Quantifying the magnetic field pattern: Ampere's law. A teaching sequence based on physics education research

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Abstract

This paper presents a pedagogical approach to address students' difficulties, identified in a previous study (*GIREP 04 Proceedings*, 170-173), in the learning of Ampere's law. The teaching approach developed in this work proceeds from the fundamental assumption that learning and teaching sciences is developed as a process of the solving of open tasks or problems which students could find interesting. The approach was developed within a rigid timetable and the programme of Physics for Engineering was the same for all the students participants in this study. The study groups were organised into small groups of 4 students which carried out the proposed activities and then discussed their conclusions with the whole class, under the teacher's management and guidance. The students work with the same methodology throughout the whole course, so the methodology used in the "Magnetic field" chapter is not new to them. The teaching sequence was mainly evaluated by two questionnaires which aim to test the students understanding of Ampere's law by a systematic analysis of its application in different situations. The results show that students in the experimental groups have a better understanding on Amperes' law than students who receive traditional teaching.

Introduction

This paper presents a pedagogical approach to address students' difficulties, identified in a previous study, in the learning of Ampere's law for magnetostatic [1]. We will only consider situations of stationary currents, so that the magnetic fields are stationary. We must remember that there is no a thing as a static magnetic situation, because there must be currents in order to get a magnetic field (and currents can come only from moving charges). "Magnetostatic" is, therefore, an approximation. However, in the syllabus of Introductory Physics Courses it is usual to teach a chapter considering only situations of stationary magnetic fields. In this research we take into account this context to teach Ampere's law for magnetostatics, which is an incomplete version of the Ampere-Maxwell law [2]

Despite its very different form, Ampere's law is essentially equivalent to the Biot-Savart law. However, in this interpretation we take into account the concept of field, which includes retardation and this is the reason why Ampere's law is relativistically correct, whereas the Biot-Savart law is not. Ampere's law holds in many stationary magnetic situations and the understanding of this law is an essential condition of reaching a scientific view of Maxwell's equations.

Previous investigations into students' difficulties indicate that students may have problems applying the concepts of electromagnetism [3, 4]. The case of Ampere's law included situations defined by mathematical operators and several variables which raises well know difficulties [5]. These difficulties have been analyzed in previous research [1] which shows that the majority of students use the following patterns of reasoning: to confuse the field operators (path integral of field) that provide information about the field and the field itself, to associate the path integral of magnetic field zero to value zero of field, to consider that the magnetic field is constant in any situation, to ignore the sources of the field (electric currents) which are outside the path.

The fact that the difficulties detected seemed resistant to usual teaching, as well as our analysis of textbooks [6, 7], induced us to design a teaching sequence to help students overcome these difficulties. So, the research question of our study is the following: How can we design a programme for teaching Ampere's law that improves students understanding of ampere's law? What learning is achieved by the students after implementing the programme in class?

Teaching approach

The teaching approach developed in this paper proceeds from the fundamental assumption that learning and teaching sciences is developed as a process of the solving open tasks or problems which students could find interesting. These are developed in a similar context, as far as possible at each level, to that of scientific research. Our proposal is specified by a collective work of *oriented research* [8]. We use the metaphor of the *"junior researcher"* whose role would consist of replicating research which is already known by "its supervisor" (the teacher). It is necessary to emphasis that this is not a matter of the students constructing scientific knowledge by themselves which took the most important scientists so much time and work, but to put them in a situation where they can familiarise themselves with scientific work and its results, covering known problems. In this approach, students are expected to prepare for class by reading and trying to do initial activities. This students initial implication allows teaching focus on the most important and difficult elements. The initial activities and reading act as an incentive to prepare the class for cooperative activities and discussion. In this part of the teaching process, students receive credit based on effort rather than correctness of their answers, which allows focusing on teaching the most challenges elements.

The teaching strategies based on Learning as Oriented Research (LOR) display three interrelated dimensions which can help students learn more and better (see figure 1).

