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How to Increase High School Students' Motivation to Learn Magnetic Phenomena

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Abstract: Electromagnetism is considered one of the most complex topics of physics. High school students face significant difficulties trying to get familiar with magnetic and electric phenomena. If the laws of electricity and magnetism and their theories are unclear to students, these phenomena become even more challenging to understand. In these situations, students usually start memorizing concepts without understanding them. One of the main reasons is that students are not paying attention to the fundamental operations, meaning students do not participate enough in inter-curricular activities to practice. Another reason that intensifies the difficulties that students face is time pressure. Limited time to learn and practice will most likely cause a decrease in the ability of students to store this knowledge and use it in the long run. This paper aims to present the development of instructional tools that make the process of learning effective, addressing the questions: How to increase the motivation of students to learn magnetism? How students delve into the topics of magnetism through learning by doing?

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1. Introduction

The concept of field plays an essential role in understanding electromagnetic interaction. This concept is undoubtedly the basis on which high school students will structure knowledge in electromagnetism, so it must be thoroughly understood. Students encounter many difficulties in familiarizing themselves with electromagnetic phenomena. It is expected that ordinary thinking will not work during their treatment, given that it is an abstract and quite advanced concept [1, 2]. The impossibility of visualizing the field with the naked eye makes it difficult for teachers to explain the topics of electromagnetism. During the last decades, well-known physicists have engaged in numerous researches aimed at investigating the sources of difficulties students encounter in understanding magnetic phenomena at all levels, from high school to university [3-5].

The knowledge gaps and misconceptions created because of low level of thinking skills such as memorization, are widely considered the origin of learning difficulties [6]. When learning about electromagnetism, students often memorize a bunch of unrelated formulas or derivations and apply them to exams without understanding whether they are applicable in that context.

A critical source of knowledge gaps is the inconsistency between the level of students' progress and the material they are presented with. From the pedagogical point of view, textbooks are evaluated as a fundamental didactic element for students to successfully acquire scientific knowledge, according to the class and cycle where they learn. However, the knowledge in the texts is often fragmented and separated and does not perceive a unity of the subject. Undoubtedly, behind the text is also the teacher, his ability, scientific and methodical interpretation to successfully explain to the students the new teaching material dictated in the text. Furthermore, for this vital mission to be carried out productively, it depends on the techniques and methods the teacher uses during the teaching process. The tendency to adapt to the new teaching approach based on phenomena has focused on the technical treatment of knowledge, where they occupy a larger space in the content, neglecting the conceptual deepening [7].

Misconceptions that influence the entire learning process in magnetism are predominantly created as the study of electromagnetic phenomena go against common intuition. The contactless interactions are surprising to most of students. Moreover, magnetism is intertwined with electricity in a way that few students fully understand, if at all. Unlike mechanics, where students' intuitions, although often inaccurate, can be improved with instruction, in magnetism, serious difficulties are encountered even after instruction. In electromagnetism, students cannot directly observe what they study; they must do experiments and demonstrations to reason about physical quantities and phenomena [8].

Students often confuse the concept of a field with that of force, thinking of the field as the force it exerts on the load. Furthermore, students do not have a fair and logical understanding of the interactions between objects [9].

All of what is above described, and other reasons make high school students give up in the first lessons of magnetism. Encountering these difficulties since at the beginning of the magnetic field treatment, it is doubtful that the students will understand the most advanced concepts and phenomena, such as the Lorentz force or the phenomenon of electromagnetic induction. For the learning process to be effective, students must be in contact with the real world [10].

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The goal of this paper is to present some of the instructional tools that support high school students to delve into the topics of magnetism through learning by doing These activities aim increasing the motivation of students to learn magnetism, coming to the lesson with ideas, questions, and curiosity about the phenomena they have observed.

2. Magnetic field concepts in high school textbooks

Even physics textbooks play an important role in learning process, however there is often little or no attention to magnetic field concepts. Definitions of fields are usually given as facts, while for students is required to understand fields as physical realities that exist regardless of their interactions [11]. The content of the textbooks is insufficient for a deep treatment of the basic concepts in the fields with more informative material. Sometimes, the texts also contain conceptual errors or inaccurate field definitions. A descriptive analysis of the physics textbooks in use in the pre-university system in Albania is realized. Magnetic field is taught at the 11th and 12th grades of high school. The data for the texts were taken separately from the catalogues of the texts approved by the Ministry of Education. For example, a textbook on the definition of the magnetic field is written: " The magnetic field is called the space around the magnet, where its action on magnetic materials is felt". One of the biggest misconceptions students have about the magnetic field is seeing it as the space around a magnet or area within it actshard. An accurate definition of magnetic field and interaction cannot be established with such a conceptually flawed definition to the students. It is challenging to change students' distorted concepts that result from such definitions.

