Teaching electromagnetism: interviewing three Greek high-school teachers

GEORGE KALIAMPOS[1], PANAGIOTIS PANTIDOS[2], KONSTANTINOS GRIVOPOULOS[3], KONSTANTINOS RAVANIS[3]

[1]*Department of Education, School of Education*
University of Nicosia
Cyprus
kaliampos.g@unic.ac.cy

[2]*Department of Early Childhood Education*
National and Kapodistrian University of Athens
Greece
ppantidos@ecd.uoa.gr

[3]*Department of Educational Sciences*
and Early Childhood Education
University of Patras
Greece
kgrivop@upatras.gr
ravanis@upatras.gr

ABSTRACT

The present study is set in the context of teaching electromagnetism in Greek high schools. In particular, it aspires to probe teachers' ideas about the way they deal with this teaching subject in classroom. For this purpose, empirical data were collected through interviewing 3 teachers who taught physics in Greek public domain schools. Research findings suggests that teachers face difficulty in teaching electromagnetism indicating its abstract nature as the main cause of it. Educational implications for teaching and learning electromagnetism are discussed in the final part of the study.

KEYWORDS

Teachers' science ideas, electromagnetism, secondary education

RÉSUMÉ

La présente étude s'inscrit dans le contexte de l'enseignement de l'électromagnétisme dans les écoles secondaires grecques. En particulier, elle vise à sonder les idées des enseignants sur la manière dont ils traitent ce sujet d'enseignement en classe. À cette fin, des données empiriques ont été recueillies en interviewant trois professeurs qui enseignaient la physique dans des établissements publics grecs. Les résultats de la recherche suggèrent que les enseignants rencontrent des difficultés dans l'enseignement de l'électromagnétisme, indiquant que sa nature *abstraite en est la cause principale. Les implications pédagogiques pour l'enseignement et l'apprentissage de l'électromagnétisme sont discutées dans la dernière partie de l'étude.*

MOTS-CLÉS
Idées scientifiques des enseignants, électromagnétisme, enseignement secondaire

THEORETICAL FRAMEWORK

During the last few decades constructivism has dominated Science Education and seems to exert a major influence in the research field of teaching and learning school science. According to this theory, students do not come to school as ‘empty vessels’ who have no idea about how physical systems operate. In contrast, they seem to have their own ideas about a number of science concepts and phenomena which play a key role in learning process (Boilevin, 2013; Driver, Guesne, & Tiberghien, 1985). The current study deals with 3 teachers views on teaching electromagnetism. Along this line, students’ ideas are presented so that the reader would be able to approach them in parallel to what the teachers think is difficult for the students. Consequently, part of this research deals with students' ideas about electricity, magnetism and electromagnetism (Kaliampos et al., 2020; Kada & Ravanis, 2016; Koumaras, Kariotoglou, & Psillos, 1997; Métioui & Trudel, 2020; Métioui, Baulu-Mac Willie, & Trudel, 2016; Ntourou, Kalogiannakis, & Psycharis, 2021; Ravanis, Pantidos, & Vitoratos, 2009, 2010; Voutsina & Ravanis, 2011).

Literature clearly shows that students confront difficulties in dealing with the ‘notions’ of magnets, fields and induction of electromagnetic flux (emf). These notions are conceptually demanding and cannot be easily understood by a significant majority of pupils. Therefore, the pupils use a number of alternative conceptions to deal with them. Erickson (1994) states that both primary and secondary pupils use a variety of models to explain the magnetic force. The most commonly used model for primary students is the ‘Pulling model’. This model deals only with magnetic attraction and suggests that any magnet is capable of ‘sucking’ or ‘pulling’ objects. On the other hand, secondary students often use the ‘Emanating’ model. According to that model, a stream of particles goes from the magnet to the object and as a result the object is attracted. Bar et al. (1997) points out that a number of pupils associate magnetic force with waves. In particular, they believe that magnetic waves originate from the magnet, travel through space and reach other objects in order to attract or repel them. This is well reflected in the following statements of two 6th and 10th grade students ‘*a magnet can pass on magnetic waves through the air*’ and ‘*magnetic attraction expands in space in waves*’ (Bar, Zinn & Rubin, 1997, p. 1149).

