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Research-oriented training for Italian teachers involved in the European MOSEM Project(*)

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Summary. — A study on the specific knots of electromagnetic induction and superconductivity for in-service teachers has been carried out within the PCK theoretical framework (Shulman L. S., *Educ. Res.*, **15** (1986) 4). The main knots listed in the literature were the object of an analysis in terms of teachers' pedagogic behaviour in planning intervention work to overcome the learning problems and organizing class activities.

PACS 01.40.Fk – Research in physics education.
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1. – Introduction

Researches conducted on the learning of electromagnetic phenomena have revealed a certain extent of learning difficulties in interpreting electromagnetic induction, which is related both to the fact that students often only have a partial understanding, due to a non-complete knowledge, of the various situations producing induced currents and also to the incorrect use of Lenz's law [1, 2].

Within the Pedagogical Content Knowledge (PCK) theoretical framework a study dedicated to the specific knots of electromagnetic induction and superconductivity for in-service teachers has been carried out; this analysis focuses on the pedagogical behaviour of teachers in planning the intervention work to overcome learning problems and organizing class activities.

Individual answers to written questions given by a group of teachers were analyzed to identify reference models in teachers' explanation strategies, pedagogical approaches and analogies.

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A discussion activity regarding these answers was carried out with groups of teachers both in person and within a dedicated web environment. The latter involved, in particular, the community of Italian teachers participating in the MOSEM Project teacher seminars. The MOSEM Project (Minds-On experimental equipment kits in Superconductivity and ElectroMagnetism for the continuing vocational training of upper secondary school physics teachers) was created as a part of the European Union's Leonardo da Vinci Programme to promote didactic innovation, developing teaching/learning methods through the use of low- and high-tech kits on superconductivity. MOSEM Project teacher seminars involved 40 teachers of 21 schools of 18 cities across 7 Italian regions.

This paper is organized as follows: after an initial introduction regarding didactic innovation within the PCK framework and an overview of the main learning knots about electromagnetic induction to contextualize the need for a global vision, we present the learning knots addressed in the PCK activity (worksheet in the appendix), we analyze data and present main results and conclusions.

2. – Didactic innovation in the PCK framework

Research literature shows the need for a new interpretation of contents from a didactic perspective starting from the reasoning and learning processes of students.

Didactic innovation implies both the knowledge of the content and the pedagogical transfer of that content [3] with the need for teachers to frame new contents within the existing one. For this reason, training rather than information is needed in order to produce continuity. A new interpretation by teachers is essential [4], teachers transform innovation adapting it to their own teaching style and to their idea of content [5]. The focus is on developing a new interpretation that takes into account a reconstruction of content for didactic purposes [6]: selected approaches are determined by the spontaneous approach of students to familiar learning knots. Taking this as a starting point, a way of reasoning—and, consequently, a path—is developed. This means that teachers need to be aware of learning knots and how to address them, according to their personal teaching style. A PCK-based research requires teachers to be familiar with contents and specific methodologies, to recognize learning knots and be exposed to them.

Quality development of in-service teacher training requires the integration of 3 models:

a) The *Metacultural Model* which is based on

   – case studies of educational methods;
   – involving critical discussion about the cultural and didactic elements of an innovative method;
   – allowing teachers to plan and produce their own educational material for students.

b) The *Experiential Model* whereby teachers carry out the same activity that is proposed alongside the students.

c) The *Situated Model* which

   – is based on the teachers' learning through reflections on their in-class experience;
   – represents the growth arising from teachers' professionalism; and
   – offers the basis for innovation, emerging from schools' particular needs.

Reflections on the professional experience within a research context (as action-research), is one of the ways in which it is possible to retrieve the informal learning taking place as a result of the experience gained.

3. – An overview of the main learning knots about electromagnetic induction: the need for a global vision

Electromagnetic interaction has an important role to play in the interpretation of electric and magnetic phenomena and various difficulties have been identified on the part of students. One of these difficulties concerns the concept of field despite its fundamental importance in describing interactions, mainly in dynamic situations. The main difficulties related to the concept of field concern: superposition [7], field sources [1, 8], field representation and systems [8, 9], field lines and trajectory [10],time-depending field sources [11, 12], electric and magnetic fields as changeable components of a unitary physical entity (the electromagnetic field) and electromagnetic induction [2, 13, 14]. Some learning problems emerge when exploring, for example, magnetic interactions in the static case: namely, the fact that the reciprocity in the interaction is not considered, the impossibility of instantaneous transmission in interactions, the fact that the interaction between wire elements carrying current appears not to be in agreement with the third law of dynamics [15], the recognition of field sources and the geometry of field lines. Further, other learning problems related to the nature of the field emerge from such problems: is it a material entity? Is it a state of space? And, if it is a material entity, how is it that, in the case of an electromagnet, this entity may be created or destroyed by means of an electric current? And, finally, what specific properties does this entity possess? [2, 14].

In the dynamic case, difficulties emerge regarding how to interpret electromagnetic induction.

In some examples from the CSEM assessment test [1], the authors found that students often use relative motion to explain electromagnetic induction, and display problems recognizing the Lorentz force, in the application of Lenz's law.

