Addressing misconceptions about electric and magnetic fields: A variation theory analysis of a lecture's learning space

A master thesis in Science Education and Communication

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Abstract

This study explored which conceptual difficulties regarding electric and magnetic fields occur amongst South African physics teachers who participate in the Sediba programme. Misconceptions that were found were regarded in light of the variation theory of learning, i.e. it was investigated which critical aspects of the concepts electric and magnetic field the teachers do not discern, which could lead to their misconceptions and confusion of concepts. Finally, a lecture of the Sediba programme, which aims to enhance the teachers' content knowledge, was analysed in light of the variation theory to investigate the space of variation that was established. The analysis determined the learning potential that emerged during the lecture in terms of the possible discernment of critical aspects, and consequently whether a change in the participants' conceptions could be expected.

Introduction

The number of South African students who qualify for tertiary studies in the field of natural science, engineering and technology is much lower than what is currently needed for the country's economy (Kriek and Grayson, 2009). Furthermore, scientific literacy amongst South African secondary school graduates remains lower than desirable. This has been a problem for many years. To enhance secondary education, substantial changes in the didactical approach of South African school subjects have been suggested in the past decade. Despite this reform, desired results in scientific literacy and the number of students reaching the university entrance level in science and mathematics remained low (Pandor, 2006). In 2003, the Trends in International Mathematics and Science Study (TIMSS) collected educational achievement data in fifty different countries. These tests indicated that South African scores were the lowest of the participating countries. The National Department of Education has since prioritized the improvement of mathematics and science teaching ("Annual Report of the Department of Education", 2009).

Motivation and Research Questions

One aspect that determines the quality and success rate in science education is the expertise of its teachers. This is especially the case in the Further Education and Training phase (FET phase), which consists of the final grades of secondary education (Reddy, 2006). Aspects that can influence educational outcomes negatively are the teachers' lack of content knowledge, of teaching approaches and of professional attitudes (Kriek and Grayson, 2009). This study focuses on deficiencies in teachers' knowledge on the subject matter. For instance, teachers may have misconceptions about topics in physics themselves (Kriek and Grayson, 2009). One of the initiatives to contribute to a solution to this problem is the Sediba programme at the North-West University, Potchefstroom, which offers a training programme for secondary school teachers. Topics in this two year part-time programme involve classical and modern mechanics and electromagnetism. The lecture on electric and magnetic fields, that takes place in the participants' second year, is the focus of this study.

Although students' misconceptions seem to be thoroughly investigated in the last decades, surprisingly little research has been done on the subject of electricity and magnetism (Guisasola, Almudí & Zubimendi, 2004; Maloney, O'Kuma, Hieggelke & Van Heuvelen, 2000). Moreover, the studies that *have* taken place usually focus on either electricity or magnetism, but not on the confusion and relation between the two (Guisasola, Almudí, & Zubimendi, 2004). Misconceptions found in prior studies are ideas such as 'all metals are attracted to magnets' and 'a magnetic field exerts a force on any charge (moving or steady)'. Some of these do seem to point to a confusion between electricity and magnetism.

In addition to this niche, there is minimal research that focuses on the misconceptions of science *teachers* instead of *students*, although there is reason to believe that misconceptions do occur amongst this group (Kriek and Grayson, 2009; Burgoon, Heddle & Duran, 2010). As Burgoon, Heddle & Duran (2010) phrased it: "Less research has been devoted to identifying teachers' misconceptions, but the results of the few existing studies demonstrate that teachers and students possess similar misconceptions." Moreover, it is stated that "very few instruments have been developed to measure teachers' understanding of science content" (Burgoon, Heddle & Duran, 2010). This lack of attention for teachers' understanding is all the more worrisome, considering the fact that research underlines the significant effect that teachers have on students' learning (Burgoon, Heddle & Duran, 2010; Reddy, 2006). Therefore, it is worthwhile to begin to occupy this gap by creating an overview of the conceptual problems regarding electric and magnetic fields that South African secondary science teachers have.

