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MENTAL REPRESENTATIONS OF NINTH GRADE STUDENTS: THE CASE OF THE PROPERTIES OF THE MAGNETIC FIELD

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Abstract. *The study of students' mental representations of Natural Sciences concepts and phenomena constitutes a central part of Science Education research, as they play a decisive role in teaching. In the study presented here, we investigate 157 ninth grade students' mental representations of the magnetic field, after they were taught about it in school. The empirical data was gathered through an interview using 4 tasks which involved the evaluation of actual or hypothetical situations. The research data included mental representations that cause difficulty in the comprehension of the properties of the magnetic field.*

Key words: *properties of the magnetic field, students' mental representations*

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Introduction

The study of mental representations of students of all ages and school levels within the context of Science Education points to the need for the creation of special teaching interventions in a wide spectrum of subjects in the teaching of the Natural Sciences. These teaching interventions aim at transforming the mental representations of the students into others that are compatible with the descriptive, functional and interpretive features of the scientific models (Méheut, 1997; Weil-Barais, 2001; Ergazaki, Komis & Zogza, 2005; Ravanis & Pantidos, 2008). However, the existed mental constructions as well the connections among them, in relation with the teaching context, affect the interpretations that students use to explain aspects of natural phenomena. Actually students' understandings of a physical concept depend on what they have already mentally shaped about other relevant physical concepts (e.g., Giordan, Girault & Clement, 1994). This perspective has been undertaken to enable us in this study to draw on students' mental representations about 'magnetic field' investigating how students conceptualize magnetic field in the context of Newtonian model.

In particular, simple magnetic behaviours constitute a cognitive area that has not been sufficiently studied, since related research is limited. Pocovi & Finley (2002) analyzed how electric and magnetic lines of force were conceived by Faraday and how they are understood by students. Many students pose ideas similar to those of Faraday in that lines of force are conceived as real physical entities responsible for the transmission of the electric and magnetic action. Michael Faraday (1791-1867) introduced the concept of "field" in order to overcome the conceptual problem of 'forces acting from a distance'. He proposed that the presence of a magnet at a point in a previously empty space, changes the properties of this space. This means that an invisible entity – a magnetic field – is created around the magnet. Therefore, one may consider that a second, smaller magnet interacts with the magnetic field with which it is in contact, rather than with the first magnet from which it is far apart.

The research of Piaget & Chollet (1973) showed that, as children discover magnetic forces, up to the age of seven they attribute them to an intrinsic property of the material which "sticks" in the case of attraction and "blows" in the case of repulsion. Later, up to the age of ten, the explanations of children are in terms of "forces" or "streams" which attract or repulse. Up to the age of fourteen, children attribute magnetic properties either to the discharge of "molecules" or "little pieces" of the magnets, or else to forces propagated by means of "a kind of gravity", "a kind of electricity", "pressure of air", "magnetic streams", "a kind of lighting", "rays" or "heat", that is, concepts deriving from everyday life or education.

The fundamental magnetic properties can become an object of study between the ages of 4-6 (Ravanis, 1994, 1996). A related study found that, within an organised environment that favours experimentation, a large number of children of this age discover the forces of attraction of magnets on metal objects and the forces of attraction and repulsion between magnets, while they also start to learn which substances are attracted by magnets and which are not. Other studies of magnetism and children of this age show similar results (Papadopoulou & Poimenidou, 2008; Christidou et al. 2009).

A study of students aged 9-18 focused on issues of understanding action at a distance (Bar, Zinn & Rubin, 1997; Bar & Zinn, 1998). The results of this study showed that 4 in 5 students aged 9 consider air necessary for the exerting of magnetic forces, a proportion that is gradually reduced, becoming 1 in 3 in the case of 18-year-old students. This study also found that children see links between magnetic and gravitational phenomena (see also Barrow, 1987). These links may go as far as mental representations acknowledging magnetism as the cause and gravity as the effect.

