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A STUDY OF THE UNDERSTANDING OF KEY CONCEPTS OF ELECTROMAGNETISM OF 11th GRADE GREEK HIGH SCHOOL STUDENTS

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ABSTRACT

This study is set in the context of teaching and learning about electromagnetism in Greek high schools. Drawing from constructivism theory, the study aspires to explore students' understandings of key concepts on both electric and magnetic field as well as electromagnetic induction. For this purpose, an experimental investigation was conducted with 80 11th grade high school students. Empirical data was collected through a questionnaire which was developed on the basis of test subjects used on past exams in Greek high schools in electromagnetism area. Research findings suggest that students face difficulties in dealing with qualitative tasks in electric and magnetic field. In addition, they seem to confront severe difficulties in conceptualizing the notion of induction of emf.

Keywords: teaching and learning science; alternative ideas; electromagnetism

INTRODUCTION

It is well known in the educational scientific community that pupils have their own ideas about a number of natural phenomena in advance of their schooling (Kalogiannakis et al., 2018; Jelinek, 2020; Ravanis et al., 2021). These ideas, also known as mental representations, naïve representations or alternative conceptions, produced by both the individual and social history of the child are in continuous interaction with the sociocultural and educational environment and hold a dynamic, developmental and evolutionary character. Thus, insofar as the ideas through which the human being interprets the phenomena of the physical world are at a distance or in contradiction with some elements of the scientific models, the dominant ideas of researches trends in Science Education aim at the construction of teaching interventions and didactic situations susceptible to pave the way from the naïve, implicit, local and non-conscience ideas of the notions or phenomena to the conceptions and the explanatory mental forms (Ergazaki & Ampatzidis, 2012; Christidou et al., 2018; Stavrou et al., 2018). Much research on alternative conceptions reveals that students face difficulties in understanding aspects of the electric and magnetic field as well as those of electromagnetism. More particular, in research conducted by Thong & Gustone (2008), a large number of university students believed that around a magnet, there are real, finite, distinct 'field lines' separated by spaces. In those spaces, the magnetic field is supposed to be zero.

Guisasola et al. (2004) state that many students seem to not recognize the existence of a static magnetic field unless the field is somehow manifests itself to them through some kind

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of interaction. In addition, several students tend to attribute the magnetic phenomenon to the 'attraction' and 'repulsion' of the field lines solely. Students often attribute the cause of the magnetic field to the electric charge, either moving or stationary, assuming that the magnetic interactions are explained by Coulomb force. In general, students' alternative conceptions often stem from the fact that magnetic field and the concept of field, in general, are dealt with in terms of force (Zuza et al., 2018).

As far as electric field concerns Viennot & Rainson (1992) identified that a charge must move in order to create an electric field. Static charges are unable to create any field. Therefore, the charges inside an insulator are incapable of creating a field. A small but noteworthy number of pupils said that the presence of a charge at a given point is essential for the existence of a field at that point. Some students face difficulty in understanding that a magnet can interact with a charge only in the case that the charge is moving. Nevertheless, pupils often consider that a magnet can interact even with charges at rest. This was explicitly shown in research conducted by Maloney (1985), in which pupils suggested that the magnet's North Pole would act as positively charged and the South Pole as negatively charged. As a result, they stated that a positively charged particle would be attracted by the South Pole and repelled by the magnet's North Pole. Maloney suggests that this alternative conception derives from pupils learning that magnetic field lines flow from North to South Pole and electric field lines flow from positive to negative charges. Wardana et al. (2019) state that academic students encounter difficulty providing a qualitative explanation of charged particles motion which comes from both electric and magnetic fields impact.

Galili et al. (2006) states that 17-year-old students face difficulties showing the correct trajectory of the movement of a negative charge entering a non-uniform electric and magnetic field with a positive charge in its centre. Indeed, most pupils failed to indicate that in such a case, the negative charge would 'follow a kind of spiral movement closing on the central charge'. In contrast, most of them suggested that the negative charge would move along the electric field lines until it reaches the central positive charge. This idea indicates a common students' alternative conception that 'a single line of force includes only one piece of information, the direction of the force applied on the charge' (Galili et al., 2006).