Paulus and Treagust (1991) state that pupils often treat magnetism as a fluid substance. In research conducted by them, 74 per cent of 16-years–old students believed that magnetism exist as a substance within magnets and is capable of moving. Specifically, it can move through materials and can flow from one material to another. This alternative conception makes students believe that a magnet loses magnetism when it attracts something to itself. Indeed, according to their belief magnetism flows to the other object and therefore the magnet becomes weaker. Bailey, Francis & Hill (1987) also refer to this alternative conception and point out that the majority of primary students believe that a new magnet would be much stronger than a used one.

In addition, a great number of children associate magnetism with air. In research conducted by Bar et al. (1997) it was found that the majority of secondary students believed that air is essential for the magnetic force acting at a distance. To quote a 9th grade pupil’s idea ‘*air affects magnetic attraction; without air, magnetic attraction stops*’ (Bar et al., 1997, p. 1140). These students also believed that a magnet would stop functioning if air is removed from its environment. As a result, many of the pupils answered negatively the question of whether a magnet can act on the moon. One child stated '*on the moon there is no air that can help the magnet to attract iron*' (Bar et al., 1997, p. 1142). Other pupils do not associate magnetism with air but with the Earth's environment in general (Bar et al., 1997). They believe that Earth holds a very special place in the universe that differentiates it from any other planet. According to a 7th grade pupil '*a magnet will only function on the Earth and not on other places*' (Bar et al., 1997, p. 1142). This idea reveals another common students' alternative conceptions; that of association of magnetism with gravity. Bar et al. (1997) state that students many times refer to gravity as an important factor for any magnetic interaction. This is well illustrated in a 11th grade child's sentence '*without gravity there is no stability and the magnet cannot function*' (Bar et al., 1997, p. 1151).

Loftus (1996) states that secondary students encounter difficulties in understanding electromagnetic induction. In particular, he found that the majority of the pupils were unable to 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, p. 93). Prosser (1994) identifies this alternative conception of charge flowing model too. Specifically, in his study university students were asked what would happen if a magnet is moved into and out of a coil connected into a circuit. While the majority of the students answered that a current would flow in the circuit, only few of them were able to explain the phenomenon in scientifically accepted terms. A great number of the pupils suggested that '*the magnet attracts charges, resulting in a current flowing in the circuit*' (Prosser, 1994, p. 198). In addition, Anderson (1985) points out that 15-year-old students used the 'charge flow' idea to explain how an electromagnet operates. Those students believed that somehow current travels from the coil of wire to the magnet in the centre and therefore the electromagnet is capable of providing a current to other circuits beyond.

While a number of researchers have extensively study students' alternative ideas on these concepts, few of them have investigated teachers' views on teaching electromagnetism (Galili, 1995; Loftus, 1996). Indeed, while teachers' ideas can shed light on the teaching process, they have rarely received a systematic view. In the current study, an initial recording was attempted of the ideas of 3 teachers who serve in Greek public high schools and teach electromagnetism at a high level preparing their students for the national exams. This recording aims at an initial qualitative depiction of particular aspects of teachers' ideas on issues related to their experiences from the Greek curriculum.

Electromagnetism in Greek Curriculum

In Greek curriculum, science is first introduced to students at the age of ten years old in primary school. In that class simple Physics, Chemistry and Biology ideas are integrated into one module called 'Φυσική'. It is only from the second class of secondary school that physics is taught as a separate module, which then becomes compulsory throughout secondary school. The taught subject matter is strongly fixed by the national curriculum for science. In particular, for every grade there is one textbook which must be followed by the teacher.