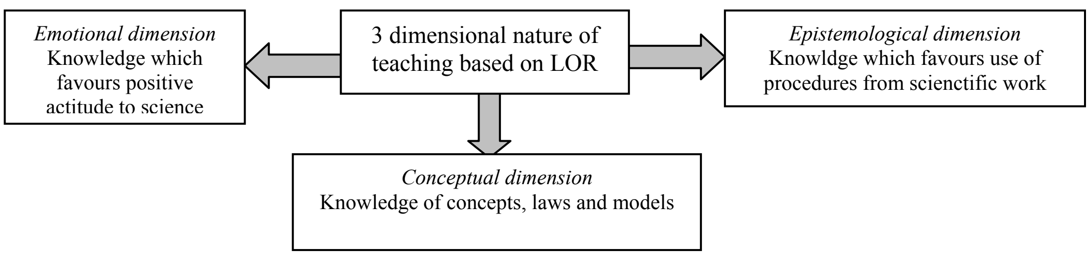

Figure 1. The three dimensions of teaching proposal based on learning as oriented research.

Another element of our instructional approach is that we use formative assessment. The main reason for this is the extensive science education literature showing that formative assessment can improve teaching and learning when it is done consciously and systematically.

The approach was developed within a rigid timetable and basic programme context established for the subject of Introductory Physics for Engineering. The groups of this investigation consist of students enrolled in the introductory physics course of engineering degree at University of the Basque Country. The students on the course had to pass a test to enter to the University and their average age was 19 years old. The participants in this study were 114 students in 3 different groups (30 students Group 1, 32 students Group 2 and 52 students Group 3). The authors of this paper served as the instructors. The students work with the same methodology throughout the whole course, so the methodology used in the "Magnetic field" chapter is not new to them. This chapter was developed over a period of three weeks (12 hours) and implemented during four courses (2001-2005).

Two control groups were included made up of 65 students with the same characteristics as the experimental students but they received traditional instruction. These two groups are referred to as Group C. The entry level of the students in all the groups can be considered as similar and with a standard knowledge level in accordance with a previous study within this same research.

Table 1. Learning Demand Analysis: The Ampere`s Law

Aspect of Science to be addressed	Students' difficulties
Ontological aspect	
Field lines are imaginary representations of the magnetic field generated by all currents in the universe	Field lines are real lines which can interact among them
Conceptual aspect	
Ampere's law established the relation between the path integral of magnetic field (circulation of field) and the sum of the enclosed currents. All currents in the universe contribute by superposition to the magnetic field, yet Ampere´s law refers only to those currents inside the chosen path because the outside currents contribute zero to the path integral	1. Confusion between the sources of magnetic field and the currents inside the chosen amperian path. 2. So that, confusion circulation of field and the field itself.
Epistemological aspect	
Ampere's law is generally applicable to all situations, however only is useful to calculate the magnetic field in special circumstances which have certain simple symmetries.	The magnetic field is constant in any situation in which Ampere's law is applied, so the law is useful to find the field in any circumstance.

Based on the learning demands of table 1, an instructional sequence was developed. In the chapter "Magnetic field", it was presented to students, different task related to Ampere's law essentially based on the analysis of situations involving: a) the pattner of magnetic field and symmetry conditions; b) Choose a mathematical closed path as a boundary and stretch an imaginary soap film over the boundary; c) interpreting the circulation of field walking around the boundary; d) Add up the positive and negative currents that pierce the soap film and finally, applied Ampere's law.

Implementation and evaluation

The successive teaching sequences were mainly evaluated by the two questionnaires which we used to detect students' difficulties. The questionnaire 1 was designed to test students reasoning about the sources of magnetic field and Ampere's law application (first conceptual aspect of table 3) and the second questionnaire was designed to test students' understanding about the difference between magnetic field and the circulation field (second conceptual aspect of table 3). In all questions, for solving them correctly, students have to use the ontological and epistemological aspects of the table 3.

The evaluation of the teaching sequence is done by comparing our teaching approach with students who had other 'standard' teaching approach (the control group). In this paper we are going to present the result of the 2004-05 scholar year (see table 2). The statistic t-test was calculated for the control group and the average of the experimental groups obtaining significant differences with a level of confidence below 1%.

