

Analysis of the Processes of Application of Ampere's Laws by Engineering Students in Introductory Physics Courses

Jenaro Guisasola, José Manuel Almudí, Kristina Zuza
Department of Applied Physics. University of Basque Country
e-mail: wupguarj@sp.ehu.es

Abstract

The main objective of this study is to analyze the reasoning of university students regarding Ampere's law of electromagnetism. It has been supposed that the problems observed in the understanding and application of the law do not only come from students' misconceptions, but also from students' reasoning based on 'common sense' methodology. To test our hypothesis four open questions, with an emphasis on explanations, were designed. The results seem to confirm that most of students use incorrect forms of reasoning that show a lack of understanding of the field circulation operator, as well as a lack of understanding of the magnetic field itself.

Introduction

Current perspectives on what constitutes the meaningful learning of science are changing. Those visions that reduced science learning to acquiring theoretical knowledge are being left behind and two important aspects are being incorporated into science learning. These are procedural and strategic knowledge, which are especially relevant to the practice of science [1]. Recent studies have tried to determinate the logic behind students' arguments and have found that one of the main difficulties students need to overcome does not arise only from the existence of preconceptions (previous ideas held by the student) or alternative ideas (erroneous ideas that persist even after instruction), but also from the use of 'common sense' reasoning [2,3].

University professors share the belief that the concepts used in the area of electromagnetism are a source of confusion among students [4,5]. In the study we are presenting we attempt to get a deep insight into the students' procedural mistakes when applying Ampere's law, and we shall analyse the forms of reasoning used. Our aim is to answer the questions below:

- a) What forms of reasoning do students use when applying Ampere's laws?
- b) To what extent can the mistakes made by students in calculating Ampere's law be explained by means of procedural difficulties due to spontaneous or 'common sense' reasoning?

The relevance of Ampere's law is not only justified by it providing a much easier way to calculate fields, when a high degree of symmetry is presented, than Biot-Savart's law. More importantly, is the fact that it corresponds to a 'field model' of electromagnetic interaction. Thus, Ampere's law is an alternative way of explaining Biot-Savart's law about magnetic interactions, the former using a field model instead of the model of action at a distance.

As a result of the lack of knowledge concerning the students' learning difficulties in this area, it is harder than in other areas design effective teaching sequences and strategies. We hope that the study presented here can contribute to clarifying the teaching strategies that will allow students to have clearly comprehend the aforementioned law.

Theoretical frame work

In an academic context, it is common to associate a collection of problems with those strategies currently accepted to reach a satisfactory solution. Thus, the calculation the magnetic field is frequently associated with one calculus strategy and with one model. We want to highlight the absence of a preliminary analysis leading the selection of one particular type of model, whether it be because this is considered trivial or for any other reason. The student gets the feeling that one problem is indissolubly linked to one single solving procedure. This is how *functional fixedness* occurs in the form of a typical algorithm [6]. This leads students to disregard the need to justify the type of model – Newtonian or field - adopted in the analysis of a problem.

Students use also other forms of reasoning such as spontaneous or induced reasoning, which are called *functional reduction* in educational research. Viennot [7] defines this concept as the tendency to reason in such a way that one does not consider all the variables that influence a problem. The most common instance of this type of functional reduction is the reduction of the number of variables in a problem of multiple variables, which leads students to 'forgetting' some of the fundamental variables.

In this study we will deal with these two types of problems associated with students' reasoning and their influence on the learning the Ampere's law and its applications.

Experimental design

We have designed four questions which are common in the textbooks used for teaching Introductory Physics in university. 65 first-year students of Technical Engineering at the University of the Basque Country (Spain) filled out the questionnaire. The questions placed an emphasis on the students' explanations. Analyzing students' responses with regard to one single law, using different situations, can enable us to discover how they reason. The questionnaire was checked by the authors of this paper and three expert professors to analyze its contents and objectives. Similarly, a preliminary pilot test was carried out to analyze the coherence between the way the questions were written and the students' answers. Three questions of the questionnaire are presented and analyzed in the next section.

The design of the questionnaire allows for test of consistency in students' responses. For example, the first and fourth questions (the solenoid and the two parallel wires) present contexts in which the concept is the same: the magnetic field on the amperian line is due to the internal and external currents-intensity. The only difference is the types of devices that it is used. After having analyzed the written responses we found that the big majority of students use the same inappropriate reasoning in both questions (60% question 1 and 66% question 4).

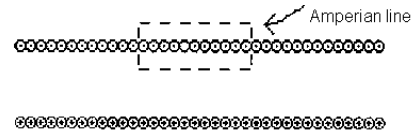
Analysis of results

How do the students use field sources and their form when they apply Ampere's laws?