Electricity and magnetism hold an important position in the Greek science curriculum and are introduced to the students from the second class of secondary school. Simple ideas about current and magnets are presented to students at that time. The academic level of those ideas gets higher as students go to the high school. The most important ideas of electricity and magnetism such as the electromagnetic theory are presented to the students in the second grade of high school at about the age of 17 years old.

Regarding the textbook of that grade, it begins in the first chapter with a reference to Coulomb's Law. In particular students are taught about the force that is exerted between two or more charges and they are supposed to make calculations for finding that force in different occasions i.e. calculate the force that is exerted when an electron moves around a proton. Then the notion of electric field is introduced. Students are taught about the different electric fields lines that are produced by different electric charges such as an electron or an electron and a proton in a certain distance. In the second chapter, students are taught about the electric current and its intensity (I=Q/t). The thermal, chemical and magnetic effects of current are analysed. Then the first and second Kirchhoff's Laws are presented and students are expected to be able to calculate the current and the potential difference between different parts of an electric circuit. Later in the chapter the notion of resistance (R) is introduced. Finally, in the third chapter of the textbook electromagnetic theory is introduced to the students. Specifically, in the beginning of that chapter there is a reference to the magnetic field and the magnetic field lines around a magnet. The magnetic fields, which a current in a wire and a coil produces, are also presented. Later in the chapter, the electromagnetic force along with motor effect, electromagnetic induction and Lenz's law are extensively discussed (Alexakis et al., 2004)

It should be noted that at the end of every chapter there are both qualitative and quantitative tasks for promoting students' understanding. In particular, in qualitative tasks the students are usually called to answer open-ended questions such as 'describe the motor effect' or 'describe two ways in which we can infer that a magnetic field exist' (Alexakis et al., 2004, p. 183). In quantitative tasks the students have to manipulate data and make calculations such as 'could you find the electromagnetic force which is exerted between two parallel current carrying conductors of I1=10A and I2=50A respectively. The length of each conductor is 1m and their distance is 2cm' (Alexakis et al., 2004, p. 195).

METHODOLOGICAL FRAMEWORK

The overview of the study

As outlined above, the present study focuses on teaching electromagnetism in Greek high schools. In this perspective, it aspires to answer into the following research question: What are the views of three Greek physics teachers about the challenges of teaching electromagnetism in high-school?

Research instrument

Tape-recorded interviews were used to probe Greeks physics teachers' views about the challenges of teaching electromagnetism as well as their ideas of how to overcome these challenges. The type of interview used was semi-structured, so that there would be flexibility in what would be discussed. Indeed, the researcher's aim was not to restrict the teachers into a predetermined dialogue. Far from it, the aim was to ask teachers some specific questions and give them the opportunity to deal with them in their own way. Depending on the teacher's reaction to an initial question area, it was decided by the researcher whether to expand the question or to progress onto the next one. Therefore, the following protocol, which allowed the opportunity of asking further questions, was constructed.

(a) *Students' difficulties*: Questions on the difficulties that students face when learning electromagnetism
(b) *Teaching approaches*: Questions on the challenges of teaching electromagnetism to 17-year-old students and appropriate teaching approaches to deal with these challenges
(c) *Students' interest*: Questions concerning ways that can make the teaching and learning of electromagnetism more interesting for the students

Administration of research instrument

Two general high schools set in an urban Greek city were chosen for administrating the interviews. Having chosen the schools, the researchers came into contact with the headmasters of the schools to apply for permission to gain access into the schools and conduct the research. Having gained the permission of the headmasters of both schools, the researchers came into contact with the Physics teachers who teach electromagnetism in the second year of the two above-mentioned high schools. After having a personal chat with them about the researchers' background and the purpose of the study, they asked them if they could be interviewed. The teachers consented to be interviewed and an appointment was arranged with each one of them over the next few days. In one case the teacher did not come to the appointment, because of personal reasons and therefore another appointment had to be arranged. In total three male teachers were interviewed, two from one school and one from the other. All three teachers hold a BSc degree in physics without any undergraduate/postgraduate studies in science education. They all had more than 15 years' experience in teaching physics in high school.