Table 2. Results obtained in the questionnaire by experimental and control groups

	Percentage of correct answers (%)					
Number of item and concept	Group 1 N =30	Group 2 N = 32	Group 3 N = 52	Group M* N =114	Group C N = 65	t p<<0,01
Q1. Solenoid	27.5	36	26	29.8	9	4.79
Q2. Three sources	76	59.5	61.5	65.6	8	6.8
Q3. Two sources	45	56	42	47,6	9	3.24
Q4. Circulation zero	83	72	61	72	18	6.45
Q5. B different	86	75	80.5	80.5	13	8.67
Q6. No symmetry	30	38	28	32	9	5.3

* Average of the experimental groups

While the averages provide a way of comparing differences between the groups, they do not directly reveal information about the students contextual coherence. Figure 2 presents the percentage of students who demonstrated contextual coherence from the 5 or 6 questions, according to the criteria given in table 1.

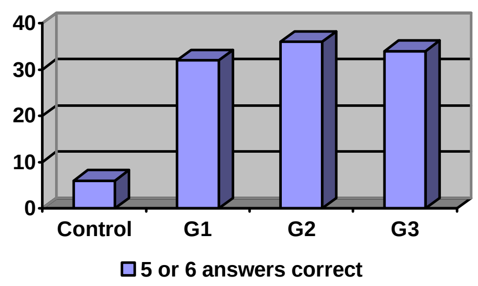

Figure 2. Percentage of students who respond correctly 5 or 6 question

Conclusion

The evaluation of the teaching approach, although limited to three groups of students, shows that the students show noticeable improvements in raising and resolving problems related to Ampere's law. Correct results were also obtained in learning on magnetic field sources and the explicative model of the Ampere's law, which are statistically significant in all cases from the control groups.

Reproducibility is an important prerequisite for science education progress. In this sense, we want to emphasise two aspects: The first deals with the context in which the programme of activities was developed. We were restricted by the programme laid down in the study plan. So, it was necessary, to produce a very detailed teaching plan of the time available and, showing that traditional conceptual contents were not lost as result of working with different teaching methodology. On the contraire, the designed and implemented learning sequence showed to give rise to enhanced learning outcomes when compared with those from a parallel class of students.

The second aspect deals with the role played by the teacher in developing the teaching sequence. The teacher has a strong influence on what and how the topic is taught, however as researchers we should make the effort to prepare a detailed guide for the teacher, as well as organise discussion seminars on the proposal where teachers would have the opportunity to discuss it and share ideas. Moreover, the teacher's role becomes highly important in our approach in terms of his own professional development, since he becomes an action researcher who will make his own critical reflection after the educational interactions and will therefore improve his educational action.

Bibliography

[1] Guisasola, J., Almudi, J.M. & Zuza K. (2004). Analysis of the processes of application of Ampere's law by engineering students in introductory physics courses, *GIREP Proceedings* 170-173

[2] Chabay, R. And Sherwood, B. (1995). *Electric & Magnetic interactions*, New York: Wiley.

[3] Maloney, D.P., O'kuma, T.L., Hieggelke, C.J. & Van Heuvelen, A. (2001). Surveying students' conceptual knowledge of electricity and magnetism. *American Journal of Physics Suppl.,* 69(7), 12-23.

[4] Guisasola, J., Almudí, J.M. & Zubimendi, J.L., (2004). Difficulties in learning the introductory magnetic field theory in the first years of University. *Science Education* 88(3), 443-464

[5] Manogne, C.A., Browne, K., Dray, T. And Edwards, B. (2006). Why is Ampere's law so hard? A look at middle-division physics, *American Journal of Physics* 74(4), 344-350.

[6] Guisasola J., Almudí J.M. & Furió C. (2005). The nature of science and its implications for physics textbooks: the case of classical magnetic field theory. *Science & Education* 14(3-5), 321-328.

[7] Pocovi, M.C. & Finley, L. (2002). Historical evolution of the field view and textbook account. *Science & Education,* 11

[8] Furió, C., Guisasola, J., Almudí, J.M. & Ceberio, M. (2003). Learning the electric field concept as oriented research activity. *Science Education* 87 (6), 640-662