In a study of students aged 9-14, an attempt was made to create general models for approaching magnetic phenomena (Erickson, 1994). The first model, the "pulling magnet" is used by younger students to describe the effect of magnets on bodies that are close by, but without indicating the underlying reasoning that would explain or interpret these magnetic behaviours. Correspondingly, Selman, Krupa, Stone & Jacquette (1982) provided evidence that children aged 3-9 years use the idea of an invisible action to explain the magnetic attraction on objects. In the "emanating model", magnetic phenomena are attributed to the emission of energy or to rays directed from the magnets to the bodies being attracted. The third one, known as the "enclosing model", acknowledges the existence of an area of influence surrounding the magnet, thus adopting a representation which refers to a naïve image of the magnetic field.

The classification of the conceptions of students aged 15-18 was also attempted in research performed by Borges and Gilbert (1998). Here, the students' conceptions were classified into 5 different categories. The first and the second refer to Erickson's first and third model, while the third category comprises conceptions that link magnetism to electricity, given that the magnetic poles show an accumulation or a deficit of positive or negative charges. The fourth category consists of the conception that magnetic phenomena are caused by electric dipoles that are formed into the magnet as a whole. Thus, one of the magnet's poles displays a positive charge while the other displays a negative one. In the fifth category, the descriptions of the interactions refer to a certain kind of magnetic field similar to the one described in formal school textbooks. But the children that use this reasoning can offer explanations on a microscopic level, alternately using the concept of elementary magnets and the concept of cyclical micro-currents.

Bradamante and Viennot (2007) tried to link magnetic and gravitational sources with their respective field lines and then use this linkage to differentiate between the two kinds of interactions. This study showed that the proposed "mapping" and the differences between the maps are accessible to a large proportion of students aged 9-11. Moreover, Bradamante & Michelini (2005) investigated spontaneous ideas of children 5-9 years of age about gravitational and magnetic fields which are emerged in an informal teaching context. The researchers indicated that children in an initial stage identify the concept of 'field' as 'power', while quite a few children recognize a 'guiding role to the magnet'. According to the same study 42% seem to have constructed an intuitive idea of magnetic field specifying the 'magnet as

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source of magnetic field or magnetism as energy', 54% identify the 'magnet as source of force', while 4% incorporate into their reasoning the existence of 'air as a medium necessary for magnetic interactions'. In the experimental situation of an iron ball entering into a magnetic field, the most of the children do not predict the correct trajectory (deviated) of the ball as a result of both its initial velocity and the magnetic force (ibid.).

Research carried out by Ravanis, Pantidos and Vitoratos (2009) studied the mental representations of students aged 14-15 in regard to the magnetic field. The study of the children's mental representations was carried out through interviews performed at the end of lessons involving magnetism and electromagnetism in the students' classrooms. The children were given 3 consecutive tasks. A discussion then developed based on these tasks. From the total results, it appears that 7 to 9 out of 10 students undertaking each task face considerable difficulty in handling the characteristics and properties of the magnetic field.

Drawing on these research literatures our paper investigates students' mental representations about magnetic field in connection to Newtonian model. Comparing to our previous work (cf., Ravanis, Pantidos & Vitoratos 2009), the current research mainly focuses on how students engage the Newtonian model in their reasoning about actions in the magnetic field. Hence, in this study the context of the interviews used to gather the data was centred to this orientation. The research questions guiding the study were as follows:

1. In what ways grade nine students associate the exertion of magnetic force with the absence of air? (task 1)

There is a broad consensus in science education research about magnetism that students aged 14-15 need to consider the existence of an 'agent' (i.e., air) as a necessary mean for the exertion ("transmission") of the magnetic force (e.g., Piaget & Chollet 1973; Bar & Zinn, 1998). Moving towards this trajectory, we chose to control the same question creating also an introductory context suitable to other research questions.

2. In what ways grade nine students interpret the properties of the magnetic field in terms of Newtonian model? (tasks 2 and 3)

This research question attempts to extend our knowledge about students' mental representations about magnetic field investigating how the students incorporate the Newtonian model into their interpretations about magnetism. Such a perspective follows past research outcomes which underscore the significance of interrelated mental representations in the construction of physical knowledge.

3. What mental representations do grade nine students construct as regards the causing permanent magnetization in metallic objects by a magnet? (task 4)

This research question adds a new aspect on students' understanding of magnetic field since the specific issue has not sufficiently investigated.