The Sediba programme aims to improve the participants' conceptual understanding. The primary goal of this study is to contribute to the effectiveness of the programme by using *variation theory* to analyse the participants' conceptual knowledge, as well as the learning space, or the established learning potential, during a lecture. Since variation theory focuses on the discernment of critical aspects of a concept, and patterns of variation within these aspects, it offers a didactical approach that focuses explicitly on similarities and differences. Because it seems that learners have trouble understanding the similarities and differences between electricity and magnetism, variation theory promises to be a valuable framework to investigate didactical methods on this subject.

Some recent studies (e.g. Pang & Marton, 2003, 2005) investigated the implications of variation theory in classroom practice and found that learning improves significantly by implementing the theory in lesson designs. Variation theory also proved to be effective for mapping and analysing learning processes in a variety of subjects, such as economics (Pang, 2003), IT education (Shuhonen, Thompson, Davies, & Kinshuk, 2008), mathematics (Mok, 2009) and chemistry (Park, Light, Swarat & Denise, 2009). A few studies took place in the field of physics education (Linder, Fraser & Pang, 2006; Ling, Chik & Pang, 2006; Park, Light, Swarat & Denise, 2009; Tao, 2001), but this field is still largely unexplored. Considering the prior successes with variation theory, it is interesting to further investigate whether the theory can be used to analyse the teaching and learning of the physics topic of electric and magnetic fields. A second goal of this study is therefore to contribute to the relatively new body of research on variation theory, and hopefully to the further introduction of this promising theory into the field of physics education.

With these goals in mind, the main research question of this study is:

Can improvement in conceptual difficulties regarding electric and magnetic fields, that commonly occur amongst South African secondary science teachers, be expected based on the space of learning that is established during a Sediba lecture according to the variation theory of learning?

To answer this question, the following sub-questions will be taken into account.

1. Which critical aspects regarding electric and magnetic fields do the South African teachers enrolled in the Sediba programme fail to discern, and what are the consequences in terms of confusion of concepts and misconceptions?

2. To what extent does an introductory Sediba lecture on electric and magnetic fields contribute to the pattern of variation that, according to variation theory, is necessary for learning and thus for revising the teachers' misconceptions?

3. Which modifications in the Sediba programme would result in more congruence with the teaching and learning strategies proposed by variation theory, and which advantages are to be expected from these changes according to variation theory?

Theoretical Framework

Conceptual change

There has been extensive research on strategies to address misconceptions over the past decades. Although discussion still exists about the topic, a majority of the science education community supports the view that has been posed by Posner, Strike, Hewson and Gertzog in 1982. According to this theory, learners have no incentive to change their conception as long as their view is functional for problem solving. However, when a learner is dissatisfied with his or her initial conception, it might be abandoned and a conceptual change can occur. Such dissatisfaction might be triggered when conflicts occur between the student's view and experimental data (Driver, Asoko, Leach, Scott & Mortimer, 1994). However, a student's initial response to anomalous data is not necessarily a dismissal of the old conception (Park, Kim, Kim & Lee, 2001). There are some additional conditions before conceptual change will be established. Firstly, a new theory must be available (Park, Kim, Kim & Lee, 2001). Furthermore, the new theory that the student is confronted with must be intelligible, plausible and fruitful for problem solving (Posner, Strike, Hewson & Gertzog, 1982). Although refinements of, and additions to this theory have been plentiful over the past thirty years, this core idea still remains widely supported.

In this study it will not be considered whether anomalies in the participants' theories are explicitly addressed. Instead, the emphasis will be on the second condition for conceptual change: is the new theory intelligible to such an extent that the participants *can* learn it? A recent theory of learning that was advanced by Marton and Booth, called the variation theory, seems to offer the theoretical framework on how students learn to understand concepts.