As one of the four fundamental interactions in nature, electromagnetic interaction exists and acts regardless of whether we observe it or not. It is responsible for all electromagnetic processes and the most common observed phenomena such as elasticity, normal force, friction, and molecular interaction. Electromagnetic interaction manifest itself as a long-range force that acts between the electrically charged particles through the electromagnetic fields. Electromagnetic fields have physical properties that produce the interactions.

To properly define the magnetic field, just as magnetic and electric fields, the field properties and the action at a distance it will exerts must be establish with students: The existence of a moving electric charge modifies the properties of the surrounding space. The space is modified, for example to a point where a second moving electric charge is located, in such a way that they feel a magnetic force acting at a distance due to the new properties of the space in which they are located.

Two 11th grade textbooks were analysed to find the ratio between the topics belonging the principles and conceptual treatments of the fields to their technical and practical application. Table 1 shows the results where the chapter "Magnetic phenomena" and "Electromagnetic induction" were examined in both textbooks.

It is noted that the 11th-grade textbooks used by students occupy more space on topics that deal with practical knowledge, such as electric motors, transformers, electromotive, etc. At the same time, concepts, phenomena, and physical laws are treated from a poor theoretical perspective in very few hours.

Table 1. Topics that belongs to the magnetic phenomena and electromagnetic induction for 11th grade Physics textbooks.

Physics 11 (Textbook 1)	**Hours**	**Percentage**	**Physics 11 (Textbook 2)**	**Hours**	**Percentage**
Magnetic phenomena					
Topics belonging to the conceptual treatments of the field	2	33.3%	Topics belonging to the conceptual treatments of the field	2	40%
Practical topics on circuits, motors, electromagnets	4	66.6%	Practical topics on circuits, motors, electromagnets	3	60%
TOTAL	6	100%	TOTAL	5	100%
Electromagnetic induction					
Topics belonging to the conceptual treatments of the field	2	33.3%	Topics belonging to the conceptual treatments of the field	1	33.3%
Practical topics on circuits, devices, transformers, generators	4	66.6%	Practical topics on circuits, devices, transformers, generators	2	66.6%
TOTAL	6	100%	TOTAL	3	100%

Physics 12 textbook belongs to the elective curriculum and it is selected only by those students who generally plan to pursue higher studies in natural sciences, medicine, and engineering. It begins with mechanics and ends with nuclear physics and although it contains physical laws and concepts treated in a deeper and expanded form, it causes a situation of a compressed material hard challenging to assimilate.

3. Instructional tools to increase student motivation to learn magnetism

Phenomena such as that observed during Oersted's experiment, of the deflection of a magnetic needle of a compass near a current-carrying conductor, remain insignificant in the memory of students because either the experiment is described in words and sketches or, at most, a quick classroom demonstration. As an example, in Oersted's experiment, when observing the displacement of the magnetic needle, the students are asked: Does the needle act on the conductor by trying to displace it? Let us not be surprised by their answers. It is hard to find a student who can answer correctly. A current-carrying wire give rise to a magnetic field around it which applies a force on a magnetic needle, trying to rotate it perpendicular to the wire. From the other side, a magnetic needle give rise to a magnetic field which applies a force on a current wire trying to displace it. So, there is also a force on the compass needle due to the wire and a reaction force on the wire due to the compass needle. Since compass needle is a tiny magnet with very low inertia, it is easily to observe its motion. Otherwise, due to the higher inertia of the wire, in the presence of the friction force, the magnetic force is small to cause an observable effect of wire displacement. Nevertheless, the students find it difficult to believe even though this can be described to them.

Among the leading causes of these misconceptions, Arons [12] lists: 1) No attention is paid to the fundamental operational bases causing students to not engage in interactive activities. 2) They are not given the necessary time to form a concrete experience sufficient for the phenomena to remain in memory. The description of magnetic phenomena by using words, pictures and demonstrations is not enough. Students need to touch the phenomenon themselves. To overcome the difficulties and achieve learning with understanding of the concepts and principles in magnetism, it is necessary to cultivate the experience by being involved in activities that require scientific thinking [13,14].