Other problems are related to the induced current varying proportionately with the current inducing it, the need for contact to exist between the magnetic flux and the coil for any induced emf, or that Coulomb or electrostatic potential difference being present in an induced electric field [2]. The researchers suggested five areas of deficiency in students' knowledge structures: 1) Often student's knowledge structures do not include central relationships (*e.g.*, Maxwell's equations) in any form, neither mathematical nor qualitative. 2) There is an overemphasis on subsidiary information (*i.e.* Ohm's law). 3) Students find it difficult to retrieve even the partial information they store. 4) Most students seem to represent the relationships only in mathematical form and do not have access to more qualitative representations. 5) Students entertain many inaccurate ideas about electromagnetism and mistakenly interpret central relationships [16, 14].

The need emerges for a global vision that may be achieved through the concept of flux and, in particular, of flux variation.

Many textbooks address the problem of electromagnetic induction by emphasising relative motion and this causes a reductionistic simplification which leads students to perceive the phenomenon only in some of its aspects, collocating it in a limited context that minimizes its real meaning and characteristics. In fact, a deeper meaning is absent with a partial representation only. For example, it is not possible to understand mechanics and the way physics describes motion if the study is limited to the two-dimensional case. A didactic approach to particular cases, therefore, does not allow for an organic framework and a methodological contribution to physics, which is always oriented to synthesising rather than analysing a given context, and focusing on a global rather than a local vision.

4. – Context and research questions

The need for a global vision has led us to make some choices regarding teacher seminars carried out within the framework of the MOSEM Project (Minds-On experimental equipment kits in Superconductivity and ElectroMagnetism for the continuing vocational training of upper secondary school physics teachers), created as part of the European Unions' Leonardo da Vinci Programme to promote didactic innovation, develop teaching/learning proposals by means of low- and high-tech kits on superconductivity. We introduced cooperative reflection [17], in which the cooperative learning was always activated through a discussion in small groups of 3-4 members. This discussion activity with groups of teachers about the individual answers was carried out both in person and within a dedicated web environment within the community of Italian teachers participating in teacher seminars.

Teacher seminars took place from December 2008 to June 2009 on seven separate occasions. Each session had a local referent, who planned the seminar and led that group of teachers, and a researcher from the Research Unit in Physics Education of the University of Udine who participated in the seminar activities via web or in person.

Four types of teacher seminars of different duration and levels of engagement were carried out:

1) *One-day intensive workshop* with group work on experiments on electromagnetism and superconductivity. Teachers carried out trials in classroom and, subsequently, met the group of researchers to discuss and analyze the results.

2) *Four-day training course* on didactic proposals, experiments and multimedia materials of the MOSEM Project.

3) *Annual training and action-research course* on didactic proposals, experiments and multimedia materials of the MOSEM Project with a case study of a class teacher of the 5th year of a scientific secondary school (Liceo Scientifico).

4) *Teacher training institutional course* (Corso di Perfezionamento IDIFO2 - Innovazione Didattica in Fisica e Orientamento 2 - of 15 CTS) developed within the framework of the "Lauree Scientifiche" (Science Degree) Project, the URDF led 15 Italian research groups from as many universities and activated, at a national level, on modern physics organized in six thematic areas. One area is dedicated to superconductivity, offering teachers one year of situated training and action-research in the framework of MOSEM.

In addition, the teachers and students from two 2nd-year classes of a Technical Vocational college and a 4th-year class from a technical secondary school (Liceo Tecnologico) took part in seminars in Latina.

The various types of seminars held had some common elements in terms of activities and materials as described below:

1) The try-out of low- and high-tech experiments both for teachers and students to familiarize among them and to decide and plan how to use such experiments within a didactic path with students.

Materials: a) Hands-On–Minds-On low-tech experiments kit. A catalogue of the 35 experiments was distributed to teachers: for each experiment, aim, required materials, methods of assembly and execution, photos and videos were made available. b) High-tech experiments on electromagnetism and superconductivity: a qualitative experiment on the Lorentz force; electro-dynamic balance and Cotton balance (Lorentz force); falling magnet into a coil (electromagnetic induction); the jumping ring (electromagnetic induction) whereby three rings each of a different materials (copper, aluminium and plastics), which are either at room temperature or pre-heated/pre-cooled, are subjected to a sudden and intense magnetic flux variation, the jump heights are analyzed in terms of material and temperature; Ohm Laws; electrical properties: resistivity *vs.* temperature measurement for metals, superconductors and semiconductors and the Hall Coefficient for metals and semiconductors; magnetic properties: the Meissner effect and pinning effect, the behaviour of Type I and II superconductors where the levitation characteristics of a magnet over a cooled superconductor are observed and discussed.

2) The use of operative proposals based, for example, on PPS or Artefacts where teachers follow the learning path in detail, appreciating the knots that student will encounter: induction in electromagnetic and superconductive phenomena; problem-solving activities to determine and understand those aspects of levitation that can be explained by electromagnetic induction.

3) Participation in a PCK activity in which the addressed learning knots are explained starting from the research and in which teachers are asked to think of how to tackle problems with their students: a) a PCK activity on electromagnetism and superconductivity; b) a workshop on an artefact and relative PCK activity: the case of a wind turbine in a jar.

4) Thirteen methods/strategies of cooperative learning that teachers experimented in person through different activities.