Regarding electric field, Pieper & Serrano (2016) pointed out two conceptual approaches adopted by high-school students. The coulomb profile, which is similar to the Newtonian approach of the gravitational field, and the Maxwellian profile, which extends the concept of field to space and time, with the former being considered a conceptual prerequisite for the latter. In addition, Furio & Guisasola (1998) recorded that students do not separate the magnitude of electric force from the intensity of the electric field and do not resort their thinking to Maxwellian profile to deal with electric field. It seems that students remain limited to a description of the mathematical expression of Coulomb's law while they often fail to connect the concept of the field with physical space (Pieper & Serrano, 2016). Özdemir & Coramik (2018) argue that the conceptual understanding of electromagnetism, the vector algebra and spatial cognition affect university students to apply correctly the Right-Hand Rule (RHR).

Secondary students' difficulties on electromagnetism topics such as current electricity, force on a conductor, the motor principle, the dynamo and electromagnetic induction are likely to be influenced by the students' achievement in maths, as electromagnetism demands high abstract reasoning (Okpala & Onocha, 1988). Galili et al. (2006) agrees with the above view and points out that students' alternative conceptions of magnetic fields 'stem from the mismatch of the methodology applied in mechanics and electromagnetism, as they are currently taught' (Galili et al., 2006). In particular, while mechanics is taught without any reference to the concept of field, electromagnetism is introduced to the students with extensive use of that concept. As a result, the pupils are unable to apply Newton's Law in electrical problems.

Concerning electromagnetic induction Loftus (1996) states that most of the pupils could not explain why a solid ring is levitated above an electromagnet with an alternating current passing through it, while a split ring does not. The most commonly used idea for students to explain this phenomenon was that the force that is exerted from the electromagnet to the split ring leaks out of the gap and therefore, the ring does not levitate. Other pupils used similar expressions such 'as the force flows out of the gap' or 'the force escapes out of the gap' (Loftus, 1996). Academic students face difficulties in explaining the induction of emf in a coil ring and explaining the discrepancies that occur in the galvanometer needle. These difficulties are due to the incomplete conceptual approach of electric fields, magnetic fields, fluxes and electromagnetic forces (Wardana et al., 2019). Prosser (1994) identifies the alternative conception of charge flowing model. Specifically, university students were asked what would happen if a magnet is moved into and out of a coil connected into a circuit. While most of the students answered that a current would flow in the circuit, only a few were able to explain the phenomenon in scientifically accepted terms.

Thong & Gunstone (2008) explored second-year university students' alternative ideas on electromagnetic induction in a system of an external rectangular coil and a solenoid. Some or students' alternative ideas are that the magnitude of the induced current is directly proportional to the current magnitude in the solenoid coil, that magnetic lines are real entities and should come into physical contact with the external coil, as well as that electrostatic potential difference is similar to emf. Also, a common misconception among third-year engineers is that they confuse field lines passing through a circuit with magnetic flux change. In general, it seems that students fail to distinguish between Faraday's law at a macroscopic level and Lorentz law at a microscopic level (Pieper & Serrano, 2016). Almudi & Ceberio (2015) showed that first-year engineering university students do not recognize the conceptual relevance between the two laws, believing that some problems are solved by one law and some by another. In fact, they do not recognize that both laws can be used to deal with electromagnetic induction, noting, of course, that in some cases, it is easier to use one law and in others the other. In addition, Zuza et al. (2018) report that students face difficulties recognizing induction of emf in cases where there is no induced current and explaining that the magnetic field causes emf. In addition, they state that students do not fully understand the concept of magnetic flux and do not connect it to the magnetic field.