Methodology of Research

Sample

A total of 157 students (77 boys and 80 girls) aged 14-15 (average age: 14 years and 7 months), from 8 different classes took part in this study. The students were attending the ninth grade of school (the 3rd grade of secondary school). Greek students are first taught certain things related to the magnetic field in primary school and then again in the second and third year of secondary school. The gathering of data from the students of the sample was carried out immediately following the teaching of the magnetic field in the ninth grade. It should be noted that all socioeconomic strata (low, middle, and high) were equally represented in the sample.

Research Design

The children's mental representations were studied through directive individual interviews. Each interview lasted approximately 20 minutes and was held in the schools' laboratories after the end of magnetism and electromagnetism lessons, without the teachers or the students knowing about the interviews beforehand. The students were given four experimental situations/tasks which were presented to them consecutively. A discussion was then initiated, based on the tasks and regarding the way in which they conceive of the properties of the magnetic field.

These tasks do not lead to one-way answers of the "right-wrong" type, but generate contexts for discussion that allow the expression of alternative answers. As the students work on the tasks and express various hypotheses, they can be led to different solutions of the problems. Thus, after the students gave us their initial answers, we asked them to explain in detail their thought process and arguments, by posing to them questions consistent with the context of each research issue.

Indeed, our aim in this study was not to have the students recall or reproduce the declarative knowledge that the students elaborated in their school lessons, since that would only produce mental representations which would be influenced by the work carried out in the classroom and severely limited by the students' means of expression. Through the tasks we assigned, we attempted to find out whether, after having been taught about it, students are able to express thoughts that make satisfactory use of the properties of the magnetic field. In particular, during the tasks 2 and 3, the formulated questions by the researchers were oriented to exploring how students interlink their conceptions about magnetic field with the Newtonian model.

Task 1

For the first research question we designed the task 1 in an effort to investigate whether the students associate the magnetic interaction to the presence of air as a necessary mean for the action of the magnetic field (see Figure 1). The specific task is a hypothetical experimental situation which imposes students to embody into their explanations as regards the exertion of magnetic force, the absence of a kind of a mean (i.e., between two magnets) rather than the presence of it (i.e., air).

Actually, we present the children with the hypothetical experiment in Figure 1 and we ask them to predict the outcome: "Inside a transparent airtight container, two magnets that are hanging from pieces of string attached to the top of the container are attracted to each other and are touching. Using a pump, we suck out all the air. How will the magnets behave now that we have taken every trace of air out of the container?"

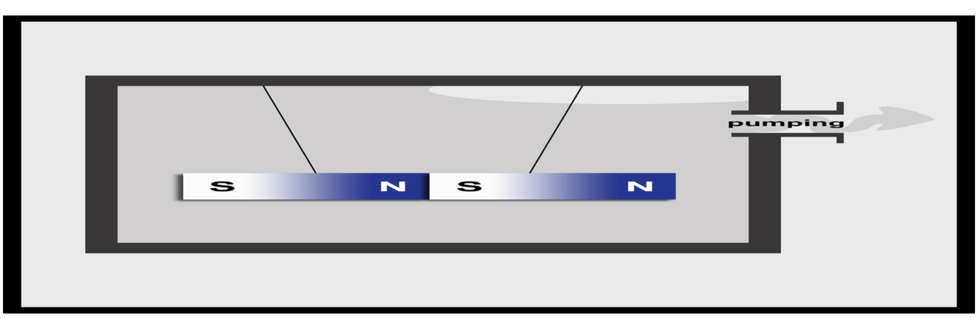

Figure 1. The exertion of magnetic forces in a void.

In this task two magnets rather than a magnet and a metallic object were used. That helped students express their thoughts independently whether the magnet interacts with the material of the object or not.

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Tasks 2 and 3

In the context of the second research question we designed the tasks 2 and 3 in attempting to extract from students explanations which, first and foremost, shed light on the concept of 'force'. Moreover, the designing of these tasks has taken under consideration the Newtonian model that is to say the connection between force and motion. For that reason the idea of 'exerting force' is included in both tasks; actually task 2, in contradistinction to task 3, contains also 'immobility' as a possible kinetic situation (state of equilibrium) of the object (nail) that is attracted (see Figures 2 and 3).

As regards task 2 we present the children with the following actual experimental situation: "On a table there is a magnet. When we bring a metallic (iron) object, like a nail, close to the magnet, the object attaches itself to the magnet. Why does this happen? We pull the object away from the magnet and put it down on the table. We observe that the object stays where we left it. What exactly is going on?" (Figure 2).