3.1 Pre-preparation

A class of 30 students is divided into 6 equal groups, each with 5 members. The proposed activities are 6: two Oersted’s experiments, building an electromagnet, Faraday's experiment, Faraday motor and demonstration of Lenz’law. It should be explained to the students from the beginning that these are not real experiments but only demonstrations that they can do themselves at any time to observe the phenomenon and be able to raise questions and, if possible, hypotheses. These activities support students to familiarise themselves with the direct observation of the magnetic field interactions.

Before reaching the magnetism chapter, students are advised to find the materials, such as magnetic needles, copper wires, batteries (6-9V), galvanometer, magnets of different shapes, iron nails, paper tubes and aluminium ring. After being given the necessary instructions, they are asked to conduct 6 activities independently in individual groups. At the end of the activities, students should be able to ask questions and raise hypotheses about what they have observed while performing experiments. At the beginning of the chapter of magnetism, students will demonstrate conducting experiments in the classroom under the teacher's supervision and exchange their experience with other groups.

3.2 Proposed activities

Activity 1: Oersted's experiment. Students only need a magnetic needle and a simple circuit to perform Oersted's experiment (Figure 1). A steady current through the wire is supplied by a battery up to 9V. A magnetic needle is set at different points around the circuit and under the wire. It is suggested students to change the poles of the battery and to observe what happens to the magnetic needle. Students are not expected to explain why the magnetic needle is deflected but to observe the perpendicular direction of this deflection and become curious why the phenomenon occurs in this way.

With personal experience provided, they will be much more attentive and careful when the concepts and principles will be elaborated during the lesson. The deflection of the needle will be used to define the idea of magnetic field produced by moving charges [11]. When performing Oersted's experiment, students observe the interaction of magnetic needle with a current currying wire and realize that controlled motion of charged particles creates a magnetic field.

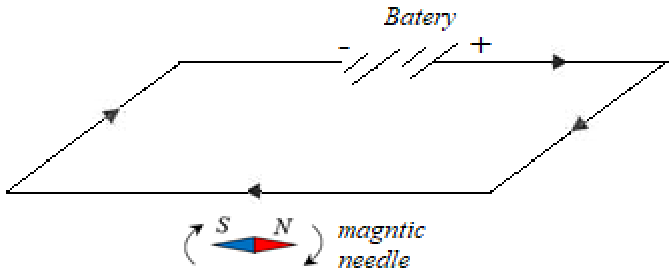

Figure 1. Deflection of the magnetic needle as the result of magnetic field creates by current wire.

Activity 2: Current loops. For this activity, students are first asked to build the circuit shown in the Figure 2. The circuit contain a battery and an electric lamp, a long flexible conducting wire folded and willing in the form shown and magnetic needles [12] completing a conducting loop from the positive to the negative terminal. The wire has negligible resistance to the current. The lamp is used as an indicator to show the current is flowing. Also, without bulb a large amount of current flows through the terminals and thus a large amount of heat causing an increase of temperature.

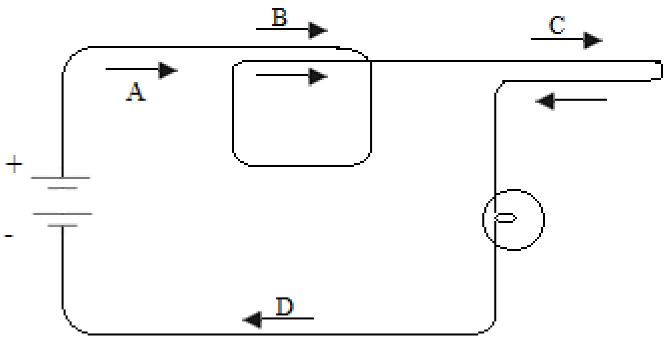

Figure 2. Oersted experiment - comparison of the deflection of a magnetic needle in different positions A, B and C. From “A guide to Introductory Physics Teaching” by A. Arons Copyright 1990 John Wiley and Sons. Inc, pg 241, [12]).

