



## **Magnetism and Gravity: Mental representations of students 15-17 years old from a historical and teaching perspective**

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### **ABSTRACT**

In the present paper we will study the mental representations of students aged 15-17 concerning action at a distance based on the manner of transfer of the magnetic force as well as the relation between magnetism and gravity. The research was carried out using structured interviews with a total of 40 students from the 10th and 11th grades. We will also attempt to study whether the students' representations show an analogical reasoning with typical historical models of the Sciences and whether there exist differences related to conventional school teaching. The results indicated points where students' representations appear to approach basic elements of historical models of the Sciences.

### **Indexing terms/Keywords**

Students' Representations, Magnetism, Gravity, History of Physics, Action at a distance, analogical reasoning

### **Academic Discipline And Sub-Disciplines**

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## INTRODUCTION AND THEORETICAL FRAMEWORK

Research for the recording of students' representations on concepts and phenomena of the Natural Sciences has yielded the past decades a wide range of findings, based on which we attempt to comprehend and handle the difficulties faced with children's thinking (Tsatsaroni, Ravanis & Falaga, 2003; Koliopoulos, Tantaros, Papandreou & Ravanis, 2004; Ravanis, Koliopoulos & Boilevin, 2008).

From this perspective, the study of the historical evolution of concepts in the Natural Sciences sheds light on the difficulties of human thinking, as resemblances between models formulated and used during the historical evolution of scientific knowledge and the children's mental representations frequently appear. Therefore, not only does it facilitate the comprehension of children's difficulties (Matthews, 1992; Dedes, 2005; Fauque, 2007; Kampourakis & Zogza, 2007), but it also helps the construction of teaching tools that allow the exceeding of the students' representations, help in the comprehension of 'relativity' of scientific knowledge and excite the interest about the 'creation' of science (Leite, 2002; Clough, 2011).

In this direction, a significant number of researches that record the students' representations has been conducted, in some of which they are compared to the models of concepts that were introduced during the natural evolution of Physics (Halloun & Hestenes, 1985; Sequeira & Leite, 1991; Bar & Zinn, 1998; Voutsina & Ravanis, 2011). In this type of researches, there appears, in a larger or a smaller scale, a remarkable resemblance between the students' representations and the models of scientists in the past, a fact that highlights the interest in the use of history of the Natural Sciences in teaching. The research presented here moves close to this prospect.

### **The historical evolution of interpretive schemata for the relation of magnetism and gravity and the transfer of magnetic force**

During the historical evolution of interpretive schemata for magnetism there was a period when a relation of magnetism and gravity appeared. This period is the beginning of the 17th century, when the philosophical movement of "physiocracy of the Renaissance" is prevalent. A key figure of this movement is Gilbert. In his book "De Magnete" (1600) he concludes that Earth is a large magnet with magnetic polarities that coincide with the geographical poles. Within these bounds, the force of magnetic attraction is considered as the cause of gravity. The force of attraction is always proportional to the quantity or the mass of the body that exerts it; the larger the mass of the magnetite the bigger the attraction it exerts on the objects. Gilbert has influenced notable scientists like Bacon, Kepler and Boyle. The latter in particular thought that gravity might be caused by Earth's "magnetic steams".

As Crombie (1959) reports, the concept of analogy between gravity and magnetism appears earlier as well, among some writers of the Middle Ages. It is Gilbert, though, that utilizes and "substantiates" that particular idea.

The concept of "action at a distance", namely the action of forces without the existence of a certain means, did not become the prevalent scientific "example" in the history of the Sciences immediately. During late antiquity and the Middle Ages, the prevalent view that was influenced by Aristotle, rejected action at a distance, hence the the transfer of the magnetic force (which we will treat here) without the existence of a means. Nevertheless, there were some exceptions that regarded that the magnetite acts at a distance and without the existence of a means, as William of Ockham and Baconthorpe report.

This tendency continues throughout the 17th century. Descartes rejected action at a distance and considered mechanical contact as the only cause of a body's deviation from its movement's course. Leibniz also rejected the vacuum and action at a distance. Physicists, starting with Gilbert and his "magnetic steams", invent ether, namely a material substance that "fills" the vacuum. Therefore, their reasonings recognized an intermediate element that was capable of transmitting all known effects, like gravity, magnetism and light. Newton formulated a claim, according to which there is an ethereal means with a composition much akin to that of air's, but much looser, thinner and more flexible. There are different opinions though, such as Gassendi's, which suggest that there are vacuums, spaces empty of all matter.