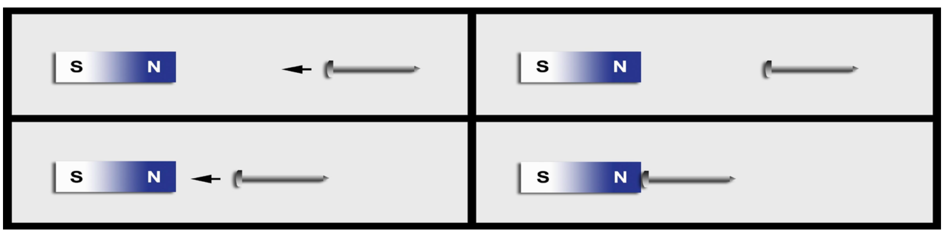

Figure 2. The exertion of magnetic forces at a distance.

By using this simple and familiar experimental situation, we attempt to find out whether the children understand the exertion of magnetic forces within the context of the magnetic field; whether and in what way they correlate the change in the strength of the magnetic field and the distance from the magnet; and, also, whether they study the movement of the object while taking into account all the forces that are being exerted on it, i.e. whether they see the action of the magnetic field as part of the larger environment of a simple experimental situation.

In task 3 we present the students with Figure 3 (hypothetical experimental situation) and give them the following information: "The two identical wagons A and B contain a piece of iron (F) and a magnet (SN) respectively. The piece of iron and the magnet are of equal mass. The two wagons are steadily linked by a wooden rod P, while the friction with the ground on which they are standing is negligible. If we disconnect and remove the rod, describe and explain what will happen. Will certain objects move? If not, why not? And if yes, why will they move?"

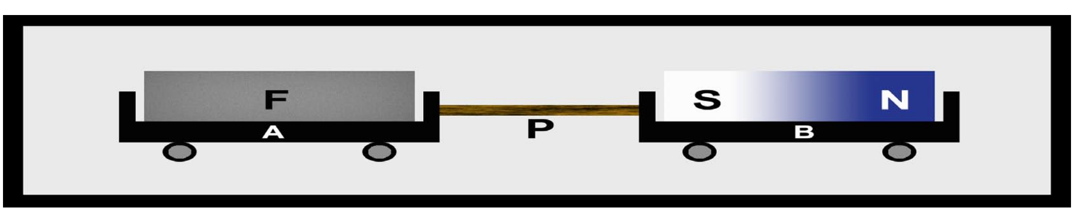

Figure 3. Interactive forces between magnets and metals.

Through this task, we are trying to establish whether the children are able to understand the magnetic field as a space of mutual actions and not as an area of the unilateral exertion of forces by the magnets on metal objects. That is to say, whether, to the children's minds, the magnetic fields display the formal characteristics of fields and whether magnetic forces are understood as interactive forces.

It should be noticed that tasks 2 and 3 function complementarily to the researches that have been already conducted since these tasks tend to explore whether students' reasoning about magnetic field incorporates the concept of motion (or of immobility) as a result of exerting force. More specifically, task 2 refers mainly to the Newton's first law and the task 3 to the third and to the second Newton's law.

Task 4

By presenting the students with yet another hypothetical experiment, we tried to see whether they believe that when metals remain inside the magnetic field, the magnetic field can create permanent magnetic properties in these metals. Task 4, which corresponds to research question four, helps investigate students' understanding of this specific property of the magnetic field. The content of the task was as follows: "Two iron rods (1-2, 3-4) take on the positions that can be seen in Figure 4 as a result of being attracted by a magnet (NS). What will happen if we move them away from the magnet, one after the other, and then bring them close together?"

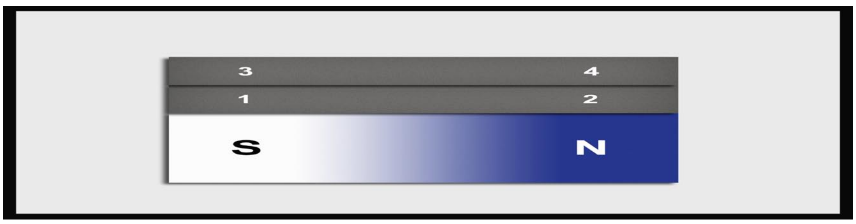

Figure 4. Causing permanent magnetization in metals.

