A case study about the comprehension of electromagnetic induction in Northern Italy

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Abstract. We discuss a study about Italian upper secondary school, undergraduate and graduate students' misunderstanding in dealing with electromagnetic induction. We suspect that most difficulties, that we found substantially common at all level of education, comes from the very poor link generally presented in teaching between the Faraday's law and the Lorenz force. We also suggest that the understanding of inductive phenomena/problems/exercises could benefit from taking into account also the magnetic vector potential "point of view".

1 Introduction

The recent reform (2010) of the Italian upper secondary school curriculum has given birth to two substantial anxiety generators in teachers: 1) some compulsory topics of modern physics and special relativity to be treated in the last (13^{th}) grade; 2) the possibility of a written test on physics in the final national examination. To train teachers and students on this last point, some simulations prepared by the ministry have been put online. Most of them contain non-trivial exercises about both modern physics and electromagnetism, in particular ElectroMagnetic Induction (EMI). In response to teachers' needs, most of the Italian Physics Education Research (PER) groups have been called to deliver training courses for teachers about modern physics and relativity for secondary school and (at least this is the Milan PER group situation) also to discuss EMI in deeper details than those generally given in textbooks. While the study of the electric and magnetic static fields can be considered an enrichment of the classical mechanics viewpoint, it is with the EMI that one enters the vast domain pertaining to electromagnetism, the comprehension of which passes, therefore, through the gate of EMI. This fact explains the efforts made by PER on this topic in the last years (see [1-4] and references therein).

This work concerns the comprehension of EMI at various educational levels and it has been carried out studying the response to a written questionnaire taken from the literature, to some given exercises and (in few cases) also to oral interviews of some secondary school physics teachers, graduate and undergraduate students in physics and mathematics, and scientific high school students.

2 Research design and method

In the last decades, EMI (and in particular Faraday's flux law) has given rise to many disciplinary discussion among physicists [2], therefore it is not a surprise that PER has put in evidence many difficulties coming from the teaching and learning of EMI [1-4]. The somewhat peculiar situation of the Italian upper secondary school (the relatively "high" level of mathematics in the curriculum, that includes elementary calculus, and the supposed high disciplinary preparation of the teachers, that must be graduated in physics or in mathematics) and the particular historical moment for what concerns the upgrading of the Italian curriculum, deserve, nonetheless some attention. In fact, the final examination based on the national curriculum requires the ability to solve complicated exercises while, on the contrary, qualitative questions are almost completely missing from both the final examination and the regular lectures. Two research questions (RQs) were asked. RQ1) Are the difficulties about the teaching/learning of EMI the same in Italy as those reported in the international literature? RQ2) If and how, do these difficulties change at different levels of education, from secondary school students to students attending a master degree in physics, to physics teachers? A previous research of ours suggests that the introduction of the magnetic vector potential already at secondary school level may cure some of the diseases generated by the “standard” introduction of the Faraday’s law. Therefore a somewhat implicit question, but strongly dependent on the answers to the previous ones, is whether such a suggestion might give a path for the EMI teaching in a way that is complementary to what we may call the traditional one. Our study has been carried out through the analysis of: 1) a 14 multiple choice questions test, taken from the literature [2, 3] given to 16 students of the course “Preparations of Didactical Experiences” (of whom, 3 graduated in Physics, 9 in the last year of the master degree in physics and 4 of the last year of the master degree in mathematics); 2) a 6 hours course about EMI delivered to 7 high school teachers in the Autumn 2017; 3) a 6 questions test (subset of the previous 14 questions test) given to students of the last year of a scientific high school. Explanatory answers have been asked for every question. We have also conducted some oral interviews with 3 secondary school teachers, 5 graduate/undergraduate and 2 high school students.

3 Results and conclusion

For what concerns RQ1), the majority of our results are in agreement with those found in the literature [2-3]. In particular, the majority of students tend to use the Faraday’s flux law even when a description in terms of the Lorenz force could be very useful and easier. Except for the “standard” textbook cases, when using the flax law, students are in general unable to consider the right surface for the variation of the magnetic flux, both in presence of a motion of the circuit and in its absence. Most students are unable to describe the induced current in a circuit in terms of forces acting on charge carriers. Concerning RQ2), we observe that, while some basic concepts have been gradually better understood with growing the level of education, for others the level of understanding remains substantially unchanged. An example of the first situation regards the concepts of circulation and flux: most of our secondary school students have difficulties about their meaning, but no graduate in physics shows misunderstanding about them (at least in simple cases). The two most interesting examples of the second situation regards: a) the greatly preferred use of the Faraday’s law with respect to the Lorenz force in dealing with EMI (in general, confusing the circuit surface with the integration area) that does not change with the level of education, and b) the ability to connect a systemic description (electromotive force) to locally acting forces, that improves very little from secondary school students to physics teachers.

From our results, it follows that a way to better understand EMI passes through a more strong connection between the flux law and the Lorenz force, while a new suggestion emerges: from a preliminary pilot study, it seems to us that the use of the magnetic vector potential [5] could help both the understanding of circulation and flux and the understanding of EMI. A sketchy proposal in this sense will be briefly presented.

References

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