Variation theory

Variation theory is the latest development in the tradition of phenomenography. Phenomenography "sets out to reveal the different ways in which people experience phenomena" (Pang, 2003). Variation theory, in turn, describes exactly how learners come to *understand* phenomena. According to variation theory, each concept or phenomenon consists of critical aspects that make it different from other concepts (Pang, 2003). For instance, to understand the concept ‘chair’, one must learn about its critical aspects, such as function and shape. These critical aspects of ‘chair’ differ from critical aspects of other concepts, as, for example, the shape of a ‘chair’ differs from the shape of a ‘table’. Their shape is thus a critical aspect of both the concepts ‘chair’ and ‘table’, but is different for each concept. Similar to this, *every* concept is built up of all its critical aspects, that together form the concept as a whole.

For learners to experience what a concept means, its critical aspects must be *discerned*. According to variation theory, to be able to discern an aspect, variation in that aspect must be experienced (Marton & Booth, 1997). That variation is a necessary condition for discernment can be illustrated by the following example. To be able to discern color, one must have experienced a variety of colors (simultaneously, or from experiences in the past). After all, if everything in the world was red, we would not be able to discern color at all (Marton & Tsui, 2004). In practice, "when some aspect of a phenomenon or an event varies while another aspect or other aspects remain invariant, the varying aspect will be discerned" (Bowden & Marton, 1998). Variation is thus key to discernment of critical aspects. In turn, this discernment of all critical aspects leads to experiencing, and understanding, the concept itself. In short, "Variation is deemed to be the key for effective discernment, and the chief mechanism of learning" (Pang, 2003).

The patterns of variation that occur during lessons determine what *space of variation* is constituted (Mok, 2009). In the words of Pang and Marton (2005): “By consciously varying certain critical aspects of the phenomenon in question while keeping other aspects invariant, a *space of variation* is created that can bring the learner's focal awareness to bear upon the critical aspects, which makes it possible for the learner to experience the object of learning." (emphasis added). This does not mean that every student experiencing a certain space of variation will learn the same thing. Variation theory only states that the *potential* for learning a concept is established by opening the space of variation (Suhonen, Thompson, Davis & Kinshuk, 2008; Ingerman, Linder & Marshall, 2009; Ling, Chik & Pang, 2006). Moreover, according to variation theory, this potential learning space is a *necessary* condition for learning to be made possible (Marton & Pang, 2006). Consequently, "The professional role of a teacher is to design a learning environment that enables students to discern the critical aspects of the object of learning, with the systematic and conscious use of variation as a pedagogical tool." (Pang, 2008). Part of this study will focus on the space of variation that is established during the Sediba lecture on electricity and magnetism.

Research design

Several methods were used to answer the questions posed in this study. First, a short overview of the methodology of this study will be provided. In the sections below, each aspect of this methodology will be further elaborated.

The concepts of electric and magnetic field were analysed in terms of their critical aspects in order to construct a list of those aspects which a learner should be aware of in order to understand, and be able to distinguish between, the two fields. Also, a questionnaire and interviews were used to create an overview of conceptual problems that occur amongst the secondary science teachers. A comparison between the occurring misconceptions and the list of critical aspects provided insight in which aspects the participants did not discern, and what the consequences were in terms of confusion of concepts and misconceptions.

Next, the space of learning that was constituted during the lecture on electricity and magnetism was investigated. The lecture footage, an interview with the lecturer and field notes served as data sets for this analysis. Since variation theory describes that a concept can only be learned when a pattern of variation occurs for a multitude of the critical aspects of the concept, it was investigated whether the required patterns for learning emerged in classroom discourse and what this meant in terms of potential conceptual change.

Participants

The participants of the study were teachers enrolled in the Sediba programme. This programme aims to improve secondary school teachers' conceptual understanding of topics in the natural sciences through lectures and practical work. The study's participants were enrolled in the physics courses of 2011-2012. At the time that the research took place, all participants taught physical science in secondary schools in South Africa. The participants differed in age (30 to 55 years), gender, and in a broad range of teaching experience (2 to 23 years). The participants came from four different provinces of South Africa and attended the contact sessions at the North-West University in Potchefstroom.