The interviews took place in vacated classrooms of the schools, as the students had other activities to do at that time i.e. physical education. Having made explicit to teachers that the interview would be confidential and anonymous, they were asked whether they would mind the interview to be tape-recorded. In all three cases, the teachers answered yes without second thoughts. The interviews were conducted face-to-face so that the researchers would have a better idea of the points made by the teachers. By doing so, there was little opportunity of there being a mismatch between the respondents' and the researchers' points of view (Cohen, Manion, & Morrison, 2004). The duration of each interview was about 20 minutes.

The overview of the analytic procedure

The data from all the three interviews were in the form of audiotape recordings. It was decided not to transcribe the content of the audiotapes. In contrast, a content analysis through listening to the audiotapes several times was adopted. In particular, for each question asked to the teachers, the researcher listened all the interviewee's responses to that question in a row and identified the key issues raised by them (Cohen et al., 2004). These issues noted down on a piece of paper and were later translated from Greek to English.

RESULTS

Students' difficulties identified by the teachers

All three teachers stated that electromagnetism is generally a difficult subject for the students. According to their views, this is due to the fact that the central concepts of electromagnetism are extremely abstract. Therefore, the students face difficulties in understanding them. In particular, one teacher pointed out *'Electromagnetism is a much more difficult field of Physics* than other *fields such as Mechanics, where the notions are relatively concrete compared to those of electromagnetism'* (Teacher 3)

In addition, all the teachers seemed to agree with the fact that the most difficult part of electromagnetism is the induction of emf. They stated that this is because the pupils cannot conceptualise abstract notions such as the notion of magnetic flux. Specifically, the teachers made the following comments *'Students encounter difficulties in understanding what the magnetic flux represents. It is extremely difficult for them to relate magnetic flux to magnetic field lines'* (Teacher 1), *'Students cannot realize that an induction of emf exists only in the case of a changing magnetic flux. They get confused with the fact that there is no induction of emf when a magnet is at rest'* (Teacher 2) and *'Students cannot realize how it is possible to have a current flow without any source of electric energy. Notions such as the magnetic flux seems to be totally abstract for their reasoning'* (Teacher 3).

Furthermore, students face difficulties in having a deep understanding of Lenz's law, as both teachers 1 and 3 identified. In particular, they stated that while students can formulate Lenz's law, they are not capable to use it in concrete tasks in order to find the direction of the induced current. *'There is no doubt that the majority of the students are capable of formulating Lenz's law. Nevertheless, only a small percentage of them can apply correctly Lenz's law in specific circuits in order to find the direction of the induced current'* (Teacher 1) and *'Almost all students can learn Lenz's law by heart. However, few of them can have a deep understanding of this law. Indeed, in the majority of the cases students are not able to apply Lenz's law in particular tasks'* (Teacher 3)

Teaching approaches identified by the teachers

Teacher 1 stated that the students should have a deep understanding of what magnetic flux represents in order to conceptualise this notion. Therefore, an extensive reference to magnetic field lines should be made before teaching magnetic flux. In particular, teacher 1 pointed out *'I am used to refer to the magnetic field lines when I am planning to teach magnetic flux. Specifically, I will not start teaching magnetic flux until I have spent a great amount of time in teaching magnetic field lines. Having done this, I precede in the teaching of magnetic flux, where I explain to the students what it represents; the magnetic flux represents the number of the magnetic field lines that passes through the unit of surface. So, if a magnetic field has intensity 4 Tesla, this means that four magnetic field lines would pass through the unit of surface. By so doing, the student realise that the magnetic flux is not a totally abstract notion. As a result, it is more possible for them to conceptualise it'* (Teacher 1).

