Pupils explore magnetic and electromagnetic phenomena in CLOE labs

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(Received 27 July 2011; accepted 25 October 2011)

Abstract

The Conceptual Laboratory of Operative Exploration (CLOE) provides an informal context for pupils that stimulates 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 reasonings 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. This particular activity was carried out with primary and lower secondary school students (from 6 to 13 years old; from 1 to 8 grade). Starting from the identification and the classification of magnets, students highlighted the presence of a space property described by the orientation of a compass (magnetic field) having as sources both magnetic objects and both an electric current. The quantities involved into the Lenz induction process are individuated exploring the conditions for the generation of an electric motive force, highlighting the transient nature of the phenomena. The task to explain the functioning of an unknown artifact (induced torch) give the opportunity to apply the ideas on electromagnetic induction. Data are collected using personal worksheets and recording of the activity looking in particular to: 1) how an operative exploration may help students to identified and organize electromagnetic phenomena; 2) how the exploration and the comparison between phenomena is useful to help students in the interpretation of artifact; 3) how exploratory elements are reused by students in the interpretation of artifacts.

Keywords: Conceptual Laboratory of Operative Exploration (CLOE), electromagnetism, reasoning in building of formal thinking.

Resumen

El laboratorio conceptual de exploración quirúrgica (CLOE) proporciona un contexto informal para los alumnos que estimulan el razonamiento conceptual y ofrecen anclajes para la construcción de los primeros pasos en el conocimiento científico de la visión del sentido común. Los laboratorios de investigación en CLOE se llevan a cabo por un investigador sobre un tema en específico, basado en un protocolo de entrevista semi-estructurada, lo que representa un entorno de trabajo abierto a través de la propuesta de los escenarios de la vida cotidiana. Fenómenos en situaciones diarias son explorados siguiendo las secuencias de los razonamientos por medio de simples aparatos de actividades manuales en diferentes contextos. Una investigación se centró en la construcción del pensamiento formal a través de CLOE y permitir la identificación de ideas espontáneas de los alumnos y caminos en la evolución conceptual del razonamiento en la interpretación de los fenómenos magnéticos. Esta actividad en particular se llevó a cabo con estudiantes de primaria y primer ciclo de secundaria (de 6 a 13 años de edad; de 1 a 8 grados). A partir de la identificación y clasificación de los imanes, los estudiantes destacaron la presencia de una propiedad del espacio descrito por la orientación de la brújula (el campo magnético) que tiene como fuentes de ambos objetos magnéticos y los dos una corriente eléctrica. Las cantidades involucradas en el proceso de inducción de Lenz son individualizados explorando las condiciones para la generación de una fuerza motriz eléctrica, destacando el carácter transitorio de los fenómenos. La tare de explicar el funcionamiento de un artefacto desconocido (inducido por la antorcha) dará la oportunidad de aplicar las ideas de la inducción electromagnética. Los datos son recolectados a través de las hojas de trabajo personal y el registro de la actividad buscando en particular a: 1) Cómo una exploración quirúrgica puede ayudar a los estudiantes a identificar y organizar los fenómenos electromagnéticos; 2) Cómo la exploración y la comparación entre los fenómenos es útil para ayudar a los estudiantes en la interpretación de artefacto; 3) Cómo los elementos de exploración son reutilizados por los estudiantes en la interpretación de artefactos.

Palabras clave: Laboratorio Conceptual de Exploración Quirúrgica (CLOE), electromagnetismo, razonamiento en la construcción del pensamiento formal.