In question 1, the students were given a problem about identifying the sources of field that they considered when applying Ampere's law. Ampere's law establishes that the circulation through a closed line depends only on the intensity of currents enclosed within the line. As is well-known, this proportionality between the resulting circulation and the enclosed intensity-current is not valid in general for the relationship between the resulting magnetic field on the line and the enclosed intensity, because the resulting field **B** at one point on the line is due both to the internal and external currents-intensity of the Amperian line.

Question 1. We consider a long solenoid, where we assume that as long as we are far from the ends, the magnetic field inside the solenoid is fairly uniform and

the magnetic field outside is very small. As you know, in this conditions we can calculate the field inside of solenoid by the application of Ampere's law. The amperian line of integration will be the line of shown in the diagram below. From this we can conclude that:



- The calculated magnetic field is caused by all the loops of the solenoid.
 - κ The calculated magnetic field is caused only by the loops inside the amperian line
 - κ Other answer
- Explain your answer

In this question, it is the presence of all the loops which determines the existence of a *special symmetry* for the magnetic field that allows for the simple mathematical treatment. If we consider the field produced only by the internal loops of the line it will not be easily calculated by applying Ampere's law, because the variations in modulation and direction of **B** at each point will impede finding a line of integration adequate for a simple calculation.

The answers given by the students have been categorized as shown in Table 1.

Answer Category	Percentage of Answers (N=65)
A : All of the loops produce the field	9
B : Only the loops inside the solenoid produce the field	60
C : The answer is not justified	11
Impossible to categorize	20

Table 1. Percentage of answers by students to question 1

In Category A, we have grouped the correct answers which indicate that the magnetic field calculated by Ampere's law is due to all currents-loops. However, no answer includes a justification, such as only the presence of all the currents-loops allows for the existence of a *special symmetry* for the magnetic field, which in turn allows the type of simple mathematical treatment which we are familiar with for Ampere's law.

In Category B, the vast majority of the students' reasoning were as follows:

“According to Ampere's law, I applied the field circulation for that line, and as we have already seen in class. In the vertical segment and in the external part

there is no circulation of B . Therefore, you would get field B from there, because we know the intensity that circulates through the loops:

$$\sum I_{\text{internal}} = \oint \vec{B} \cdot d\vec{l} \Rightarrow 10I = B d$$

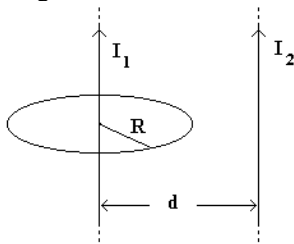
Since there are 10 loops within the integration curve, I multiplied the intensity by 10, and 'd' is the length of the rectangle of integration".

According to the students' reasoning, it seems that, based on the formula, students establish a link of causality between the intensity enclosed by any line and the field at the points on that line. A functional fixedness was observed in the choice of strategies used, based on the mathematical expression of Ampere's law [6].

In Category C are those answers which do not consider Ampere's law, but instead are based on the general principle that the magnetic field is generated by all of the loops, without providing any further justifications

The fourth question was designed with the intention of investigating the reasoning used by students in a situation in which it is necessary to explicitly take into account which field is involved in Ampere's law.

Question 4. Here are two very long parallel straight wires, a distance d apart. The left wire carries a conventional current I_1 and the right wire carries a conventional current I_2 in the same direction. A student states that Ampere's law is useful to calculate the total magnetic field in all points of the circular path of radius R . Do you agree with this student?



Most students use similar reasoning that we have analyzed in question 1. The results are the followings:

Answer Category	Percentage of Answers (N=65)
A : The two current intensities interact to produce the field	9
B : The internal current only produces the field	66
Impossible to categorize	13
No answer	12

Table 2. Percentage of answers by students to question 4

In Category, B, the students consider that the only field sources are those which enclose the Amperian path. Let us see two examples:

Example 1: "I agree, because

$$\oint \vec{B} \cdot d\vec{l} = B 2\pi r = \mu_0 I \Rightarrow B = \frac{\mu_0 I}{2\pi r}$$

Example 2: "I agree. If we apply Ampere's law, we find that field B and the intensity are proportional."

It seems as if the students use two manners of reasoning which sometimes overlap. Firstly, there is a style of reasoning characterized by a functional fixedness regarding the operational definitions of the law that is used in a non-critical manner (see example 1). The erroneous inference is made that the only sources of the field are those enclosed by the Amperian path. Secondly, and to a lesser extent, there are forms of reasoning which confuse the field with the operator of field circulation (see example 2), falling into functional reduction. The two styles of reasoning also appear in the third question of the questionnaire.

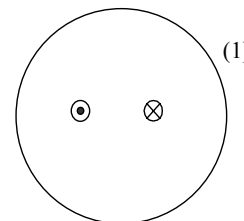
How do students use field circulation operator?

In the third question, a situation is proposed in which the circulation of the magnetic field through a closed line is zero.