Jelicic et al. (2017) pointed out three mental models of secondary school students about emf. In the first mental model, the idea of two separate magnetic fields is used for both the magnet and the coil. In particular, as soon as the magnet moves towards the coil, the two fields start overlapping. The second mental model is based on the idea that the magnet exerts force on the electrons of the coil circuit while moving to and from it. This model is based on the concept of force. The third mental model is based on the attraction or repulsion between the magnet and the coil to which a positive and / or negative pole is assigned. Finally, Sağlam & Millar (2006) pointed out that upper high school students fail to distinguish 'change' from 'rate of change' of magnetic flux.

The current research lies in the context of the above-mentioned studies and tries to investigate mental representations on electric and magnetic field as well as induction of emf. Its novelty based on the ethnicity and the group age of the sample gives into the results a comparative nature. Nevertheless, it is subject to limitations considering the small sample as well as the limited scope of questions.

METHODS

As outlined above, the present study draws from constructivism theory and focuses on teaching and learning of electromagnetism in Greek high schools. In this perspective, it aspires to answer the following research question: What are the understandings of the key concepts of electromagnetism, namely electric and magnetic fields and induction of emf of a sample of 80 Greek students aged 17-year-old?

The research is qualitative in nature as it aims to study the categories of students' responses. A descriptive research design was employed using a questionnaire as research instrument (Creswell, 2015). The questionnaire consisting of 4 items in the form of distinct cards was developed to deal with the research question of the study. In developing the questionnaire, firstly, the content area of electromagnetism that would cover was clarified. The majority of the questions were chosen from a list of past national exams in Greek high schools. As a result, both open-ended and multiple-choice questions followed by further explanation were selected to form the questionnaire. Leading and complex questions were avoided, so that any external factor wouldn't influence students' answers.

In addition, the size of the questionnaire was considered as an essential issue (Cohen et al., 2018). It was decided that the students should not get tired or irritated during the process of completing it. Moreover, that they were able to fill it within a didactic hour, therefore, it was decided that the questionnaire should not be greater than 4 questions. Great attention was given to the layout of the questionnaire (Cohen et al., 2018). Hence, the cover was designed to look simple with the layout throughout to be clear and approachable, along with plenty of space given for answers.

The questionnaires were administrated to 80 11th-grade students of two randomly selected high schools set in an urban Greek city. Schools were selected through the usage of a number random generator. Students were ensured that their answers would remain anonymous and only be used for research purposes. They were also explicitly told that filling the questionnaire was voluntary and it was their right to refuse to complete it. All of them agreed to participate in the research and fill the questionnaires.

The data analysis was done by coding the students' answers. The criterion for this coding was the proximity of the students' answers to the scientific model. The arguments led to three categories of answers: 'Fully Scientifically Acceptable Responses' in which the arguments were fully compatible with the scientific model, 'Partially Scientifically Acceptable Responses" in which the arguments were compatible with the scientific model but limited and 'Scientifically Unacceptable Responses' in which the arguments were incompatible with the scientific model. The analysis and categorization of responses was performed by two independent researchers. The agreement among the two researchers was higher than 90%.

RESULTS AND DISCUSSION

The 1st question of the questionnaire Q_1, composed of two parts, was given to students to probe their understanding of electric field lines. Students' responses were divided into three distinct categories.