5) The phenomenology of superconductivity (overview of a superconductor and its electric and magnetic characteristics, microscopic explanation of superconductivity (BCS theory), applications of superconductors, different types of superconductors, T_c, I_c and B_c, a history of superconductivity and Nobel prizes) to reflect on and analyse how to move from phenomenological observation to a representation of superconductive transition and the pinning effect.

6) Examples of already experimented didactic paths: an analysis of didactic paths taught during the SUPERCOMET Projects.

7) Planning a didactic path: a) From learning knots and difficulties to research questions and the learning path itself. An example of a path on electromagnetic induction. Monitoring and reporting trials: evaluation. b) From an activity based on the reflection on certain learning knots with the "expert" approach.

8) The try-out of multimedia materials: On-line computer applications (overview of the nine modules and/or their use to show and analyze some experiments and situations) both for teachers and students to familiarize among them and to decide and plan how to use them in a didactic path with students as well as discussing the usefulness of a multimedia laboratory in comparison with a real one.

9) A modelling activity on electromagnetic induction using Coach, VnR and Excel.

The teacher-experimenter compared his/her experiences with those of other teachers from the same country and other countries as well as with university researchers, both in person and within a dedicated web environment. This blended mode (of discussing aspects related to disciplinary and conceptual knots) highlights the need for teachers to focus didactic planning reflections on educational proposals already focusing on departmental discussion of conceptual knots and to adapt a proposal according with personal style and classroom context.

Problem-solving activities played a fundamental role in reflection and new elaboration: in fact, teachers came up with original proposals compared to those proposed by the project, as emerged from a comparison with a previous experimentation (the SUPERCOMET2 Project), where teacher planning simply focused on a reorganization of the materials produced by the project.

In-service teacher training requires a certain amount of time and different methods. The experience already obtained highlights the importance of a blended mode focused on contents and pedagogic issues, which is research-based in terms of materials and methods.

We worked with a total of 17 teachers for the PCK activity presented here: seven teachers came from a teacher seminar in Treviso, seven from Bari and three from Bolzano. This research has the features of a case study.

The main research questions are as follows.

RQ1: How does the reflection on the knots enable us to deal with certain aspects that have a later role planning the didactic path?

RQ2: Which approach do teachers choose to address some of the main learning knots?

5. – Learning knots addressed in the PCK activity

In this study, our choice was to use some learning knots from the literature. For each situation presented in the PCK activity sheet (see Appendix A) typical answers given by students are provided that imply some learning knots; teachers were asked to experience and recognize the learning difficulties and knots of students and choose an appropriate approach to address them in class.

Here, below, is a presentation of the learning knots that were addressed:

1) In the dynamic case, difficulties in interpreting electromagnetic induction emerge.

   In some examples of the CSEM assessment test [1], the authors explore whether students associate induction with relative motion or if they recognize the role of the flux variation and the parameters which generate it. Results showed that the majority of students explained the idea that motion of either the loop or the magnet is necessary to generate an induced current. Only a few students saw the collapsing loop as a case in which the magnetic flux changes, or the rotating loop as a case in which it does not.

2) Another question in the CSEM test on electromagnetic induction phenomena concerns a moving conducting bar in a magnetic field. Results showed that many students did not distinguish electrical and magnetic effects and that they did not recognize Lorentz force or understand that there are moving charges inside the conductor.

3) The researches have also revealed learning difficulties related to the application of Lenz's law [16]. Students often have problems in determining the versus of the

induced magnetic field, probably because of an incorrect interpretation of textbook sentences such as "The induced current resists its cause", because this is interpreted as opposite compared to the induced magnetic field.

4) The difference between magnetic suspension and levitation, the problem recognizing that a magnetic suspension of magnets is possible only where they are restrained, the fact that the poles of permanent magnets are fixed while in levitation, that the pole of the superconductor is always opposed to the facing pole of the magnet and that levitation is possible only thanks to pinning effect.

5-6) Recognizing the two different effects (Meissner effect and pinning effect), for type-II superconductors with low pinning: there are two very different situations in the substance (even if they appear to be similar when observed) when the sample of YBCO is cooled inside or outside a magnetic field.

7) The problem of stability of levitation with high-pinning superconductors depending on the magnetic-field configuration.

8) Recognizing the fact that superconductivity is the sum of two different yet linked properties, one of which is electric and the other one magnetic: zero resistivity and zero magnetic field inside the superconductor.

9) Distinguishing between Type I and II superconductors.

10-11-12) Recognizing the contribution of electromagnetic induction and, in particular, the Faraday-Neumann-Lenz's law in interpreting the phenomenology of superconductivity.

6. – Data analysis and results

1a)

As for the learning knots evident in the students' answers, teachers did not focus on each student but eight of them considered the first student, five the second one, three of them the third one and three of them the fourth one. Nine teachers also gave answers referring to all four students.

In eight cases the *first student*'s answer showed a recognition of the learning knot that the induced current is related to relative motion of the barycentre of the systems: "the first student might have known Faraday's Law but he recognized a flux variation only in the case of relative motion".

As for the *second student*, teachers interpreted the choice of case III in four ways, recognizing:

– The knot of relative motion (2): "The student probably remembered only some sentences or experiments carried out where there was relative motion and therefore includes the case of the rotating loop in his answer" (2).