Question 3. Through each of the two "infinite" threads flows an intensity of current of I ampere. These threads are perpendicular to the paper plane, and in one the current is outward whereas in the other it is inward. Trajectory (1) is circular, moves anti-clockwise and it contains two threads.

A student, using trajectory (1), applies Ampere's law and concludes that the circulation of the fields being nil, therefore that the field B is also nil at all points of the trajectory (1). Do you agree with this student?

Justify your answers



The student must use meta-cognitive skills to justify their agreement or disagreement with the explanation presented in the question. In this question, the correct interpretation of Ampere's law would lead one to reject the argument offered. The students' answers are shown in Table 3.

Answer Category	Percentage of Answers (N=65)
Category A: $\Gamma = 0$ does not imply that $B = 0$	18
Category B: $\Gamma = 0$ implies that $B = 0$	57
Impossible to categorize	13
No answer	12

Table 3. Percentages of answers by students to question 3

Most of students' explanations of the category B still a sequence as following one:

"If we apply Ampere's law:

$$0 = \oint \vec{B} \cdot d\vec{l} = B \oint dl \Rightarrow B = 0,$$

then I believe the student is right."

In this category it seems that students do not distinguish significantly between the circulation operator and the field itself and establish a proportionality between the two. This form of reasoning seems to respond to a strategy commonly used in class but which has a very specific field of validity (**B** constant in the amperian line). However, the students apply it in a general manner, that is, it happens a kind of wrong reasoning that it is named 'functional fixedness' based on formula [6]

There is a minority of students in category B (about a quarter of them) that use another variant of reasoning this includes those answers which explain that, because the circulation is nil, the resultant intensity of currents enclosed is zero and therefore the field will be zero. This is coherent with the wrong idea that only internal currents on the Ampere's line produce a magnetic field on the points of the line. In this case, it seems as if the students are simplifying a situation which requires complex arguments based on constructing simple inferences such as "a cause produces an effect" in the form of a linear chain, using Ampere's law as a link. This kind of wrong reasoning is named in the bibliography 'functional reduction' [7].

Conclusions

In the theoretical corpus of physics there is a clear distinction between the field operators that provide information about the field and the field itself. However, the results obtained, in this study, seem to demonstrate that, after training, most of the students use wrong forms of reasoning such as the following:

A. Functional fixedness based on operative definitions: Explanations that implicitly consider that the field is constant in any situation in which Ampere's laws is applied.

B. Functional reductions based on the construction of simple views of complex phenomena:

B.1. When the circulation was zero, it was deduced that the field value is zero in the Amperian path.

B.2. The only sources of the field are those enclosed by the Amperian path.

C. Production of an 'ad hoc' explanation for each case. The process of reasoning does not search for the generality or the systematic approach which is common in the scientific way and which impose more strict and rigorous conditions.

The deficiencies detected in reasoning, lead us to think that it will be necessary to introduce modifications in usual physics education. It seems evident that appropriate teaching should not only include sequencing and clarification of the concepts involved within the theoretical framework, but it should also include procedural and ontological aspects to which reference should be made. In other words, it cannot be expected that the students will learn the conceptual contents if some procedural and ontological aspects, such as the following, are not taken into account:

- It is necessary that the students are familiarized with the model of field lines and with the concepts that can provide some information about it, such as the field circulation, before presenting Ampere's laws in an operative way.
- The students must know what the problems are that justify the introduction of new concepts.
- The design and production of teaching materials that put into action the points mentioned above are the main objectives of our next research work.

References

[1] NATIONAL RESEARCH COUNCIL (1996). *National Science Education Standards*. Washington. D.C: National Academy Press

[2] LAWSON, A. (1994). Uso de los ciclos de aprendizaje para la enseñanza de destrezas de razonamiento científico y de sistemas conceptuales. *Enseñanza de las Ciencias*, 12 (2), 165-187

[3] PINTÓ, R., ALIBERAS, J., y GÓMEZ, R. (1996). Tres enfoques de la investigación sobre concepciones alternativas. *Enseñanza de las Ciencias*, 14, 221-232.

[4] TÖRNKVIST, S.; PETTERSON, K.A. and TRANSTRÖMER, G. (1993). Confusion by representation: On student's comprehension of the electric field concept". *American Journal of Physics*, 61(4),335-338

[5] GUIASOLA, J.; ALMUDÍ, J.M. and ZUBIMENDI J.L., (2004). Difficulties in learning the introductory magnetic field theory in the first years of university. Students'. *Science Education* 88(3), 443-464

[6] ANDERSON, J.R. (1990). *Cognitive Psychology and its implications*. W.H. Freeman and company. New York.

[7] VIENNOT, L., 1996. *Raisonnement en physique. La part du sens commun*, (De Boeck Université Paris). Translated to English in Kluwer Academic Publishers.