During the 18th century the concept of ether wasn't of much interest. However, during the 19th century it was once again in the limelight as an offset of ever-increasing importance to the insufficiencies of a mechanics that exclusively relied upon the forces that were related to movement and the collision of individual bodies. That is when systematic efforts to trace ether started. Those researches recognized ether as a means for the transfer of drawing and not repellent forces, but also as a concept that could be mathematized within the bounds of the conservation of energy. According to Young, ether is luminophorous, thin, flexible to a large extent and it imbues the universe. Faraday rejects action at a distance, rejects the "atoms-vacuum" diptych as a model of reality. Maxwell had no doubts that interplanetary and interstellar spaces are not empty. He believed that they are occupied by a material substance or a body that is definitely the biggest and maybe the most integral body we know.



In the beginning of the 20th century, Einstein with his relativity theory rejected and abandoned ether, since every attempt to trace it ended in failure and it had to have the exact same imaginary properties that rendered its effects untraceable. Einstein correctly comprehended that the only need ether served was mental and not physical, thus he turned to the search of relationships between the laws of the models that he formulated and not to a hypothesis based on an imaginary entity that would have to exist in nature, even if it was impossible to trace or have its existence proved, even mathematically. As a result, the need for existence of a means for the transfer of all actions disappeared, and so did space, which it had ended up embodying (Butterfield, 1949; Crombie 1959; Gillespie, 1960; Mas, Perez & Harris, 1987; Westfall, 1997; Rossi, 1997).

### **Student's mental representations for the relation of magnetism and gravity and the transfer of magnetic force**

Research concerning magnets and magnetism, conducted by Barrow (1987) on elementary school students of various ages, has shown that before being taught, most of the students gave no explanation of magnetism. After them being taught, there was mention of a kind of gravity, energy, electrodes and protons.

Research conducted by Borges and Gilbert (1998) that showed the representations of 15-18 year old students, technicians and teachers on electrical current, magnetism and the relationship between electricity and magnetism, among other representations schemata on magnetism, one of them shows up as magnetism as a cloud. Namely, it is recognized that there is an atmosphere, a "sphere of influence" around the magnet, responsible for the actions on the bodies that enter its domain. This representation seems to originate from the identification of magnetic action and gravitational action according to which magnetic phenomena are interpreted as an inherent property of the magnet.

In a study carried out by Seroglou, Koumaras and Tselfes (1998) involving 10- to 15-year-old pupils and students of university education departments, and investigating whether their representations showed the existence of a relationship between electrostatic and magnetic phenomena, about half the university students and the majority of the pupils associated electrostatic attraction with magnetic attraction. Their explanations showed that they made this association because of the pull they observed in both phenomena. A certain percentage of the pupils also associated these two phenomena to gravitational pull. In their research of 9- to 18-year-old pupils' representations of action at a distance in terms of magnetism, Bar, Zinn and Rubin (1997) found that many pupils believed that air had to be present as a means for the transportation of the magnetic force. Among the 9-year-old pupils, this belief was shared by 80%, evening out at 35% in the case of the older pupils (Barrow, 1987; Borges & Gilbert, 1998; Bar, Zinn & Rubin, 1997).

In research aimed at recording the representations of 15-17 year old students on magnetism and their possible connection to interpretive models that were historically introduced for the interpretation of magnetism, the representations for the cause of the creation of magnetic properties, the concept of the magnetic field and the relationship between magnetism and electricity were investigated (Voutsina & Ravanis, 2011). The results showed that less than half of the students could reason within the framework of a structured model of approach of magnetic phenomena and not always towards the "right" direction. We also observed a relative resemblance between the children's representations and some of the historical models on magnetism, without them being completely identified, since some of the children's representations didn't refer to models out of Science history, while some of the historical models weren't found in the representations of students participating in this specific research.

Finally, in two more recent researches about the comprehension of fundamental qualities of the magnetic field by 14-15 year old students, the results showed that children do not regard the field as a space of interactions, but as an area of unilateral exercise of forces, from magnets to iron objects, have great difficulty in recognizing the cause of permanent magnetization in metal materials and only 1 out of 3 children accept the exercise of magnetic forces in the vacuum (Ravanis, Pantidos & Vitoratos, 2009, 2010).

In this paper we will study the representations of 15-17 year old students on action at a distance based on the manner of transfer of magnetic force and on the possible relationship between magnetism and gravity. At the same time, we will attempt to study the possible relationship between those representations and the interpretive models that were introduced historically on the issues above, as well as study the evolution of the students' representations through conventional teaching.