– An incorrect analogy in terms of the student remembering a similar experiment but with a different shaped coil (1): "He/she actually carried out some experiments in which an induced current was observed in rotating square-shaped loops, for example" (1).

- An interpretative model in which the current is caused by inertia of electrons with respect to the rotation of the loop (1): "The student might think that electrons do not immediately follow the rotation of the loop due to inertia and that this causes a current" (1).
- An interpretative model in which the current is due to the rotation kinetic energy of the system (1): "The student might think in terms of energy: the only way to produce current is to give energy to the system making it move and, in particular, rotate" (1).

In the case of the *third student*:

- One teacher said "He/she has only recognized in a case a flux variation" (1): this teacher cited a sentence that is merely a hypothesis. In fact the student understands the bulb light is caused by the deformation of the loop, flux is not considered because he/she would write their answer in terms of the number of field lines or magnet-loop interaction or other physics entities such as the field.
- Two other teachers said that "the knot is that induction is thought to be linked only to the surface of the loop" (2). Teachers gave their personal interpretations of the students' answers, interpreting and extrapolating according to their method of observation of that phenomenon, therefore encountering difficulties in identifying the real problem or the point of view of the student.

Teachers' attitudes in interpreting student answers emerged, as they imagined what the students might know and the reasons for answering in such a way.

According to one teacher, the *fourth student*, who considered the picture as a reproduction of a real experiment, is correct: "there is no observable induced current, we would need a large amount of coils (and not only one), a galvanometer (and not a bulb) and a stronger magnet" (1).

Another teacher said that "this student thinks that it is possible to have a current only with a d.d.p. source" (1);

Another teacher said that "this student does not understand the link between induced current and flux variation" (1) and does not recognize any specific learning knot.

In general, some teachers (9) recognized certain learning knots from students' answers that can be divided into three categories:

- Magnetic-field flux variation (8): "flux variation" (6), "the recognition of a situation in which there is flux variation" (1), "the knot of magnetic field variation" (1).
- Lorentz's law (1): "motion of a charge in a magnetic field" (1).
- The recognition of all variables that determine the phenomenon (1).

1b)

In order to discuss with students the thesis that when there is relative motion between magnet and circuit there is an induced current by using these or other situations, teachers' planning methods focused mostly on refuting the thesis (12) by using one or more experiments that they considered emblematic for this aim.

a) Six teachers used experiment II and/or III from the test to refute the thesis of relative motion of the barycentre systems: "A comparison between the cases III and IV" (3), "I suggest using the third experiment (case III) to refute the thesis" (2), "I suggest using the case II experiment" (1).

b) In four cases, teachers suggested an experiment that would not be very effective in achieving the desired aims: "I suggest using a tester to measure d.d.p. in cases I and IV so that flux variation is highlighted as well" (4).

c) One proposal focused on identifying all situations that generate an induced current in order to link them to flux variation "I suggest introducing a coil in a magnetic field to recognize that the variation of number of field lines linked to the loop is the reason for the induced current" (1).

d) One teacher proposed "using the thesis of relative motion as a «temporary», in other words, a possible interpretation/description of phenomenon" (1) but the teacher did not specify how to achieve a global view based on magnetic-field flux variation.

Two teachers thought it was unnecessary to refute the thesis and give some examples to prove it instead (2): in these cases the need for a global view on the part of the teachers also emerged.
2a)

Teachers were asked to recognize interpretative models and types of student reasoning.
In case (a), teachers

– focused on Lorentz's law (3): "The student is incorrect in applying Lorentz Law, that he/she fails to recognize that, if the bar moves, electrons move as well" (1), "According to this student a magnetic field does not influence a moving charge" (1), "The student does not know the effects of a magnetic field on a moving charge" (1);

– recognized the knot related to the fact that a polarized bar may be neutral when subjected to electric induction: "the bar is globally neutral" (1);

– recognized the knot related to the sources that generate a charge separation (3): "The first student probably thinks that for a charge separation a d.d.p. source is necessary" (2); "The student thinks that a charge separation is only possible when an electric field is present" (1);

– focused on magnetic field (2): "The student thinks that the bar does not detect the magnetic field" (1), "Answer a) implies the idea that the motion cancels the field" (1).

In cases (b) and (c), two teachers recognized that students have an interpretative model in which the polarization of the bar is linked to the inertia of charges inside the bar: "answer (b) implies a model linked to the velocity (free moving charge, remain behind due to inertia)" (1), "students think the bar is polarized" (1).

In case (d), three teachers focused on the student's partial or incorrect application of Lorentz's law:

– the student only recognizes the existence of the Lorentz force "a force pushing charges on the side is generated" (1);

– the student only recognizes the existence and direction of the force and not the versus "answer (d) implies the recognition that **F**, **B** and **v** are mutually perpendicular" (1), "the student does not know the sign of charge carriers" (1).

Only one teacher focused on case (e) and probably failed to recognize it as the correct answer because he/she talked only about the direction of the Lorentz force "this answer implies the recognition that **F**, **B** and **v** are mutually perpendicular" (1).

Six teachers gave general answers for cases (b), (c), (d) and (e), showing the difficulties in determining the learning knots in relation to each student's answers. They recognized:

– that the knot concerned the difference between electric and magnetic fields (2): "they do not distinguish between electric and magnetic fields" (1), "students refer to electrostatic induction" (1);
– problems in applying Lorentz's law (8): "the other students probably found it hard to apply the vectorial product" (4), "they do not know the sign of charge carriers" (4).