After completing the circuit, the students are asked to place the magnetic needles at different locations A, B C and D as showed in figure 2. In the positions A and D there is a single wire that carrying the same current. Otherwise, in positions B and C there are two wires carrying the same current but in same (B) and opposite directions (C).

Students must record the direction of magnetic needle deflection at all points outside and inside the loops and different observed effects of currying-current wires. Even in this case, it is not expected that students are able to explain why the effects are different but only to observe these effects and record the direction of the magnetic needle deflections. The results will be used as qualitative understanding of the magnetic field of a loop via superposition principle. This activity aims that students will better understand that superposition is dominated by nearest current wire segment [11, 12].

Activity 3: Building an electromagnet. To build an electromagnet, students need simple materials: battery, copper wire, a big iron nail and several small nails. All elements have magnetic properties, but most of them do not show them in an apparent way. Iron nails are used because their strong magnetic properties, unlike what happens to the aluminium nails where ordinary magnets have no effect. Knowledge in the future lessons on what is going in the atomic level will enhance the understanding of the differences between the magnetic properties of materials.

Students are instructed to create an electromagnet by wrapping a copper wire around an iron nail and running the current through the circuit as shown in Figure 3. Students observe that the big nail attracts the small iron nails. They can also change the battery and record the changes. What the students know is that small nails are attracted by a magnet. What the students observe is that the same effect is created due to the current through the wire. Even here, no matter how simple the experiment may seem, it is not expected that students are able to understand the magnetic field created around the nail.

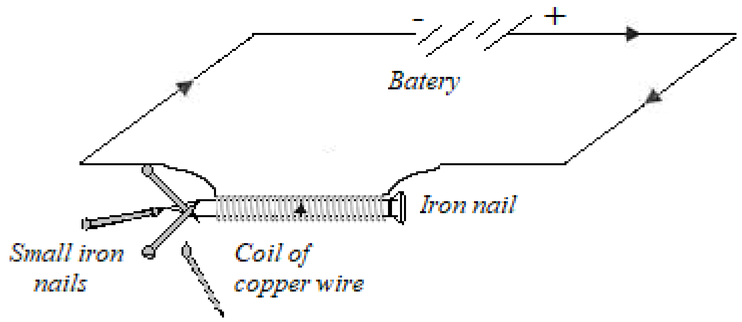

Figure 3. Building an electromagnet.

Just like in all other activities performing by students, they are asked to keep a record of what will be observed, and about variables being involved that impact the strength of an electromagnet. Beside developing motor skills, this demonstration will be used to show the equivalence of magnetic field generated by a solenoid to that of a permanent bar magnet. It is an important demonstration where students can discover by themselves that electric field in the wire coils create a magnetic field.

Activity 4: Faraday's motor. Faraday's motor will be a simple but very funny experiment for students. Students need a battery, a neodymium disc magnet, and copper wire to perform this experiment. During the experiment, the students observe that copper wire rotates, and they wonder how and why it happens. They are asked to keep a record of their observations; the variables being involved that influence the effectivity of the motor. Thus, with this simple experiment they will become curious to figure out what is happening, how the electromagnetism turns into motion. Faraday's motor principle will be used as a motivation to introduce the idea of a magnetic force acting on a current wire.

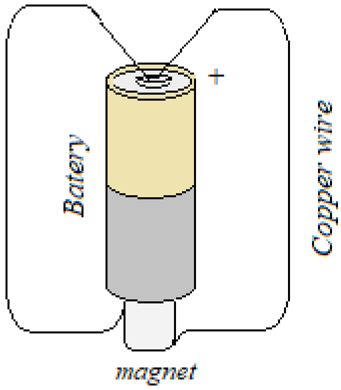

Figure 4. Faraday's polar motor. From https://javalab.org/en/homopolar_motor.

Activity 5: Faraday's experiment. During this activity, students will demonstrate Faraday's experiment. To perform this experiment, students need a bar magnet, copper wire, galvanometer, and a paper tube (Figure 5). Students are given instructions trying to push the bar magnet faster or slower near (or pulled away from) the coils and record what they observe. At the end of the activity, the students record the observations and address the questions: What happens when a powerful magnet is passed through the coils faster or slower? Will the galvanometer needle deflect back and forth when the bar magnet is held stationary? What happens reversing the motion? Is the same effect produced when moving ether magnet or the coils? Is there any relationship between changing magnetic field through the coils and produced current? What happens when the area of the loop changes?