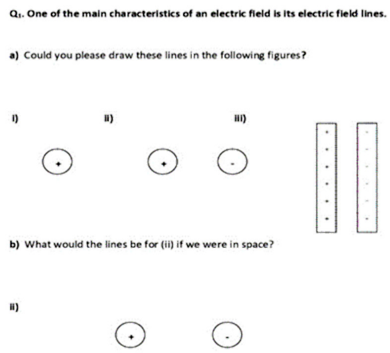

Figure 1. Card Consisting the 1st Item of the Questionnaire

First, fully scientifically acceptable arguments. There were 11.5% of the students gave a fully scientifically acceptable answer in both two parts of the question. These students drew the electric field lines in the correct direction and took into account that each line should be at the same distance as its neighboring lines. By so doing, the spherical symmetry of field (i) and the axial symmetry of field (ii) as well as the homogeneous nature of field (iii) were clearly represented. In addition, these students recognized that the electric field lines would not be different in the Earth's environment and the space, as the electric field propagates in both air and space in the same way. Hence, they drew the same electric field lines for figures a. (i) and b. (ii). Second, partially scientifically acceptable arguments. There were 21.5% of the students gave a partially scientifically acceptable answer as they drew the direction of the field lines correctly, but they failed to depict the spherical and homogeneous nature of fields (i), (ii), and (iii), respectively. Their answer in the second part of the questions was also correct. Third, scientifically unacceptable arguments. Almost 48% of the students failed to answer correctly about the form of the electric field lines in space. These students seemed to get confused by this question, and either they did not provide any answer at all or gave a scientifically unacceptable answer. In particular, some students believed that air is essential for the existence of electric field and therefore they stated that no electric field lines would be in the space. 'In space does not exist electric field, so there does not exist electric field lines too' (Student). As stated above, this alternative conception was also identified by Bar et al. (1997). Specifically, in her study, she found out that 60% of the pupils responded positively on whether gravity or air is needed for electrostatic interaction or not.

While other students recognized that an electric field can exist in space, they thought this field should be much stronger than Earth. Therefore, the lines they drew were extremely dense comparing with those they drew when the charges where in the Earth's environment. In addition, a significant percentage of students (about 19%) did not give correct answers about the form of the field lines in both the Earth and the space environment. Some of these students thought that the electric field lines around a positive charge have a circle form. Some others managed to correctly represent the lines' form but failed to show their correct direction; they believed that the lines have a direction from negative to positive charges. In addition, some pupils thought that the electric field line between a positive and negative charge could be well represented by a single straight line between these two charges. The percentages of scientifically acceptable and unacceptable students' responses are presented in Table 1.

Table 1. Percentages (%) of Different Types of Students' Responses (N=80) about Electric Field Lines

Type of Response	Entirely scientifically acceptable responses in Q_{1a} + Q_{1b}	Partially scientifically acceptable responses in Q_{1a} + Q_{1b}	Partially scientifically acceptable responses in Q_{1a} and scientifically unacceptable answers in Q_{1b}	Scientifically unacceptable responses in Q_{1a} +Q_{1b}
Percentage of Students	11.5%	21.5%	48%	19%

The 2[nd] question of the questionnaire Q_2 was given to students to probe their understanding of magnets and magnetic field lines. Students' responses were divided into four distinct categories

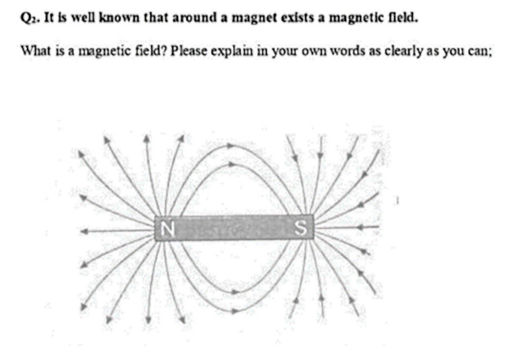

Figure 2. Card Consisting the 2[nd] Item of the Questionnaire

First, fully scientifically acceptable arguments. Only 10% of the students managed to give a fully scientifically acceptable response to the above question. These students did not refer to only one characteristic of the magnetic field, such as the magnetic field lines. In contrast, they dealt with the notion of field from different perspectives, referring to space, field lines and field vector. Such responses were similar to the following 'Magnetic field is the space around a magnet, in which a magnetic force would be exerted to any other magnet placed in this area. One way of representing this field is via magnetic field lines. The vector of the magnetic field is always adjacent to each point of these lines. The stronger the field, the more density the field lines are. These lines are always closed, they start from North Pole reaching South Pole and they never intersect' (Student). In addition, a small percentage of 7.7% of the students made a correlation between charges and magnetic field. These pupils understood that it is the movement of the electrical charges that actually causes any magnetic interaction. This is well reflected in the following student's statement 'Magnetic field is a space around an object in which a current flow. This object is capable of exerting a force to any other electrically charged object' (Student)