Misconceptions

A literature study was done to investigate which misconceptions on electricity and magnetism are known to be common amongst science learners. Since little research has been done concerning secondary science teachers (Burgoon, Heddle & Duran, 2010), a conceptual questionnaire was developed and administered amongst the Sediba learners. In this questionnaire, multiple-choice questions were used for those concepts which have been researched priorly in other studies and thus had research-based misconceptions available. These research-based misconceptions functioned as distracters for the multiple-choice items, a method in accordance with Gronlund (2003). For concepts which are less (or not) researched, open ended items were used to probe the line of reasoning of the participant.

Some questions from previously used research tools were used for inspiration, such as the Conceptual Survey of Electricity and Magnetism (Maloney, O'Kuma, Hieggelke & Van Heuvelen, 2000) and questionnaires developed by Guisasola, Almudí, and Zubimendi (2004) and Tanel and Erol (2008). This was done to grant more validity to the questionnaire, since these tools were based on prior research and have been tested and modified where necessary.
A number of questions in the questionnaire focused explicitly on the confusion between electric and magnetic fields, an example of which can be found in figure 1. In the question that accompanied the situation sketch on the left, the participants were asked what would happen (attraction, repulsion, neither) to a variety of objects (an iron screw, aluminium plate, wooden block, copper coin, and plastic ring) in the presence of a magnet. In the question that accompanied the sketch on the right, it was asked what would happen to those same objects in

the presence of a charged rod. The participants' answer patterns provided insight in their understanding of electric and magnetic fields and the difference between the two.

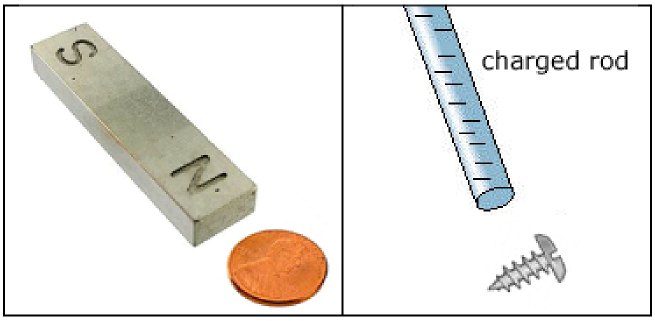

Figure 1: Situation sketches for questions that focused on the confusion of the effects of electric and magnetic fields on materials

The questionnaire consisted of 13 questions, which were mostly divided in a number of subquestions (see appendix 1). A total of 36 participants completed the questionnaire.
Ethical aspects were adhered to and the teachers participated willingly.

The data of the questionnaires were processed statistically to determine frequencies of occurrences of (mis)conceptions and consistencies in the participants' responses. The latter lead to more insight in the consistent conceptual ideas that each participant had. Analysis also showed whether participants gave similar answers for electricity and magnetism questions, and thus whether the two are commonly confused.

Since little prior research has been done on the subject, it was worthwhile to gain more in-depth understanding of the participants' conceptions. To achieve this, individual semi-structured interviews with open-ended questions were conducted with three participants (see appendix 2). The focus of the interviews was on deficits in the participants' knowledge and understanding of similarities, differences and relations between magnetic and electric fields (i.e. their sources, effects, forces etc.). The interview questions were developed in this study, and were partly based on the results of the questionnaire data. To gain in-depth insight, the researcher was free to deviate from the interview scheme and ask additional questions according to the participants' responses. During the interviews, some objects for electricity and magnetism experiments were present, such as bar magnets, insulating rods, etc. Participants were free to test their conceptions with the equipment and explain their observations. Pen and paper was provided so that the participants could elaborate their views with drawings. Member checks, to validate the respondents' views, were done throughout the interview process (Kirk & Miller, 1986). The length of each interview varied between 40 and 50 minutes. Video and audio recordings were made of the interviews. The sessions were transcribed verbatim and subsequently analysed to determine patterns and trends in the participants’ reasoning.