In addition, both teachers 1 and 2 stated that the students could better understand Lenz's law if they realized that this law is in step with the conservation of energy. Therefore, according to their views, the link between Lenz's law and the conservation of energy is more than necessary. In particular, these teachers pointed out *'It is only when students think in terms of the conservation of energy that they can have a deep understanding of Lenz's law'* (Teacher 2) and *'The majority of the students seems to be reluctant in accepting Lenz's law. Nevertheless, they often get convinced when they realize that this law is not in contradiction with the conservation of energy'* (Teacher 1).

As teacher 1 pointed out, a possible reason for the fact that the students encounter difficulties in electromagnetism is that they do not know solid geometry. According to his view, the majority of the pupils are not capable to draw a shape nicely. This makes them unable to cope with tasks that demand a great sense of space, such as the spiral movement of a particle in an electromagnetic field. Therefore, a way of helping students to deal with those tasks is to teach them a bid of solid geometry in parallel with electromagnetism.

All the teachers seemed to agree that practical work is a great tool for teaching electromagnetism. Nevertheless, two of them pointed out that even with practical work the students would not be able to have a deep understanding of the induction of emf, as the mechanisms of this phenomenon are at a microscopic level. Specifically, one teacher stated *'There is no doubt that practical work can help students to have a better idea of the induction of emf. However, even in this case the pupils can observe only the results of the phenomenon and not the phenomenon itself. Indeed, they may be capable of observing lamp lighting in a circuit in which there is not any source of electrical energy, but they are still not able to observe the changing of magnetic flux. The procedures of the induction of emf are in a microscopic level while practical work has macroscopic nature'* (Teacher 2). Moreover, another teacher pointed out *'Practical work can help in the direction of convincing the students that the induction of emf can happen in everyday life; indeed, it is possible in real life to have current flow without any source of electrical energy. However, practical work seems to be unable to make students conceptualise abstract notions such as the magnetic flux'* (Teacher 3).

Students' interest in Electromagnetism

Finally, the teachers expressed different opinions of whether the students find the lesson of electromagnetism interesting or not. In particular, teacher 1 stated that the pupils like electromagnetism, as it is a field with many applications in everyday life such as the motor effect, the generators and the transformers. However, he recognized that these applications are not made explicitly in class as the main part of the lesson is in dealing with quantitative problems.

On the other hand, teachers 2 and 3 stated that the pupils find electromagnetism boring, as they are not capable to conceptualise its abstract notions. The fact that electromagnetism is taught in an entirely quantitative form with plenty of difficult mathematic problems makes the students dislike it as a subject. Nevertheless, they both pointed out that the national exams which the students have to take at the end of high school does not allow them to try make it more interesting by referring to application of electromagnetic theory in everyday life. In particular teacher 2 stated '*Students do not show any interesting in learning electromagnetism, as they cannot have a deep understanding of its notions. A possible explanation for this may be their young age. Moreover, that the lesson of electromagnetism is mainly consisting of difficult quantitative tasks. However, the national exams in the end of the year demands that the pupils would be able to cope with these tasks and therefore our role is inevitably confined into just helping them in this direction*' (Teacher 2).

In addition, teacher 3 made the following worth mentioning point '*Many students seem to be afraid of learning electromagnetism. We suspect that this happens because the students are influenced by the way that current is treated in everyday life. In particular, current is supposed to be a dangerous thing from which everyone should keep his distance. As a result, the pupils are not interesting at all in learning about anything which is related with the current*' (Teacher 3).

DISCUSSION

Regarding the views of Greek Physics teachers about the challenges of teaching and learning electromagnetism, all the three of them indicated that electromagnetism has an abstract nature and therefore it is difficult to be understood by students. In particular, they stated that the concept of magnetic flux could be difficult conceptualised by pupils. This is in line with the findings of literature review. Specifically, Paulus and Treagust (1991) pointed out that students couldn't understand magnetic flux and therefore they dealt with magnetism as a fluid substance. Guth and Pegg (1994) also found that students face difficulties in conceptualising the notion of magnetic flux. According to their research, pupils hold the view that magnetic flux consists of real, finite and concrete field lines. Along this line stands the ‘charge flowing model’ where magnetic flux and current can travel from one circuit to another one at a small distance (Anderson, 1985; Loftus, 1996; Prosser, 1994).