2b)

Regarding the planning proposals to address student problems:

– in nine cases a preference for traditional teaching methods emerges, which would explain some important related contents or solve the exercise "by retackling the concept that had just been explained" (5) without saying how, "retackling definitions of electric and magnetic fields and the differences of the effects on charges" (1), "using Lorentz's law to define the correct answer" (1), "analyzing it from a mathematic point of view" (1), "explaining that the motion generates an induced current generated by an induced fem" (1);
– in two cases, a preference for the use of interactive methods emerged, for example a student discussion with no explicit specific idea on how to conduct it, with the aim of "suggesting leading a discussion between students to highlight the contradictions" (1);
– in one case a teacher suggested to use the experiments, but he failed to specify the precise experiments and their aims (1).

2c)

Teachers recognized learning problems related to

– magnetism of matter and the Lorentz force (2): "Students have problems recognizing the difference between the effects of a magnetic field on the matter (ferromagnetism) and on moving charges" (1), "they think that the field magnetizes the bar" (1);
– the Lorentz force (1): "the knot is the interaction between moving charges and the magnetic field" (1);
– the Hall-effect–induced magnetic field (1);
– two other teachers made a general statement that there are problems in applying the theory.

2d)

The planning proposals to address problems in class were divided into two categories:

– the use of experiments with certain specific aims (8) "showing Lorentz force with an experiment with cathode rays tube" (2), or "the Pohl experiment to make students aware that there are charges in a conductor that may move if they fill a force"

(1) although the teacher fails to specify how, "experiments on interactions between magnets and ferromagnets" (1) or, in general, "demonstrating experiments on electromagnetic induction" (4);

- dealing with theory (9) "Weiss models are needed" (1), "explaining Lorentz's law again" (4), "tackling the effects of magnetic field on current" (1), "talking about the effects of a magnetic field on charges" (1), whilst two other teachers simply suggested talking in more detail about the theory.

3a)

12 teachers focused on this question and highlighted the learning knots related to Lenz's law (4), the fact that flux variation generates an induced current (4), energy conservation (1), the fact that induced current generates a field that opposes flux variation (2), the relationship between current and the induced magnetic-field versus (1).

We noted that teachers frequently considered as a knot a general content that in reality is not a specific and crucial aspect of it.

3b)

Planning proposals to address these problems with students involve

- performing experiments (10) "moving coils in uniform and not uniform magnetic fields" (1), "experiments with coil pairs" (3), "different situations and experiments" (6);
- dealing with the related theory (9) "explain theory of Lenz's law" (4), "referring to energy conservation" (1) and, in general, "explaining theory" (4);
- using everyday examples (1);
- using simulation applets (1).

Teachers failed to identify the aims and the types of activity that would be appropriate.

4a)

As for the identification of the learning knots emerging from the students answers, teachers did not specify knots appearing in each sentence, but they recognized some general knots for the situation, *i.e.* they are related to:

- phenomenology (6) definition of levitation (4), difference between suspension and levitation (2);
- interactions (6) difference between repulsion and levitation (4), interactions (2).

4b)

Planning proposals to address the problem in class are related to:

- theory (5) "explaining theory" (3), "with analogy between magnetic and Coulomb forces" (1), "situations of force equilibrium" (1);
- experiments (7) "the same exp putting off the stick" (3), "with experiments" (4);
- showing technological applications (1);
- showing film (3).

4c)

Teachers identified the following correct aspects: “levitation is generated only by magnetic interactions” (1), “the need for a constraint to have suspension” (3).

Teachers identified the following incorrect aspects: “You have levitation between a magnet and a cooled superconductors, without referring to pining” (1), “It is possible to have levitation with magnets” (1).

5a)

The zero-field–cooled experiment and field-cooled experiment are deeply different for the majority of teachers (13), who recognized that they are equivalent only in terms of the observed phenomenology (1)—“equal from the point of view of the observed phenomenon” (1)—but very different in interpretation (12).

Teachers recognized that “they are not equivalent” (6) in terms of:

– flux variation at transition temperature (3) “in second case there is no flux variation, in the first one there is” (3);

– transition phase (1) “in first case we cannot determine the moment of transition, whereas in the second case we can” (1);

– interpretative models (2) “first case is due to the pinning effect” (1), “the second case is due to the Meissner effect and less stability” (1).

In two cases, only the teachers identified some incorrect aspects showing a deep need for training on modern physics: “they are equivalent” (1), “in the first case I observed the Meissner effect, in the second one the pinning effect” (1).

5b)

Planning proposals to highlight the similarities and differences of the two experiments showed the fact that it is likely that teachers were unfamiliar with these types of situations. In fact, teachers proposals lacked focus and did not address the aims. Proposals involved:

– Experiments (9) exploring the behaviours of systems (3): “with experiments” (6) “after students have made predictions” (1), “moving the magnet in both the cases” (1), “analyzing through experiments behaviour above and below transition temperature” (1), “exploring the behaviour of magnets at low temperatures” (1). It is likely that this particular teacher thought that the difference between the two experiments was due to the temperature of the magnet.