Using both quantitative and qualitative methods, methodological triangulation was applied to cross-examine the participants' responses (Denscombe, 2007). The detection of conceptual difficulties and the interpretation of the researcher was thus secured and convergent results were achieved.

Critical aspects

To understand the participants’ conceptions in terms of variation theory, it was necessary to make an analysis of the concepts ‘electric field’ and ‘magnetic field’ in light of the discernment of their critical aspects. To realize this analysis, the researcher relied on her own understanding of the phenomena to identify the critical aspects of each concept. To gain more reliability to the analysis, she also consulted with several experts on the subject and revised the list of critical aspects accordingly. Finally, a comparison was made between the revised overview and the critical aspects that are (implicitly) addressed in two different textbooks on the subject. The final result consisted of two lists, one for ‘electric field’ and one for ‘magnetic field’, including twenty critical aspects each. Since the focus of this study is the confusion between electricity and magnetism, these two lists were then combined to make an overview of the critical aspects that participants must discern to be able *distinguish* the electric field and magnetic field. Again, this lead to a list of twenty aspects. The compiled list provided a framework for the analysis of both the participants’ ideas and the Sediba lecture. It is impossible to be certain that these lists are complete, and no such claims are made here. Instead, it should be seen as a first attempt to establish those features that a learner must discern in order to grasp both concepts.

The misconceptions that were found in the questionnaire and interview data were investigated in light of the critical aspects. For each misconception, it was determined which critical aspects were probably *not* discerned by the participants to lead to their alternative understanding.

Lecture

From the analysis of the misconceptions an overview was constructed that details which critical aspects were *not* discerned by the participants. It was then investigated whether improvement could be expected from the Sediba lecture. To achieve this, it was investigated which *variations* took place in the lecture. After all, for a learner to discern a critical aspect, that aspect must vary while other remain invariant. Each variation in the lecture thus contributed to the space of learning, which gave participants the opportunity to discern those critical aspects which they were previously not aware of. By discerning new critical aspects, the learners' conceptions could be elaborated and enhanced. If, however, the space of variation did not allow a learner to discern new critical aspects, improvements were very unlikely (Marton & Pang, 2006).

By comparing the space of variation that was opened in the lecture to the analysis of undiscerned critical aspects, it could be determined which aspects could be newly discerned and which were still not addressed. Consequentially, it was determined which *misconceptions* could be expected to be improved, namely those misconceptions that were related to critical aspects that were previously not discerned, but which *were* part of the space of variation in the lecture so that new discernment was made possible. Maybe even more importantly, it could be determined which misconceptions would most likely remain unchanged, which were those that relied on critical aspects which were previously not discerned and not addressed in the lecture either.

The data that were used for this analysis were the video and audio recordings of the Sediba lecture on electric and magnetic fields, in addition to field notes of the lecture written by the researcher. The lecture took place at the North-West University in Potchefstroom, South Africa, and was attended by the same participants who filled out the questionnaires. The length of the lecture was 50 minutes. During this time, the structure of the lecture was clearly controlled by the lecturer, but there was constantly room for input and questions from the learners. The video and audio recordings of the lecture were transcribed verbatim and subsequently analysed, with a focus on occurring variations. The researcher's analysis was subjected to review by another expert.

In addition to the lecture footage and field notes, an hour-long semi-structured interview with the programme lecturer was conducted after the lecture (see appendix 3). This was meant to give more insight in what the lecturer hoped to teach in his class. The interview questions focused on teaching strategies, didactical views, variations and critical aspects of the concepts ‘electric field’ and ‘magnetic field’. The interview was video and audio taped and transcribed verbatim for its analysis. Prior to the lecture and the interview, the lecturer was not aware of the variation theory of learning. However, according to Marton and Pang (2006), even teachers who are unaware of the variation theory often seem to incorporate its strategies in their classrooms practice.