In addition, two teachers (1 and 3) identified that students have difficulties in understanding Lenz’s law. They stated that while the majority of the students can quote Lenz’s law, only a few of them could apply it in specific tasks. This is in line with student’s responses in question 6, where the majority of them were not able to explain in a fully scientifically acceptable way the induction of emf. What is noteworthy here is that the problems that pupils face in Lenz’s law seem not to be extensively referred in academic literature. For example, in a large-scale study conducted by Okpala and Onocha (1988), about the most difficult Physics topics, Lenz’s law was surprisingly not included at all in a list of 53 of those topics.

In all these teachers’ statements it is apparent that students face difficulties in conceptualizing the theories-models and object-events that are related to the knowledge pole of the didactical triangle (Amigues, 1988); the other two being learning and teaching pole. Drawing from the specific theory of the Two Worlds proposed by Tiberghien, Vince and Gaidioz (2009), the implementation of modelling activity is required in both physics knowledge to be taught and everyday students’ knowledge. Through this modelling process students are expected to gain the ability to conceptualize the explanatory ideas that are associated with the observed events that govern the physical world. Particularly, students should be able to distinguish the objects and events, both at macroscopic and microscopic level from the theories and models that are related with the field of electromagnetism. In the first category lie the observation of atoms, current flow and magnetic field lines through simulation devices and the diverse measurements with specific laboratory devices such as voltmeter and amperemeter while on the second category lie the theoretical statements such as Lenz’s law and the calculation of the current through the treatment of specific measurements in experimentation process. It is this distinction that will enable students, in a second stage, to gain the required set of knowledge regarding emf.

With regard to teaching strategies, two teachers (1 and 2) pointed out that the students could better understand Lenz’s law if the link between this law and the conservation of energy is made explicitly to them. In the context of the Two Worlds theory, both these notions fall into the theories-models pole where modelling elements could help students to relate theory with observed and selected events (Tiberghien et al., 2009). By successfully doing the above-mentioned link, pupils find Lenz’s law plausible and therefore can more easily accommodate it (Posner et al., 1982). Moreover, one teacher (1) stated that the notion of magnetic field lines should be extensively taught to the students before proceeding in teaching magnetic flux. This teacher also pointed out that teaching solid geometry in parallel with electromagnetism will help pupils to draw shapes nicely and gain a better sense of space. This will make them capable to deal with notions that demand a great sense of space such as the spiral movement of a particle in an electromagnetic field. Tiberghien et al. (2009) refer to the crucial role of semiotics in the teaching pointing out that drawings and pictures can play a key role in the process of knowledge analysis. All the three teachers mentioned that practical work would help the students to have a better idea of the induction of emf. Nevertheless, two of them (2 and 3) stated that practical work seems to be unable to make students conceptualise abstract notions such as the magnetic flux. This is because these notions have a microscopic nature while practical work is in a macroscopic level.

Finally, two teachers (2 and 3) stated that students find electromagnetism boring while one teacher (1) stated that students like it as a subject. In particular, teacher 2 and 3 pointed out that students cannot understand abstract notions such as magnetic flux and Lenz's law and therefore they do not like electromagnetism at all. In addition, the fact that electromagnetism is taught in a totally quantitative aspect, due to the national exams, made electromagnetism an extremely hard subject. In contrast to this, teacher 1 stated that pupils like electromagnetism, as it is a subject that has many applications in everyday life. Nevertheless, he admitted that these applications are rarely made explicitly in the class, as the national exams in the end of the year demand from the students to be able to cope with quantitative and rather than qualitative tasks.

Implication of research findings

Judging from the findings of this piece of work as well as from findings of other research (Bagno & Eylon, 1997), there is no doubt that teachers encounter severe difficulties in teaching electromagnetism. 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 might be adopted by the teachers, if we are to make students gain a better understanding in electromagnetism.