Results of Research and Discussion

Research Question 1: In what ways grade nine students associate the exertion of magnetic force with the absence of air? (task 1)

Students' answers that we have been tracking in task 1 seem to confirm the research literature. Indeed, in this hypothetical situation, the answers given by the children depend on whether they believe that the presence of air is necessary for the exertion of magnetic forces. Some of the children answer "I don't know", but in some cases their reasoning is very interesting (see Table 1).

Table 1. Frequency of subjects' answers to Task 1 (The exertion of magnetic forces in a void).

	Frequency	Percentage
(a) The exertion of magnetic forces does not depend on the presence of air	61	38.9
(b) The exertion of magnetic forces depends on the presence of air	85	54.1
(c) Inability to express a definite answer	11	7

a) Several children express thoughts which clearly show that the presence of air is not related to magnetic interactions. For example, "The air is not necessary for the magnetic field… the magnet will attract the other magnet and without the air (S.12); "Nothing will change if there is no air left. The magnetic field exists in the void and everywhere" (S.129).
b) More than half the children think that the existence of air is necessary for the exertion of forces. For example, "If the whole…the whole air goes away, magnetic field and magnetism might not exist... the magnets will unstick" (S. 37); "The air is necessary for the magnetic field… namely, for the propagation of the magnetic field" (S. 99).

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c) A small number of children answers "I don't know". Among them, certain ones express certain interesting representations. For example, "It seems that is like gravity… It needs the air… But the Moon has gravity without having air… I do not know I do not have enough information to think" (S. 112). "I'm not sure whether magnetism is like sound… if it is, then when we remove the air it will cease to exist… but if air is not needed, then they [the magnets] will stay where they are… but I can't be sure of it" (S. 151).

The range of ninth grade students' answers confirm to some extent Piaget's & Chollet's (1973) views on the capacity of students to be focused either on the existence of a 'mean' (e.g., "a kind of gravity", "pressure of air") or, on transferred 'entities' (e.g., discharge of "little pieces" of the magnets) which mediate in order a magnet to attract a metallic object. In this regard our findings also confirm the outcomes of Bar, Zinn & Rubin (1997), Bar & Zinn (1998) as well Erickson (1994) (the "emanating model") who underscore that students of that age consider the existence of an active agent – except the magnet - as a prerequisite for the exertion of magnetic force.

Finally, in linguistic context of task 1, the use of 'absence of air' instead of 'presence of air' seems that did not affect students' answers during the interview.

Research Question 2: In what ways grade nine students interpret the properties of the magnetic field in terms of Newtonian model? (tasks 2 and 3)

Our discussions with the children in task 2 produced three types of answers that ranged from the systematic analysis of the forces being exerted on the object to the simple description of the experimental situation (Table 2).

Table 2. Frequency of subjects' answers to Task 2 (The exertion of magnetic forces at a distance).

	Frequency	Percentage
(a) Evaluation of the total forces at play in the experimental situation	16	10.1
(b) A qualitative reference to "how strong" the magnetic field is	99	63.1
(c) The weight of the object and/or the distance from the magnet	42	26.8

According the data presented in Table 2 students' answers are ranged in three categories:

a) Answers in which the various positions taken by the object are systematically analysed in terms of the exertion of forces within the magnetic field and the forces of friction between the table and the magnet. In this case, the students take into account the magnetic force as it fluctuates according to the distance, as well as the friction exerted on the magnet by the experiment's environment. For example: "If we take account the forces exerted to the object, then, there is also the friction from the table as well the force from the magnet which is getting stronger as closer we are to the magnet" (S.146); "In order to may predict what is going to happen, we have to consider not only the force from the magnet which is getting stronger as we approach the magnet, but also the other forces… (Researcher: In task 2 what are the other forces?) … Friction" (S.150). "At each point, the force exerted (by the magnet) is different... In order to give a precise answer, we have to examine the total force exerted on the nail..." (Subject 127).
Students' answers seem to establish a coherent view on how the value of magnetic force depends from the distance, in relation to their already constructed knowledge about Newton's first law. Thus, students explain this specific situation by means of engaging the notion of 'equilibrium' with the notion of 'magnetic force'.

b) Answers in which the result of the experimental situation is linked to "how powerful" the magnetic field is or "what the force of the magnet is", but always in relation to the distance from the magnet. However, references to this parameter are always vague and completely qualitative. For example, "There the nail is far away and as the magnetic field is weak is unable to move it" (S. 40); "It depends on how powerful the magnetic field is in the area in which the nail is located" (S. 62). "The magnetic field doesn't seem to be strong enough at that point to pull the nail" (S. 142).