Second, partially scientifically acceptable arguments. In this category fall all the responses that are scientifically acceptable but do not ensure that the student has a deep understanding of the notion of magnetic field. Indeed, these responses are scientific-sounding phrases that the students can easily learn without a deep understanding lying behind these words (Kada & Ravanis, 2016). So, a relatively high percentage of students (around 23%) pointed out that the magnetic field is an area around a magnet in which a magnetic force would be exerted to any other magnet placed in this area. These students confined to the abovementioned statement without referring at all to the magnetic field lines and the vector of the field. There were 9.2% of the students tried to explain what a magnetic field is by pointing out that it is the area where a force is exerted on the needle of a compass. Specifically, a student stated 'Magnetic field is a place where a force is exerted to the needle of a magnetic compass. The direction of the field is represented by the direction of the needle' (Student).

Third, scientifically unacceptable arguments. Almost half of the students gave a scientifically unacceptable answer about the notion of magnetic field. The students seemed to get confused about magnetic field lines and what they are supposed to represent. Moreover, they seem to have difficulty grasping the idea that magnets are able to exert magnetic force and interact only with objects that constitute metal materials. Particularly, 14% of the students pointed out that magnetic field is the area around a magnet where a magnetic force is exerted to any object placed within that area. Pupils could not differentiate between objects with and without magnetic properties. They believed that all the objects could get magnetic properties. So, they thought that a magnet could attract every object that is placed around it. These ideas are well reflected in the following students' statements 'a magnetic force would be exerted to any material which is near a magnet' (Student) and 'a magnet can attract any material near it' (Student)

In addition, 12.5% of the students made a strong association between magnetic field and force. They believed that magnetic field is a kind of force that is called magnetic force. In this case, the students thought that the notions of field and force have almost the same meaning. Below are given some of those students statements 'magnetic field is the force between two magnets' (Student) and 'magnetic field is a type of force'(Student). There were 14.8% of the students believed that real, concrete field lines form the magnetic field. These lines are visible and can be counted. This students' alternative conception was also identified by research conducted by Guth & Pegg (1994) and has been analysed above. Students with this way of reasoning point out that a magnetic field is the field lines around a magnet. To quote some of the student's responses 'Magnetic field is some lines which exist around any magnet' (Student).

Finally, a small percentage of 2% of the students tried to associate magnetism with electrical charges in a completely wrong way. This is well reflected in the following student' statement 'Magnetic field is a field due to positive and negative charges, where positive charges are gathered in one side of the object and negative charges to the other side of it. The interaction between these two electrically charged parts produces a magnetic field' (Student). Student's ideas on magnetic field lines are summarized in Table 2.

Table 2. Percentages (%) of Different Types of Students' Responses (N=80) about Magnetic Field Lines

Type of Response	Content of Response	Percentage of Students
Fully Scientifically Acceptable Responses	Magnetic field as the space in which a force is exerted to any other magnet places in this area Magnetic field lines Properties of the field lines	17.7%
Partially Scientifically Acceptable Responses	Magnetic field as the space in which a force is exerted to any other magnet places in this area	23%
	Magnetic field as the space in which a force is exerted to the needle of a compass	9.2%
Scientifically Unacceptable Responses	A magnet can attract any object	14.8%
	Magnetic field as a force	12.5%
	Magnetic field as real, concrete magnetic lines	14.8%
	Association of magnet with electric charges	2%
Other Responses	Magnetic field as a surface No responses	6%

The 3rd question of the questionnaire Q_3 was given to students to probe their understanding of a charged particle moving along a solenoid. Students' responses were divided into four distinct categories