It is quite important in teaching electromagnetism and Physics generally, that the students will not be just passive recipients of new knowledge (Driver, Guesne, & Tiberghien, 1985; Ravanis, 2010). Far from it, the students should actively participate in the learning process by asking questions and interact with both their teacher and their classmates. Therefore, the teachers should adopt an interactive/dialogic communicative approach where they discuss, probe and support students learning (Mortimer & Scott, 2003). By doing so, the teachers are able to take into accounts students' thinking and adjust their teaching strategies into pupils' needs.

Drawing from constructivism, the distinct grand theory of learning that takes into account students' prior knowledge, a theoretical framework could be drawn up to design specific teaching sequences. Through this process it is considered essential the didactical transposition from the reference knowledge (scientific knowledge) towards the knowledge to be taught (official curriculum, textbooks) and finally the taught knowledge (knowledge of a classroom). Across these stages, the modelling approach of the Two Worlds proposed by Tiberghien et al. (2009) could provide the theoretical framework for constructed specific tools that will guide the framing and designing of specific teaching activities.

Along the designment of these teaching sequences, the use of a conceptual map can help students to gain a deeper understanding in electromagnetism (Bagno & Eylon, 1997). Indeed, by using conceptual maps, the teacher has the opportunity to make explicit the link between a number of variables. Pupils can realise the link between electricity and magnetism by observing for example how electric force corresponds to magnetic force and how electric charges corresponds to magnets. Furthermore, a conceptual map is undoubtedly a very useful tool for summarizing the domain of electromagnetism.

In addition, teachers can adopt a number of other strategies in order to help students gain a deeper understanding of electromagnetism. For example, by making explicit the link between Lenz's Law and conservation of energy, the students are likely to find Lenz's law plausible and therefore able to accommodate it (Posner et al., 1982). Moreover, teaching magnetic field lines in advance of magnetic flux can help students to understand what the magnetic flux represents. Having a good understanding of magnetic flux can lead students to conceptualise central notions of electromagnetism such as the induction of emf. Furthermore, teaching solid geometry along with electricity and magnetism can help students to gain a better sense of space. This will make them capable to deal with notions that demand a great sense of space such as the spiral movement of a particle in an electromagnetic field.

Moreover, ICT tools can add value to teaching and learning electromagnetism (Kalogiannakis, Nirgianaki, & Papadakis, 2018). In particular, simulations can help students 'to make abstract concepts real through the imaginative use of interactive animated graphics' (Rogers & Finlayson, 2003, p. 109). Indeed, pupils get a visual focus of the scientific concept and therefore they are able to comprehend it in a much deeper way. They have the unique opportunity to look at the microscopic level and observe a number of models showing what is going on there (Scaife & Wellington, 1993). As a result, students are able to grasp ideas about abstract notions such as the electric field and the magnetic flux. Nowadays teachers have the opportunity to choose from a wide range of simulations for teaching electricity and magnetism. An extremely good simulation, which might raise the standards of achievements in teaching, is FurryElephant (https://www.furryelephant.com). Nevertheless, an important point arises here when using ICT tools. In particular, while ICT tools are often clarified as inherently advantageous for promoting science learning, it is only when they are used in a specific context and for a specific purpose that they can add value to teaching and learning in science. Therefore, teachers should not try to adapt their teaching method to what is available (Lewis, 2003). Far from it, they should try to incorporate these tools into their existing teaching techniques and generally use ICT in the light of their experience.

Limitations of the study

The extremely small sample suggests a limitation of the study that makes our findings to be treated with caution. Undoubtedly, a follow-up to this exploratory study is needed in order to obtain more robust result. In this larger scale investigation, drawing from the grand theory of constructivism, the epistemological conceptual framework of the two Two-World specific theory could be used to further analyze teachers' responses and act as a basement for designing specific teaching activities on electromagnetism.

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