## **METHODOLOGICAL FRAMEWORK**

### **Subjects**

The research was conducted on a total of forty students (21 girls and 19 boys). Twenty out of forty were in 10th grade (15-16 years) and twenty in 11th grade (16-17 years). All forty students were taught in class about the fundamental concepts of magnetism. Furthermore, the 11th grade students were extensively taught about electromagnetism as well. Regarding





action at a distance, the students came in touch with that concept mainly through the concepts of free-fall and gravity in the 8th and 10th grade.

### The research material

The study was carried out using structured interviews. The questions were designed based on historical models of magnetism and the earlier research concerning students' representations. The study aimed at answering the following questions;

1. What are the children's representations;

- On the concept of action at a distance, namely the need or the absence of the need of a means to transfer magnetic force
- On the relationship of magnetism with gravity.

2. Do any analogies exist between the students' representations and the corresponding representations formulated by scientists of the past?

3. Are there any differences between the representations of 10th and 11th graders?

### The interview

We first presented the students with two rod-shaped magnets, steel needles, a silver ring, a wooden and a plastic object, a magnetic compass and string with which to suspend one of the two magnets. The students were encouraged to examine all these objects. We then asked them questions 1, 2 and 3 (Appendix), thus creating a context for discussion within which we attempted to record the students' representations of magnetic properties.

Question 4 regarded the magnetic compass. After a demonstration of its function, it was used to incite the student's interest, thus helping the formulation of their representations. The students gave some very interesting answers to this question, connection magnetism to gravity, as we will see in the results' analysis.

Question 5 was an open question on the manner of transportation of magnetic force and specifically on the need for a means to exist, or not.

Question 6 was a multiple choice question, regarding the description of an experimental alteration of Earth's environment. The students were required to consider what would happen if we removed the air.

Question 7 regarded the environment of a spaceship, where there existed air, but no gravity. This question was used to ascertain whether the students think that there is a relationship between magnetism and gravity, and specifically if there can be magnetic force without gravity.

## RESULTS

Based on the analysis of the results, the following representations were recorded:

### Representations of the need of existence of a means (or air) for the transfer of magnetic force (questions 5 and 6)

In question 5 we observed an equal distribution of student's representations concerning the need of existence of a means for the transfer of magnetic force. To be exact, around half of the students ( $n=21$ ) didn't deem the existence of a means for the transfer of magnetic force necessary. Eight of them were 10th graders and thirteen of them were 11th graders. Twelve 10th graders and seven 11th graders thought that air is necessary as a means to transfer magnetic force from magnet to body.

In some of the second category students' representations, air appears to be a key element to the creation of a magnetic field or the transfer of magnetic forces through magnetic field lines, as the following interview excerpts show;

R: What happens if the air goes away?

S36: If the air goes away, won't the magnetic field fall apart?

R: So will it pull or will it not, without air?

S36: No, because if there is air, the magnetic field will be repaired and it will pull.



R: How is magnetic force transferred to the body?

S27: Through magnetic field lines... If there isn't any air.. that makes it difficult for the magnet... it makes it difficult for the field lines to pull the object.

R: You mean there must be air, in order for magnetic field lines to be created?

S27: No, the magnetic field lines are created by the magnet. It's just... When the air's there it's easier for them to be transferred to the other body.

R: What happens when we have a vacuum, though?

S27: The magnetic field lines can't be transferred to another body in another way.

Furthermore, in some of the other representations, the existence of a stable material means between the magnet and the body seems to obstruct the transfer of magnetic force, as we can see in the following:

R: How is magnetic force transferred? Do we need to have anything between the magnet and the needle?

S39: We need air.

R: Is air necessary?

S39: Yes, because if there's an iron here and a wood over here in the middle and another magnet, it can't pull it.

**Table 1: Existence of a means for the transfer of magnetic force**

Q. 5: 'Means' for the transfer of magnetic force?	Q. 6: Magnet without air	Grade 10		Grade 11	
		Subjects	f	Subjects	f
A. No means required	Air doesn't affect the magnet	1,4,9,10,12,14,19,20	8	22,23,24,25,29,30,31,32,34,35,37,38,40	13
B. Air is needed as a means	Force is reduced	7,16	2	21	1
	It needs air to act	5,6,8,13,15	5	28,36	2
	Necessary for the transfer of magnetic force	2,3,11, 17,18	5	26,27,33,39	4

In question 6 we had similar results. We were presented with three representation categories concerning the need of existence of air for the transfer of magnetic force.

The first category includes the answers where the existence of air, or its absence, doesn't affect the transfer of magnetic force. It comprises around half the students that participated in the research (f=21, 8 10th graders and 13 11th graders).