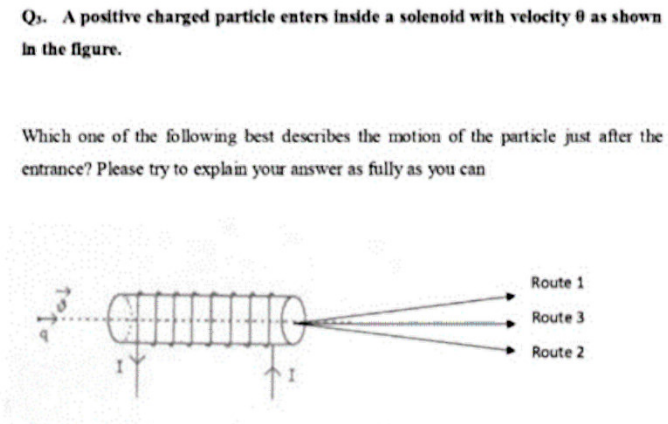

Figure 3. Card Consisting the 3rd Item of the Questionnaire

First, scientifically acceptable arguments (route 3). Only an extremely small percentage of students (3.7%) gave a fully scientifically acceptable response to this question. In such a response, it was supposed that the pupil would describe step by step what happens when the current starts flowing to the solenoid. In particular, a student was expected to give a similar to the following response 'A current flows to the solenoid. The current produces a linear magnetic field within the solenoid. The charged particle is moving in a route parallel to the magnetic field lines. As a result, no force will be exerted to the particle, which will follow route 3' (Student).

Second, partially scientifically acceptable arguments (route 3). The majority of the students (almost 59.8%) managed to indicate the correct route of the particle by giving a partially scientifically acceptable explanation. These students confined their answer to just referring to the fact that the field is homogenous or that the particle moves along the magnetic field lines. To quote one student 'The particle will follow route 3, as it is moving in a homogeneous field' (Student). Third, scientifically unacceptable arguments: a) Route 1. There were 9.2% of the students indicated that the particle would follow route 1. Some of the students gave this answer according to the following reasoning: the particle would follow the direction of the current and therefore, in the end of the solenoid, the particle would move upwards. Specifically, a student pointed out 'The particle will follow route 1 because at the time the particle goes out of the solenoid, the current at that point is moving upwards' (Student). Some other students indicated route 1 just because they failed to use correctly the right-hand rule. This is well reflected in the following students' statement 'The current produces a linear magnetic field within the solenoid. By using the right-hand rule, we can find that the particle will follow route 1' (Student); b) Route 3. There were 5.6% of the students indicated the correct route 3 by providing an explanation that was scientifically unacceptable. Such an explanation is the following one 'The correct answer is route 3 as the particle is positively charged and therefore no force will be exerted to it' (Student); c) Route 2. The same small percentage of 5.6% indicated route 2 as the correct answer. Their way of thinking, as it is explicitly shown from the following response, was influenced by their misunderstanding of the notion of voltage 'In point 2 there is negative voltage and therefore the positively charged particle will move towards point 2' (Student).

Fourth, no response. A relatively high percentage of 16.1% did not provide any answer at ll. Students' responses are summarized in Table 3.

Table 3. Percentages of Students' Responses (N=80) about the Notion of a Moving Particle in a Magnetic Field Produced by a Solenoid Current Carrying Conductor

Type of Response	Route	Content of Response	Percentage of Students
Fully Scientifically Acceptable Responses	Route 3	Current flow to the solenoid The current produces a magnetic field within the solenoid The particle is moving parallel to the magnetic field lines No force will be exerted to the particle	3.7%
Partially Scientifically Acceptable Responses	Route 3	The particle is moving in a homogeneous field The particle is moving along the magnetic field lines	59.8%
Scientifically Unacceptable Responses	Route 1	At the time the particle goes out of the solenoid, the current at that time is moving upwards	9.2%
	Route 2	The voltage in point 2 is negative, so the positively charged particle will move towards point 2	5.6%
	Route 3	The particle is positively charged, so no force will be exerted to it	5.6%
No response			16.1%

The 4th question of the questionnaire Q_4 was given to students to probe their understanding of the induction of emf. Students' responses were divided into four distinct categories