– Discussions (2) analyzing the contribution of Faraday’s law (1): “guiding a discussion between students” (1), “analyzing the contribution of electromagnetic induction in this phenomenon” (1).

6a)

Teachers recognized the following learning knots related to:

– Faraday’s law (1) “the relationship between flux variation and induced current” (1);

– magnetic properties (4) “properties of magnets and superconductors” (2), “magnetic properties of matter, magnetic screen” (1), “the difference between magnet and superconductor” (1);

- magnetic interactions (2) "attraction in pinning effect" (1), "both the answers concern the interactions between a magnet and a superconductor" (1);
- the relationship between conductivity and temperature (1).

6b)

Planning proposals involved:

- experimental activities (6) "with experiments I can analyze the stability of levitation in both cases" (1), "with experiments (5) concerning the Meissner effect and the pinning effect" (1);
- explanation of the theory (1);
- showing video (1).

7a)

Two teachers recognized cases (a) and (b) as possible configurations for the Maglev train, due to their symmetry (2).

Two teachers considered the pinning effect to be the basis of the functioning of Maglev train: "train is based only on pinning effect" (2), while another teacher attributed this to the Meissner effect: "the train is based only on Meissner effect" (1).

7b)

To help the students understand the principle of functioning, teachers

- would encourage students to consider both the pinning and Meissner effects: "I would tell students to take both effects into account" (1);
- would perform experiments to compare the interactions in the Meissner and pinning effects—"with experiments: moving the magnet, in the Meissner effect the magnet fall, in the pinning effect it does not" (2)—or to compare levitation with superconductors to the case of phirolitic graphite "in explaining the effect (4) in the laboratory with quadrupole and phirolitic graphite" (3);
- would deal with theory: "explaining the Meissner effect" (1).

In one case the teacher could not explain the principle of functioning: "I do not know how to explain it, the train is probably based on both effects" (1).

8a)

Teachers recognized the following aspects in the students' answers as correct: the relationship between resistivity and temperature (3), the zero resistivity in superconductors (1) and magnetic properties and their relationship with the applied magnetic field (1).

Teachers recognized the following aspects in the students' answer to be incorrect: the fact that students only take into account the aspects related to the electric properties "the relationship with resistivity only: an ideal conductor is a superconductor" (1), "superconductivity is the ideal conductivity" (1), "resistivity does not became zero in conductors" (1).

8b)

When planning a discussion with students, teachers would highlight the following aspects:

– physics of matter "phase transitions, different matter organization in superconductors and conductors at low temperatures" (1), "the different characteristics of materials" (2);

– electrical properties "the differences between an ideal conductor and a superconductor" (1), "analysis of resistivity *vs.* temperature graphs" (3),

– analysis of field lines before and after transition (1).

9a)

In order to address problems in class

– two teachers would choose a student discussion as a method: "leading a discussion on different matter states, on the variables (temperature and field) that change its properties, on modality of transitions: sudden or with mixed states" (1), "leading a discussion starting from students' answers" (1);

– nine teachers would use a traditional approach dealing with the related theoretical aspects: "analyzing the two types and BCS theory" (2), "explaining the different characteristics of materials" (2), "explaining the link between superconductivity ad external magnetic field" (1), "explaining the different characteristics of Type-I and -II superconductors" (2), "explaining the magnetic properties of matter" (1), "explaining theory" (1);

– one teacher would perform some fundamental experiments: "showing how the behaviour of Type-I and -II superconductors depends on how magnetic fields pass through them" (1).

10a)

One teacher would lead a discussion starting from the experiments (1), another teacher would explain the theoretical aspects related to resistivity (1).

11a)

One teacher would lead a discussion asking the student to justify his/her answer with examples, too (1). Two teachers would choose a traditional approach explaining that there is nonzero resistivity in the other parts of the circuit (2).

12a)

The three teachers who answer this question would deal with certain aspects related to

– Faraday's law (2): "explaining Faraday's Law and that induced currents may have any intensity if the resistivity is zero" (1), "induced currents inside the superconductor" (1);

– the properties of superconductors (1): "dealing with superconductors and their properties, and induced magnetic fields" (1).

7. – Conclusions

Sometimes teachers attemped to interpret and justify the answers of the students, to identify what students did and did not know instead of focusing on the implied learning knot.

Many teachers chose an experimental approach to address the learning knot of relative motion for induced current but they did not specify how they would do the experiment, the methodology, which path they would follow.

Teachers often suggested to explain concepts and models again, when they do most of the talking and students listen and do not deduce anything. The attitude of the teachers can almost be said to be based on frontal assertions, and they do not consider that the personal involvement of the subject, with the object of study, is fundamental. Some teachers proposed to repeat what is normally covered during the lesson without identifying the specificity of the problem and organizing a path of reasoning starting from that of the students.

Often teachers suggested discussions between students as a tool to highlight the contradictions in their answers. This means that teachers would use a methodology of cooperative learning but this does not constitute an adequate response, in that the knot is not explored, either from a methodological, operative or conceptual perspective. The only choice was a type of activity where ideas are shared with no prediction on how it can develop or a plan on how to guide the situation towards students reasoning.

Some teachers had, themselves, problems in the contents about superconductivity.

They possess a sort of intuitive perception of MRE in which they felt a deep need for content:

- in their opinion the phenomenological observation and the reconstruction with didactic aims are not sufficient to address the students' knots;
- they require a deep content basis.