First and foremost this specific group of students seems to have an intuitive idea about the relation of magnetic force with the distance from the magnet. Thus, students' utterances in task 2 do not engage magnetic force in the Newtonian model which allow us to make the assumption that either students have not mentally constructed linkages between Newtonian model and the magnetic force, or students have shaped insufficient mental representations about Newton's laws.

c) Answers in which reference is made to the "magnet's force" and/or the weight of the object. For example, "It might be related to how heavy the object is… the nail is not heavy but the magnet seems to be weak" (S.67); "If the magnets are strong they can overcome the weight of the objects" (S.123); "The object is heavy and at this distance the magnet can't pull it" (S. 53).

In this case students recognize the exertion of a force to the nail as a consequence of the magnetic field. Although students incorporate weight in their reasoning they are unable to connect it with the friction in the context of forces equilibrium.

The reasoning expressed by the children in task 3 shows that they experience considerable difficulty in analysing the interactive forces within the magnetic field. Here too we observed three categories of answers (Table 3).

Table 3. Frequency of subjects' answers to Task 3(Interactive forces between magnets and metals).

	Frequency	Percentage
(a) Interactive forces between the magnet and the piece of iron	17	10.8
(b) Movement of both vehicles without satisfactory answers	11	7
(c) Exertion of force by the magnet and movement of the piece of iron	129	82.2

a) Answers in which the children correctly foresee the existence of interactive forces between the magnet and a metal object and, therefore, the simultaneous approaching movements. For example, "The exerted forces are as we say… mutual. The magnet will pull the iron and the iron the magnet and then both will be moved approaching" (S. 85); "The magnet pulls the iron, but the iron also pulls the magnet. They'll move towards each other... I don't know if they'll move alone or together with the wagons... but they'll both move" (S. 111).

In this category the students embody in their reasoning mainly the third Newton's law, although they do not approach the notion of 'interactive forces acting from a distance'. That issue, especially when it concerns the interaction between a magnet and a metallic object is more complex than the corresponding question of gravitational interaction of i.e., two celestial bodies. In task 3 students confine their views in a phenomenological level predicting whether the two entities (magnet, piece of iron) are going to move or not. Actually, any further cognitive infiltration would demand explanations which should describe in what way the force exerted by the piece of iron to the magnet is originated.

b) Answers in which the problem is addressed using intuitive terms, but in which the children cannot explain their thought process through reasoning based on interaction. The following dialogue is typical. Student 55: The magnet attracts the piece of iron and thus the wagon with the iron starts to move towards the magnet. However… the magnet will also move… or perhaps… it will surely move a bit… Researcher: Why? For what reason? S.55: Because it is not constant but on a wagon with wheels. R: Yes but how? S.55: I do not know the real reason but I think it will be moved a bit towards the side of the iron.

From the above dialogue seems that students although they predict the imminent move-

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ment of both entities, they do not explain these movements taking into consideration the interaction between forces. It should be noted that the categories (a) and (b) of the answers could be considered as equivalent, since they are both commanded by an intuitive approach as regards 'interaction'.

c) Answers in which the concept of interaction is not introduced at all, but which simply acknowledge that the magnet will exert a force of attraction on the piece of iron. For example, "The magnet will pull the wagon with the piece of iron till…the iron come on it" (S.82); "the wagon with the magnet will stay in its place and the wagon with the piece of iron will move towards the magnet because it is attracted" (S. 103); S. 117: "The wagon with the piece of iron will move and roll into the wagon with the magnet".

Here, it is made clear that students have not constructed the notion of 'interaction between forces' in the context of 'forces acting at a distance'.