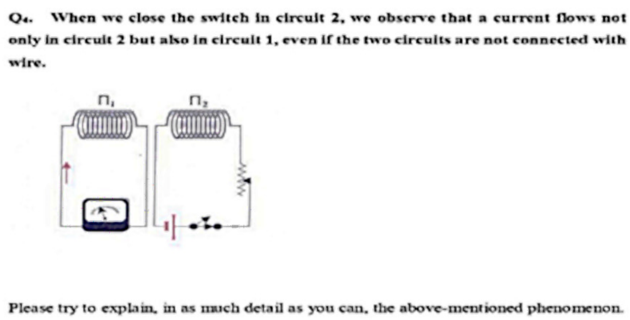

Figure 4. Card Consisting the 4th Item of the Questionnaire

First, fully scientifically acceptable arguments. There were 16.1% of the students managed to explain the phenomenon by using fully scientifically acceptable arguments. Their responses had a clear structure where it was explicitly shown, step-by-step because a current would flow in circuit 1. Such a response is given below 'A current flows in circuit 2 when we close the switch. As a result of this current, the number of magnetic field lines which pass through coil 2 (called magnetic flux) changes. This flux changing in coil 2 causes a flux change in coil 1. The change of flux in coil 1 induces a voltage in circuit 1. Therefore, a current flow in circuit 1. Lenz's Law determines the direction of the current' (Student). Second, partially scientifically acceptable arguments. There were 23% of the students gave a scientifically acceptable response without explaining the phenomenon clearly and accurately. Instead of describing step by step the phenomenon from the beginning to the end, they just referred to some specific stages of the whole process. Such kinds of response is the following 'A voltage is induced in circuit 1 because of the changing flux in circuit 2' (Student) . Third, scientifically unacceptable arguments. There were 23% of the students explained the phenomenon by using a 'charge flowing model', where charges could travel from one circuit to another. This students' alternative conception has been identified by a number of science education researchers such as Anderson (1985), Prosser (1994) and Loftus (1996). The students whose thinking was dominated by the 'charge flowing model' responded to the following: 'A current flow in circuit 1 as the circuit 2 is near circuit 1' (Student) and 'The current will flow from circuit 2 to circuit 1' (Student). 14.9% of the students used other alternative ideas to explain the phenomenon mentioned above. These students seemed to be unable to think in terms of electromagnetic theory. For example, 'A current flows to circuit 1 due to an induction of voltage' (Student). Fourth, no response. A high percentage of 23% did not give any response at all. These students were unable to deal with the induction emf. Students' responses to the question mentioned above are presented in Table 4.

Table 4. Percentages of Students' Responses (N=80) about the Induction of emf

Type of Response	Content of Response	Students' Percentage
Fully Scientifically Acceptable Responses	Close switch Current flows in circuit 2 Changing flux in circuit 2 Changing flux links in circuit 1 Changing flux induces voltage in circuit 1 Current flows in circuit 1	16.1%
Partially Scientifically Acceptable Responses	The changing of current in circuit 2 induces a voltage and a current in circuit 1 Any flux change in circuit 2 causes a flux change in circuit 1. Hence, a current flow in circuit 1 A current flow in circuit 1 because of the mathematic equation E= (-) N*DF/Dt	23%
Scientifically Unacceptable Responses	Charge flowing model	23%
	Other ideas	14.9%
No Response		23%

Judging from the above, students seem to face difficulties in dealing with tasks concerning electromagnetism. While alternative approaches should be adopted by teachers to help students overcome those difficulties (Okulu & Ünver, 2018; Ouasri, 2018; Kähkönen et al., 2020; Lemmer et al., 2020; Prytz, 2020; Kaliampos et al., 2021). On average, less than 20% of the students gave a fully scientifically acceptable response to each question. Only a slightly higher percentage of about 30% managed to provide a partially scientifically acceptable response. Therefore, it can be concluded that students did not have a good performance in this questionnaire. It is worth mentioning here that the pupils had just been taught the subject of electromagnetism in school.