Some teachers showed perplexity and difficulties in answering because they did not believe situations were contextualized enough: they did not assess the students' prior knowledge the situations referred to, rendering it difficult to interpret students answers. Therefore, in some cases, before answering, teachers would make hypothesis on the students' prior knowledge. This is a not scientific approach because there emerges the need to know the students personally, and teachers do not realize that a model, an idea, a knot is recognizable by itself.

A PCK activity is a useful tool because teachers:

- face the knots directly;
- are forced to recognize the knots of the students;
- in the discussion phase, after the first individual phase, learn how to recognize that it is possible to extrapolate an idea, an interpretative model of the students by directly analyzing their answers and without further information about the students themselves.

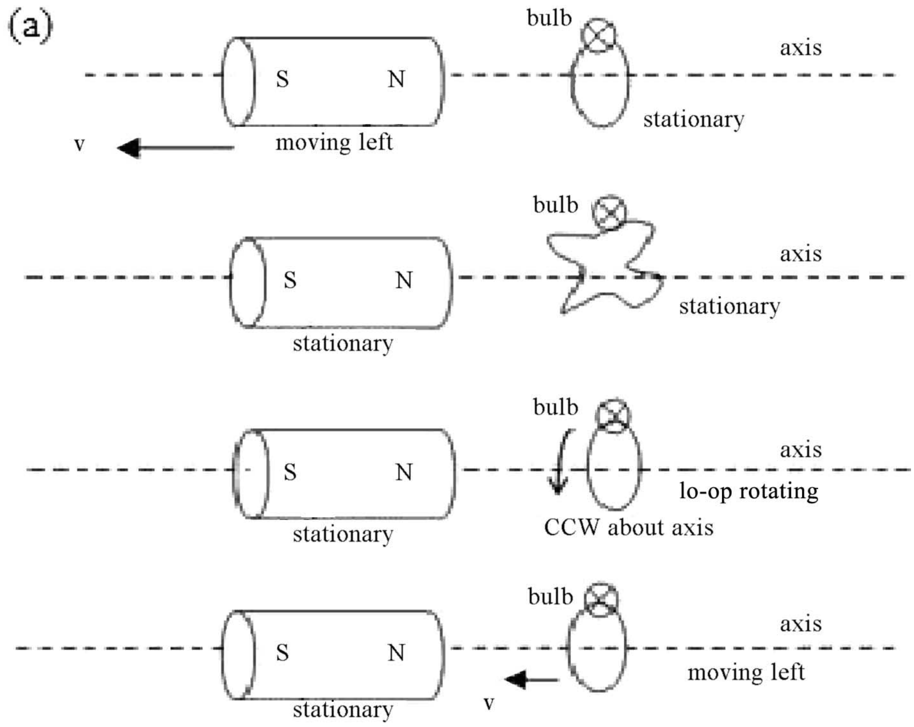
Appendix A.

(PCK sheet)

Electromagnetic Induction and the Lorentz Force

1) Your class must solve the following problem:

Define the situation in which the bulb lights with a cylindrical magnet and a coil with a bulb.



One student answers that "the bulb lights when I bring them near or far from each other" (cases I and IV).

Another student answers that "it lights when I bring them near or far from each other or when the coil rotates" (cases I, III, IV).

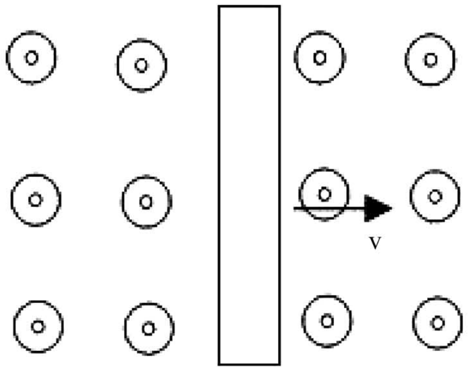
Another student says that "it lights if I deform the coil" (case II).

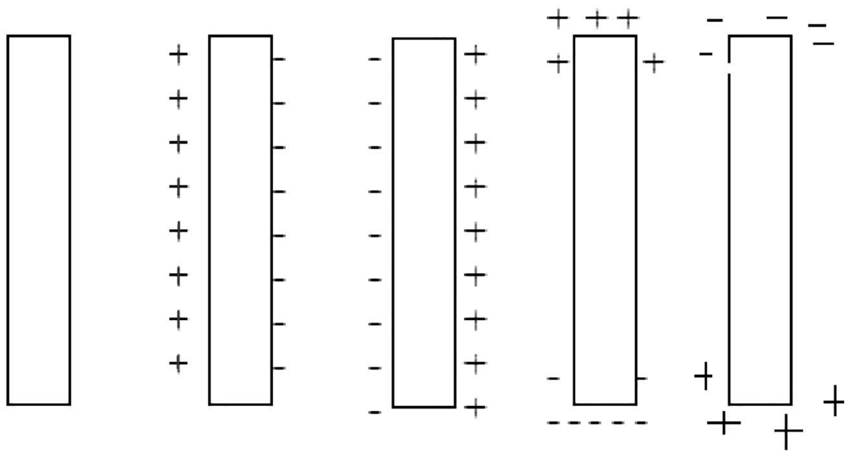
Another one says that it is impossible that the bulb lights.