Nevertheless, in all categories of students' answers in task 3, an intuitive linkage between the exertion of force and the motion (i.e., second Newton's law) is recognized.

Research Question 3: What mental representations do grade nine students construct as regards the causing permanent magnetization in metallic objects by a magnet? (task 4);

In this task we try to see whether the children believe that remaining inside a magnetic field can cause the permanent magnetisation of metal substances. The children's answers were divided into three categories.

Table 4. Frequency of subjects' answers to Task 4 (Causing the permanent magnetisation of metal substances).

	Frequency	Percentage
(a) Strength of the magnetic field / material of rods	20	12.7
(b) Absence of permanent magnetisation with no explanation	95	60.5
(c) Permanent magnetisation of substances	42	26.8

a) Answers in which the children systematically express thoughts and hypotheses concerning the strength of the magnetic field and the material the rods are made of. For example, "I don't believe that the other metals will be magnetised, unless it's some kind of super magnet and is able to magnetise them… but from what I see in the illustration it's just a regular magnet…" (S. 102); "If the material the rods are made of is very sensitive to magnetism, then they may become magnetised for a little while, but if afterwards we bring them close together, I don't think they'll be attracted or repelled. I don't believe it's so easy to make an artificial magnet" (S. 27).
Probably the fact that students lack relevant experience either from their daily life or from such experimental contexts at school do not allow them to make concrete and clear reasoning about the progress of this experimental situation. Barrow (1987) has already supported that teaching interventions concerning magnetism sometimes do not improve the relevant mental representations of students because the experimental content which is used is far from students' daily experience about the specific phenomenon (magnetism).

b) Answers in which the children do not acknowledge any affect the magnetic field may have on the metal rods, but without supporting their claims with arguments or reasoning. For example, S.82: "The rods won't be affected by the magnet's magnetic field… Researcher: What if we bring them close to each other? S. 82: "No, nothing, nothing at all." S. 36: "You mean you want to know whether the magnet magnetises them? …No, I don't think it does."
These students seems to have strong views about the situation because they do not include in their utterances any sort of causality.

c) Answers in which the children believe that the rods become permanent magnets. These answers are clearly influenced by experiments in which metal substances displayed a temporary magnetisation. It seems that their experience both from daily life and school essentially affect their explanations. For example, "…I see… the rods will become magnetized, they'll become like magnets… but they'll be weak, like the nails that attract the pins" (S. 100); "They'll be attracted to each other because they will also have become artificial magnets" (S. 89).

Conclusions

The results of all four tasks show that the students face considerable difficulty in evaluating actual or hypothetical experimental situations involving the application of the properties of the magnetic field. It is indicative that, with the exception of the task concerning the exertion of magnetic forces in air to which approximately 4 out of 10 students responded adequately, in the remainder of the tasks only about 1 out of 10 students are able to fully process the situations presented, to express reasoning and formulate hypotheses based on declarative school knowledge. Of course, this is not solely due to the inadequate comprehension of magnetic properties (as in Task 4, concerning the permanent magnetisation of certain substances), as well as the inability to correlate characteristics caused by the magnetic field and the rest of the characteristics of the experimental situation. For example, as we saw in Task 3, the exertion of interactive forces on the magnetic field is closely linked to the question of interactive forces within a field, which is a problem we generally come across (Solomonidou & Kolokotronis, 2001). We could, therefore, address the question of organising the appropriate teaching activities in order to make the properties of the magnetic field better understood, as well as the question of reorganising sections of the curriculum in order for the study of magnetic properties to become systematically linked to questions of the general properties and the nature of fields. Especially, the discussion about tasks 2 and 3 indicates that any teaching intervention about magnetic field is fruitful to be designed in connection students' mental representations about Newtonian model.

Moreover, it appears that a discussion concerning a satisfactory comprehension of the magnetic field has to encompass not only the specific properties of the magnetic field, but also the special applications of these properties in various experimental situations. This will make it possible for students to elaborate magnetic properties in a functional way and to alternate back and forth between the model and reality, finally arriving at the construction of the model of the magnetic field. This sequence of steps is very important since, as the results of our study have shown, students who merely followed conventional lessons on the magnetic field and had already completed the first round of a qualitative approach to magnetic and electromagnetic phenomena have considerable difficulty in using the fundamental properties of the magnetic field.

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