PACS: 01.40.Fk, 01.40.eg, 01.40. **ISSN 1870-9095**

I. INTRODUCTION

For the XXI century people, a basic knowledge of the main important electromagnetic phenomena is pivotal. During each day everyone uses several electromagnetic devices to do a wild range of activities. Even pupils, playing with several toys that involve magnet and/or electricity, observe in their games some basic electromagnetic behavior. In this way pupils, observing the world in their everyday life, construct spontaneously their own mental models to interpreter the reality [1]. The pupils' naïve models are related to conceptual elements and reasoning on problematic situation that pupils face in their everyday life [2]. Previous researches [3] show that pupils' mental models are coherent explanatory framework that has the form of a theory, although differs from a scientific type of knowledge [4]. The pupils spontaneously have more coherence need at local level rather than a global one [5]; so it is necessary to design educational interventions that help pupils to bridge from a common sense to a scientific interpretation of the phenomena overcoming spontaneous model [6, 7] through predictive conceptual models [1, 8, 9]. In the framework of MER – Model of Educational Reconstruction – [10] connection between different scientific topics and everyday knowledge is one of the main learning problem in scientific field [6]. The role of experiences is pivotal in the construction of knowledge [11, 12]. Some typical persistent conceptions [13, 14, 15] constitute difficult barriers to overcame [16]. Informal hands-on and minds-on labs activities involve students in the process of building knowledge [17] and promote a cognitive re-structuring of students' concepts by means of dynamic mental models that are inextricably linked to the context promoting the conceptual change [18, 19].

As concern the specific case of the electromagnetism, research literature in physics education, highlight the presence of several typical conceptual knots in the students' knowledge related to the concept of field in static [20, 21 22] and in dynamic situation [23, 24] at all school level [25]. Interesting results emerging in intervention experiments in primary school on electromagnetic phenomena [26] and the important role of gradual building of concepts in learning [18, 19] suggest the proposal to create a vertical curricula based on a continuum learning process that start to face electromagnetic phenomena in primary [26].

Regarding to this aims, the Conceptual Laboratories of Operative Exploration (CLOE) were designed to provide pupils informal exploration of phenomena [19]. In CLOE labs pupils' reasoning are stimulated by the analysis of simple situations working as conceptual anchors for the pupils' developing of formal thinking [19]. Several research based CLOE labs were carried out on particular topic (thermal phenomena [27], circuits and current and electrostatic [28],) by means of semi-structured interview protocol and inquiry based learning method [29]. In CLOE everyday-like scenarios (realize with poor everyday objects) pupils explore the phenomena, 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 environment conditions in which a reflective inquiry process could affectively take place [30, 31, 32, 33].

II. ELECTROMAGNETICS CLOE LAB

In the first part of a CLOE lab the primary school pupils interpretative reasoning on phenomena of electromagnetic induction is explored by means of semi-structured interviews in the framework of a specific inquired-based learning path. The steps of the interview protocol (Table I) are focused on specific learning knots of an experimental situation that pupils explore directly, discussing key questions proposed by the researcher.

TABLE I. 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 constraint magnets	Q5a Take two magnets in the hands. 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	Q9 Using a compass, can you identify which objects produce magnetic property

magnets	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?

In the second part of the CLOE lab, the analysis of an unknown artifact (an induced torch) was proposed to low secondary school pupils student in a structured way: a) preliminary description of the artifact only looking at it, b) exam of the artifact by touching it and looking at its functioning, c) improving (or modification) of the first description.

Data were collected using audio-video registration of the discussions and pupils' personal worksheets for what concern the description of the artifacts. In particular the investigation done was focused on three main aspects: 1) how an operative exploration may help students to identified and organize electromagnetic phenomena; 2) how the exploration and the comparison between phenomena is useful to help students in the interpretation of artifact; 3) how exploratory elements are reused by students in the interpretation of artifacts

III. SAMPLE AND DATA

The electromagnetic CLOE lab was carried out in the informal context of the GEI (*Giochi Esperimenti Idee* – Games Experiments and Ideas) exhibition [34] 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 article) for a total of 201 primary and 114 lower secondary school pupils and 19 of kindergarten.

The single main pupils' ideas that they had before the explorative investigations and the shared pupils' idea after the experimental explorations (Table II) are collected by analyzing the audio-video recording of the little groups pupils' discussions.

TABLE II. 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 contact they have only to be near	- Magnets feel the presence of the other magnets and 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	- 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

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[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.

	same direction	
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

In the second part of the CLOE lab all answering pupils (94%) identify explicitly the artifact as an electric torch and 38% of them specify *with a coils that produce energy* (or *current*). They focalize attention on structural or functioning aspect of different part of the artifact before and after its exploration, according with Fig. 1 and 2.

IV. DATA ANALYSIS

Comparing the two columns of Table I emerge the conceptual change of expressed ideas on the different conceptual knots and the change of modality to express ideas: in columns one we found sentences that are like "statements" (Q2, Q4 and Q5a for instance) and are lees detailed than the other reported in the right column (Q2, Q4, Q5b, Q6b, Q7b).