The second category includes the answers where the existence of air is deemed necessary for the transfer of magnetic force. It comprises 16 students who answered either that the magnet needs air in order to act, or that air is necessary for the transfer of magnetic force (10 10th graders and 6 11th graders).

The third category includes the answers where it is recognized that the absence of air reduces the magnet's force. It comprises the rest of the students that participated in the research (2 10th graders and 1 11th grader).

We observed a self-consistency and a stability in the children's representations, since the students of the last two categories of Question 6 are the same students that deemed the existence of air as a means for the transfer of magnetic force necessary in Question 5.

### Representations of the possible connection between magnetism and gravity (questions 4 and 7)

An interesting result that came to light after the analysis of the children's representations, specifically from the answers in Question 4, concerning the behavior of the magnetic compass, is the following: the connection of gravity with magnetism, not just regarding whether gravity is deemed necessary for the existence of magnetism, (Question 7), but also regarding the deeper correlation between the two phenomena. This correlation was found in the representations of two 10th graders. The first student thought that there is a correspondence between the causes of gravity and magnetism and more specifically, she thought that the gravitational field exists because of Earth's magnetic forces.

S2: ...essentially the center of the Earth is a magnet that pulls us and the materials inside the magnet, their arrangement, creates this attraction that pulls inwards.

R: Now you've mentioned the center of the Earth, what do you mean by that?

S2: When we're pulled, there's the magnetic force... um... it is attributed to the center of the Earth where, from what I've read, there are some materials that pull us and that's why gravity exists.

R: What kind of materials?

S2: Magnetic materials.



R: Do you mean that we associate gravity with the magnetic forces that exist in the center of the Earth?

S2: Yes.

The second student thought that there is an interaction between magnets and Earth's gravitational field, since the magnetic needle is pulled to where the gravitational field is strongest.

R: Why does the compass point to the geographical north?

S5: It has a magnet in it, right?

R: Yes it has the magnetic needle. What is pulling it to that specific direction?

S5: Maybe because the Earth isn't round. It's wider along the equator.

R: Wider along the equator?

S5: Yes, the north and south poles are more compressed and closer to the Earth's core. Maybe that's why... they're closer to the center and we have stronger forces exercised on the needle.

R: Do you mean that the powers exercised on the magnetic needle have something to do with the mass and the shape of the Earth?

S5: Yes.

R: Do you mean that they are affected from the gravitational pull?

S5: Yes.

**Table 2: Relation between magnetism and gravity**

Q. 7: Magnet without gravity	Grade 10		Grade 11	
	Subjects	f	Subjects	f
Gravity doesn't affect	1,3,4,6,7,9, 10,11,14,15,17,18,20	13	22,23,26,27, 28,29,30,31, 32,33,34,35,36,37,38,40	16
Doesn't work without gravity	2,5,8,12,19	5	21,39	2
Only in Earth because of magnetic poles	13,16	2	24,25	2

The analysis of the results of Question 7 has spawned three representation categories concerning the possible effect of gravity on magnetic force.

In the first category, gravity doesn't affect the action of the magnetic force. It includes the majority of the students (f=29) that answered that the magnet works even if there is no gravity (13 10th graders and 16 11th graders).

In the second category, gravity is deemed necessary for the action of the magnetic force. It includes representations of one out of about five students (f=7) that answered that the magnet doesn't work because there is no gravity (5 10th graders and 2 11th graders).

In the third category, the action of the magnetic force is recognized to be affected by the Earth's magnetic poles. It includes representations of one out of ten students (f=4) that answered that the magnet works only in Earth because of its magnetic poles. (2 10th graders and 2 11th graders).

## DISCUSSION

Based on the representation charts' results, we will attempt to answer the three specific research questions that we posed.

### **1. What are the children's representations concerning the need of existence of a means (or air) for the transfer of magnetic force (first part) and the relation between magnetism and gravity (second part)?**

As observed in the first part, the children's representations were equally distributed. Approximately half of the students thought that air is needed as a means for the transfer of magnetic force from the magnet to the bodies, while the other half didn't deem the existence of a means necessary for the transfer of magnetic force. As we reported before, the stability of the children's representations is remarkable, since all of them retained their interpretive model in both of the differently posed questions of the interview (Questions 5 and 6) that regarded the need of existence of a means for the transfer of magnetic force.

In the second part, the representations regarding the relation between magnetism and gravity, followed two directions. In the first one, a deeper correlation between them is found; either magnetism is the cause of gravity, as observed in one





case, or there is an interaction between the magnets and the Earth's gravitational field, as observed in another. The second direction concerns has to do with whether or not gravity affects the magnet's action. The results have shown that a noteworthy, albeit small, percentage thinks that the magnet cannot act without gravity. There is also a small percentage that thinks that a magnet can only act on the Earth, because of its magnetic poles, thus presenting it as unique in the manifestation of magnetic phenomena.

