96% of the students refer their answers only to the direction of the needle.

**Figure 5:** S2Q1 Analysis.

Analysing questions S2.Q1 four different students’ approaches are manifest (Figure 5): 39% of the students looked for a collective behaviour of the needles, 24% recognized the presence of a pattern, while the remaining 31% of the students who answered to this question reported only a change in the needle directions. In particular, 5% of the students highlight a casual effect.

As concern for question S3.Q1, the more interesting part was the students discussion in which each everyday object was analysed and in particular, relating to the case of the fire extinguisher, students propose a method aimed at discerning if an object that is able to change the needle orientation have or not an own magnetic field.

Instead, during exploration of the artefact it is interesting to examine how students’ descriptions evolve from before to after that they can touch and analyze the artefact in an experimental way. In particular, in Figure 6 are displayed which are the elements that they used to describe the artefact. Is interesting how the pure structural elements (as for instance the plastic skin) almost disappear after the experimental phase making way for new emerging functional elements (as magnet and lamp).

This trend was even more explicit when we look at the changes in the students’ explanations of the functioning of the induction torch (Figure 7). Structural description fall down from 55% to 6% and two principal different approaches emerge in the artefact analysis: one looking at the physical principles (49%), the other looking at the technical principles (26%).
Conclusions

From this experimentation tree main important results emerge: 1) an operative approach helps students to focus on relevant elements for the processes to switch from a structural to a functional description; 2) comparison and analogies between artefact elements and explored elements allow students to re-use their preview discovers into the interpretation of the artefact; 3) Experimental exploration allows and promote the switching between a structural to a functional description of the artefact highlighting so which are the scientific and the technical principle on which the artefact works.

References


Michelini M, Vercellati S, Primary pupils explore the relationship between magnetic field and electricity, GIREP vol. 2, 2009.