Table 5. Percentages of Students' Scientifically Acceptable Responses (N=80) in Each Question

Type of Response	Q_1	Q_2	Q_3	Q_4
Fully Scientifically Acceptable	11.5%	17.7%	3.7%	16.1%
Partially Scientifically Acceptable	21.5%	32.2%	59.8%	23%

In relation to electric field (Q_1), only 11.5% of students correctly drew the electric field lines in the tasks given (Guth & Pegg, 1994). Moreover, few of them pointed out that there would not be any difference between the electric field lines of two charges on the Earth and in space, respectively (Bar et al., 1997). In contrast, almost 48% of the students failed to give a correct response about the form of the electric field lines in space. These students either believed that the electric field cannot exist in the space or thought that the electric field could exist in the space only in a totally different form. As question Q_2 shows, students have several alternative conceptions of magnetic flux. In particular, 44.1% gave several scientifically unacceptable responses related to magnetic flux. Some pupils believed that a magnet can attract any object or that magnetic field is a kind of force, while others thought that magnetic field lines are real, concrete lines. Moreover, as question 4 indicates, many pupils treated magnetic flux as a substance that is capable of moving from one circuit to another.

As question Q_3 shows, students seem to deal quite well with the notion of a moving particle along a magnetic field which is produced by a solenoid current-carrying conductor. A high percentage of 59.8% managed to give a partially scientifically acceptable response. Indeed, most of the pupils stated that no magnetic force would be exerted on a particle moving along the magnetic field lines. A possible explanation for this remarkable high percentage of correct answers may be that the students had just been taught electromagnetism, and therefore they may quote this scientifically sounded phrase. However, this does not mean that the pupils had a deep understanding of this phrase as only the 3,7% of the students gave an entirely scientifically acceptable response to the question. Finally, as question Q_4 shows, students face difficulties in understanding the induction of emf (Okpala & Onocha, 1998). In particular, 37.9% used alternative ideas to explain the phenomenon. So, many of the pupils referred to the 'charge flowing model' where current can flow from one circuit to another (Anderson, 1985; Prosser, 1994; Loftus, 1996). It is worth mentioning that a remarkably high percentage of 23% did not give any response at all.

As literature review shows, there seems to be a gap on exploring Greek high school students' ideas on electromagnetism, as Greek researchers tend to focus on studying electric and magnetism on primary or secondary school level. Therefore, novelty of the current research lies on its originality, as mental representation of 17-year-old Greek high school students on electric and magnetic field as well as induction of emf are studied for first time in the literature. Results set new parameters that have not be formulated so far and gives new insights into the way students of that age conceptualize electromagnetism.

CONCLUSION

In broad terms findings indicate that students face difficulties in dealing with the concepts of both electric and magnetic field as well as induction of emf. By comparing the findings mentioned above with those in the international research literature, there seems to be a remarkable overlap. In particular, regarding electric fields, the findings of question 1 are in line with literature review, where it is stated that pupils often hold the view that electric and magnetic fields can only exist in Earth. Moreover, the finding of this work that students often treat magnetic field lines as real, concrete lines is consistent with literature review findings. In relation to induction of emf, the findings of question 4 show pupils often use the 'charge flowing model' to deal with electromagnetism tasks. Apart from the above-mentioned overlapping between the findings of this work and those of international research literature, there are some differences. Quite interestingly, student's difficulty in Lenz's law was revealed here. As research findings explicitly shows, a high percentage of students who graduate from high school do not have a deep understanding of the concepts of electromagnetism. Even if they are able to quote some laws or scientifically sounded phrases, they cannot apply them in specific contexts. Therefore, alternative approaches for teaching in this area should be adopted by teachers, if we are to make students gain a better understanding in electromagnetism and/or magnetic and electric field. An important limitation of the study lies on the fact that data was collected solely through questionnaire. Undoubtedly, semi-structured interviews that follow the questionnaire would give to the researchers a better insight on students' ideas. In addition, further research followed by specific teacher interventions as well as pre-test and post-test practices would shed light on the persistency of these ideas. It should be noted that in the current research, national and international research ethics guidelines were followed.

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