## **2. Are there any analogies between historically introduced models and the children's representations?**

Trying to associate the students' representations we recorded with models that were introduced during the history of the Sciences, we observed that in the representations of around half of the students, air appears to affect the transfer of magnetic force. Consequently, those students failed to comprehend action at a distance without the existence of a material means. This fact can be encountered in the history of the Sciences, as the majority of scientists up until recent years (with some exceptions), did not accept the transfer of forces without the existence of a means.

It must be noted though, that while in the history of the Sciences during the 17th century the invention of the 'abstract' concept of ether satisfied the need of a means, in children's minds this need is satisfied by an existent, albeit invisible, means, like air.

Regarding children's representations on the relation between magnetism and gravity, it is observed that in the mental representations of a percentage of the students, the prevalent view is that Earth, either because of gravity or because of its magnetic poles, affects the magnetic force in such way that the magnet is unable to function away from it. A relative similarity to the 17th century models is then presented, especially to those of Gilbert and Kepler, who associated magnetism with gravity.

A remarkable resemblance to Gilbert's model in the representations of two students must also be noted. In one of the two in particular, as in Gilbert's, Earth is presented as a large magnet and gravity seems to originate from Earth's magnetic forces.

## **3. Are there any differences between the representations of 10th and 11th graders?**

Regarding the representations that concern action at a distance, and specifically if the existence of a means (air) for the transfer of magnetic force is necessary, we observed a differentiation with the students' grade. Thus, in grade 10 more students thought that the existence of air affected the function of the magnet, than in grade 11, (thirteen 10th graders and six 11th graders).

Regarding the possible relation between magnetism and gravity we observed that it is more related in grade 10 (7 students) than in grade 11 (2 students). We also observed that the deeper correlation between magnetism and gravity was realized by two 10th graders.

The results above show that the more detailed instruction of electromagnetism in grade 11 seems to have helped many students dissociate magnetism from gravity, but not all of them. This may be because the correlation of gravitational and magnetic pull is strong and not easily overcome through conventional teaching. Furthermore, students find difficulty in accepting the concept of action at a distance, since a large percentage of them think that in order for the transfer of forces to occur, a material is needed.

The results of this study have pointed out parts where the students' representations seem to approach basic elements of historical models of the Sciences. Therefore, based on these, we can try, through specially orientated didactic interventions and curricula, to transform the students' representations into representations which are related to those of the modern scientific models we have constructed for education (Wandersee, 1986; Van Driel, De Vos & Verloop, 1998; Koliopoulos & Ravanis, 2000; Dedes & Ravanis 2009a, 2009b). Besides, as our research showed, conventional teaching does not seem capable of guiding students' thought processes towards the necessary reasoning.

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## APPENDIX: THE QUESTIONS OF THE INTERVIEW

We supply the following objects: two rod-shaped magnets, iron filings, steel needles, a silver ring, a wooden or plastic body, a magnetic compass, and a piece of string with which to hang one of the two magnets. We give the children the objects to examine, we answer whatever questions they may have and then we immediately begin the discussion. The series of questions was as follows:

1. What does the magnet do?
2. Does it attract all these objects, or not? And if not, why is that?
3. (We hang one of the magnets from the piece of string so that it is suspended in the air; we give the other one to the student and ask him/her to bring it close to the first magnet.) What kind of force does one magnet exert on the other? Is the force the same everywhere, or does it depend on the position of the magnets? Why is this?
4. How do you imagine a magnetic compass works? What pulls the needle in that direction?
5. How do you think magnetic forces moved on the body? You must have "something" between the magnet and the body?
6. In a glass vessel which contains a pump which can be removed in air, to a fixed point is suspended with a magnet. Put into container another magnet and observe the suspended magnet is away from the vertical position. Leaving the provision in its current form, remove the air from the container. What do you think will happen?
  - a) The magnet needs air to act.
  - b) Air is necessary for the transport of magnetic force.
  - c) Without air decreases the strength of the magnet.
  - d) Air does not affect the action of the magnet.
7. Suppose an astronaut inside a spacecraft moving through space, wherein the air but is no gravity. Astronaut wants to use a magnet for removing an iron nail. What do you think will happen?
  - a) The magnet works even if there is no gravity.
  - b) The magnet does not work because there is no gravity.
  - c) The magnet works on earth because the magnetic poles.