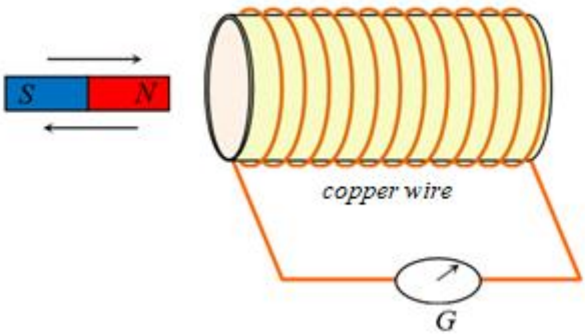

Figure 5. Faraday's experiment.

Even in this case, it is not expected that students are able to explain how and why the galvanometer deflects back and forth but to observe that a current is generated without the presence of a battery and become curious why this beautiful phenomena occurs. Students need practice and time to explore by themselves the experimental evidences that changing magnetic fields does produce a current, before introducing the ideas of flux, induced current/motional emf and induced electric field [11,12]. Most teachers are aware that their students think that the induced field opposes the applied field rather than the change in the applied field [11]. Knight

(2004) [11] argued that this error comes from lack of qualitative reasoning rather than from any fundamental misconception about the nature of magnetic induction. He suggests that an early introduction of Lenz's law about the direction of the *emf* allows a cleaner statement of Faraday's law about the magnitude of induced electromotive force (*emf*.). He criticises the treatment of Lenz's law as an adjunct to Faraday's law. Lenz's law is essentially a law of conservation of energy. Also, discussions about the connection of Faraday's law, Lenz's law, and the law of conservation of energy would be of great interest because magnetic field itself is incapable of performing the work. Wood et al (2004) [15] have presented an experiment that demonstrates qualitatively and quantitatively several aspects of Faraday's law of electromagnetic induction and Lenz's law, while also verifying conservation of energy.

Activity 6. Demonstration of Lentz law. Introduction of Lenz's law as a new law of nature is demonstrated with an aluminium ring suspended by a long string and a magnet.

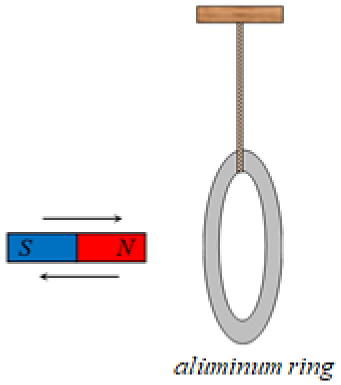

Figure 6. Demonstration of Lentz' law.

Students are instructed to observe and record what happens when the magnet moves quickly towards or away from the ring, what happens when magnetic poles has reversed. Unlike the previous, this experiment requires stronger magnets or quickly movements to perform satisfactorily. Students know aluminium is a non-magnetic material, so the forces that cause the hanging ring to change state remain a puzzle until the future lessons in magnetism.

Conclusions

Through the proposed activities, students develop the experience they lack in magnetism. They touch magnetic phenomena closely so that their background is not just mathematics or rote formulas for them but more. Theoretical analysis will be based on their observations of the electromagnetic interactions.

These activities, which are not too difficult to carry out, support active learning by enabling students to practice independently, develop cognitive skills and critical thinking, and interact with the physical world. Suggestion is that students manage to carry out the experiments themselves long before the magnetism chapter begins. In that case, they begin with new topics that will be approached with intelligent questions and curiosity to understand how things work. In order to get the answers to the questions of how and why they happen, students must first see the phenomena themselves, have the necessary time to observe, and reflect, and only after that move to the next stage of explaining why they happen. Claiming that students understand electromagnetism based on theoretical treatment with only sketches on the board or a quick demonstration it is far from understanding how students learn.

Spending time to the experimentation in these activities for students is useful to develop the motor skills, the ability to predict and analyse the observation results, to explain the variables introduced and their impact. In this way, students are put in contact with the physical world and the conditions for the students to grow in motivation and love for science are created, without which no field of physics can progress and much less electromagnetism.

In this work we only suggest a development of instructional tools bringing about an effective process of the high-school students learning concerned with electomagnetic phenomena. Identifying and analysing the ideas, answers, mistakes, omissions, failures, as well as the success of high-school students developed by using proposed activities before being taught about the electromagnetic phenomena require further research.

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