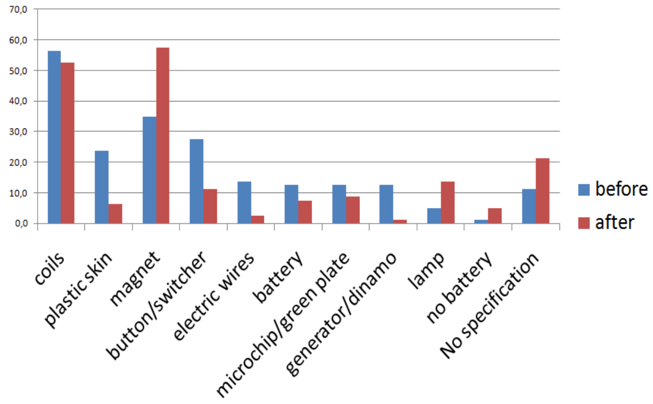

FIGURE 1. Element used by pupils to describe the artifact before and after the experimental exploration of the artifact.

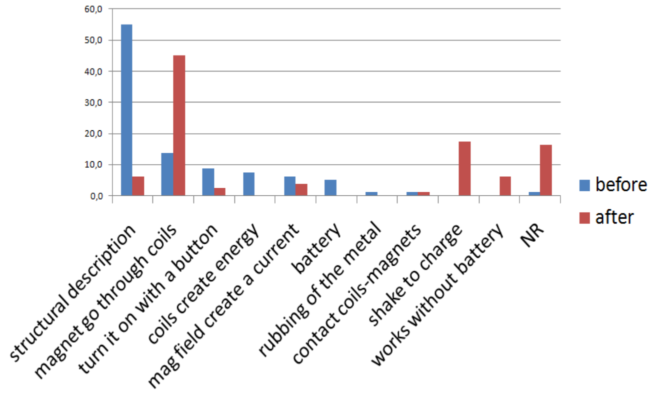

FIGURE 2. Description of artifact: structural and functioning aspects, before and after the experimental exploration of it.

The description of the artifact by pupils moves on the important functional parts of the artifact (in particular coils and magnet) selected after exploration (Fig. 1) between a large number of details reported before exploration, when a structural perspective prevail on a functional one (Fig. 2). 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 Fig. 3 this shift is represented in a graphically ways. And in particular, in Fig. 4 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.

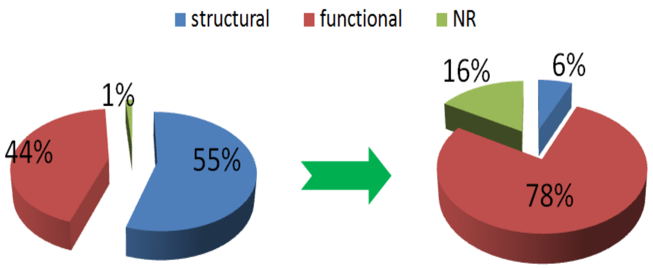

FIGURE 3. The percentage change of structural and functional description of the artifact gave by pupils before and after the experimental exploration of the artifact.

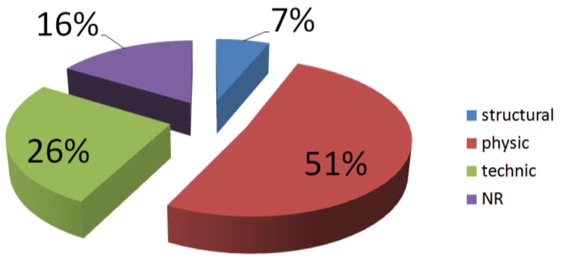

FIGURE 4. Typology of description provided by pupils after the experimental exploration of the artifact considering the functional distinction spitted in technical and physical description of the functioning.

V. CONCLUSIONS

Data collected show that an operative approach helps pupils to focus on the relevant interpretative elements characterizing the explored phenomenology. The structural description is a rich details' result, when the explanation or the interpretation is not explicitly peformed. In addition, comparison and analogies between component of unknown object (the artifact) and elements that were previously explored allow student to re-use their preview discover into the interpretation of exotic (not-laboratorial) situations. In this perspective, experimental exploration allows pupils to move from a structural to a functional description of the artifact.

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