1a) Which learning knots does each answer imply?

1b) Which of these or other situations would you use to discuss the thesis that there is an induced current when there is relative motion between magnet and circuit? In which way?

2) A neutral metal bar moves with constant velocity, as in the picture, and is located in a region of space in which there is a uniform magnetic field. Students are asked to draw the distribution of charges on the surface of the bar.





One student says that nothing happens (a).

Other students draw the situations b) c) d) and e)

2a) What interpretative models and types of reasoning do these student have?

2b) How might teachers address the problem with them?

Only a few students recognize that there is a force that pulls the charges towards one extremity or the other of the bar—answers d) and e).

One student says that "the bar is only attracted to but not polarized by the magnets that produce the field".

Another student chooses to answers b) and c) saying that the "magnetic field leaves the charges on the bar but they repel each other and the same goes the opposite sides of the bar"

2c) What problematic knots emerge?

2d) How might teachers address the learning knots these answer imply in class?

3) I suddenly made a change to a magnetic field and have thus induced a current in the circuit. This induced current may produce a magnetic field with the same versus of the magnetic field that generated it.

Students are asked to say whether they agree or not using examples too.

One student answers "No, It is false, induced magnetic field has an opposite versus because it is due to an induced current that opposes the field that produces it".

Another student says: "Yes, it is true, because a current always produces a field".

Another student says: "No, it is false, because otherwise I would find a way to make the inducing field greater and greater".

3a) Which learning knots does each answer imply?

3b) How might teachers address these problems in class?

3c) Which experiments and actions would you use to help students overcome them?

Sospension and Levitation

4) One of your students says that the magnets in the figure are levitating.

Another student says: "No, It is false, because they need a stick; if they were really levitating you would not need a stick".

Another one says that "levitation may be obtained with two magnets at room temperature or with a magnet and a cooled superconductor".

4a) Which learning knots does each answer imply?

4b) How might teachers address these problems in class?

4c) Which correct and incorrect aspects can you find in the given answers?

Meissner Effect and Pinning Effect

5) Two students are asked to plan an experiment on superconductivity. They know that hey have to cool YBCO samples (with low pinning) and study their interactions with a magnet.

A student proposes to cool the sample with liquid nitrogen and then bring the magnet near from a given height.

The other one proposes to put the magnet on the YBCO sample and then to cool the system with liquid nitrogen.

5a) Are both ways equivalent?

5b) How might teachers highlight the similarities and differences?

6) Students are asked to identify similarities and differences from the previous experimental situations.

One student says that "there are no differences because in both the cases the sample of YBCO is cooled and the experiments regard the interactions between a magnet and a superconductor".

Another student says that "the two methods are deeply different because in one case there is attraction, in the other one repulsion".

6a) Which learning knots does each answer imply?

6b) How might teachers address these problems in class?

7) Student observe a prototype of the Maglev train and are asked to explain its functioning. At the bottom of the train there is a sample of YBCO with high pinning.

Four students draw the track as in the picture.

N	N	N	N	N	N	N	N
S	S	S	S	S	S	S	S
N	N	N	N	N	N	N	N

(a)

S	S	S	S	S	S	S	S
N	N	N	N	N	N	N	N
S	S	S	S	S	S	S	S

(b)

S	S	S	S	S	S	S	S
S	S	S	S	S	S	S	S
N	N	N	N	N	N	N	N

(c)

N	N	N	N	N	N	N	N
N	N	N	N	N	N	N	N
S	S	S	S	S	S	S	S

(d)

In addition, one student says that the principle of functioning of the MAGLEV train is the Meissner effect. Another one says that it is the pinning effect.

7a) Which correct and incorrect aspects can you find in each answer?

7b) How can the teacher help the students understand the principle of functioning?

Electric and Magnetic Properties of Superconductors

8) As is well known, the recognition of the materials is derived from their properties and their behaviour when subjected to temperature changes.

One student says: “Yes, there are electric properties and, in particular, the resistivity and temperature”.

Another student says: "No, it is false, as both the superconductor and the ideal conductor have zero resistivity at low temperatures".

Another one says: "A conductor with $\rho = 0$ is a superconductor".

Another one: "in a superconductor $\rho = 0$ but $B = 0$ too".

Another one says that: "A superconductor has $B = 0$ but not necessarily $\rho = 0$".

8a) Which correct and incorrect aspects can you find in the given answers?

8b) How might teachers plan a discussion with the students?

9) As is well known, superconductors are divided in type I and II.

One of your students says that the only difference is the critical temperature.

Another one says that the difference is the value of resistivity: zero for type-I almost zero for type-II superconductors.

Another student says that the difference is in the magnetic properties.

9a) How might teachers address these problems in class?

Persistent Currents

10) A student says that $B = 0$ in a superconductor because $J = 0$ inside it. However, the student fails to understand how the existence of persistent current is possible.

10a) How might teachers plan a discussion with students?

11) A student says that persistent currents may exist in a superconducting wire in a circuit.

Another student says this is not possible.

11a) How might teachers plan a discussion with students?

Electromagnetic Induction and Superconductivity

12) A student cannot understand the relationship between electromagnetic induction and the phenomenon of superconductivity.

12a) How might teachers address the problem in class?

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