Since the study provides insight into the degree of accordance of the current programme with the variation theory, it also establishes an overview of where the programme deviates from the theory. Analysing congruencies and disparities lead to recommendations on how the programme may be altered to achieve a greater learning effect, according to variation theory.

Results

Critical aspects

In order to analyse participants’ conceptions and the space of variation in the lecture, a list was constructed of twenty critical aspects that a learner must discern to understand and distinguish between electric and magnetic fields (see table 1). The misconceptions that were found in this study and their relation to the lack of discernment of specific critical aspects are discussed below.

Table 1: Critical aspects of electric and magnetic fields

#	Critical aspect
1	Electric fields are induced by electric charges (moving or stationary), while magnetic fields are induced only by moving charges (e.g. a current).
2	Electric fields around objects are induced by excess charges. An object can either have an excess charge in itself, or the distribution of positive and negative charges in an object can cause either side to carry excess charge. Magnetic fields are induced by the magnetic moments in atoms, which together make up aligned magnetic domains.
3	Charges are fundamental properties of some particles (electrons and protons). Magnetic polarity is a

	secondary effect of the motion of charges and the direction and alignment of the magnetic moments that are present[1].
4	Electric fields are created by changing magnetic fields. A magnetic field is created by a changing electric field.
5	The electric and magnetic fields can exist independently[2].
6	The direction of the electric field is, by convention, from a positive to a negative charge. The direction of the magnetic field is, by convention, from the north pole to the south pole.
7	A charged object / induced charges can be caused by friction, electrolysis and changing magnetic fields. An object can be magnetized permanently by heating above the Curie temperature and then reducing its temperature in a magnetic field.
8	A charged object can lose its charge in a relative short amount of time. A permanent magnet will keep its magnetic strength for a long time.
9	Both electric and magnetic forces can be attractive and repulsive. However, two objects with like charges will always repel each other due to the interaction of their electric fields. In the case of two magnets they can either attract or repel, depending on the orientation of their poles.
10	The force on a charge in an electric field is proportional to the magnitude of the field strength and the magnitude of that charge. The force on a charge in a magnetic field is proportional to the magnitude of the field strength, the magnitude of that charge *and* the magnitude of its velocity.
11	Electric fields can affect any material (its charges) (conductors and insulators). The strongest magnetic effect, ferromagnetism, affects only (ferro)magnetic materials. These are materials that can retain magnetization and thus become magnets themselves. Other effects of magnetism are much less strong.
12	Electric fields affect both moving and stationary charges; magnetic fields affect only moving charges.
13	Unlike electric fields, magnetic fields do no work.
14	Electric fields are easily shielded: they may be weakened, distorted or blocked by objects such as earth, trees, and buildings. Magnetic fields are not as readily blocked.
15	A wire conducting a constant current will not induce an electric field, and will not be significantly affected by an external electric field outside the wire. After all, the total charge in the wire is zero: the same amount of positive and negative charge. Since only the negative charges are moving in the wire, a magnetic field *will* be induced and the wire will be affected by an external magnetic field.
16	An electric force is in the direction of the electric field for a positive test charge. A magnetic field affects a moving charge by the Lorentz force, which is perpendicular to the magnetic field and direction of motion of the moving charge.
17	Positive and negative charges can exist independently (electric monopoles). A north/south pole cannot exist in isolation (as far as we know).
18	When a charged object is cut in half, either side will contain excess charge (either both positive or both negative). When a bar magnet is cut in half, both sides will have two poles and be

[1] Or, in quantum mechanics, an effect of the atomic structure and spin.
[2] Relativism is not taken into account. It is assumed that the situation is regarded from one intertial frame of reference.

	magnets in their own right.
19	The SI unit of the electric field is newton per coulomb. The unit of the magnetic field is tesla.
20	An electric field can be made visible with the semolina grains experiment. A magnetic field can be made visible with iron fillings or compasses.

Misconceptions

To identify patterns in the participants' reasoning that indicated misconceptions and confusions regarding the electric and magnetic field, data from the questionnaire were analysed. The results were then compared to the data from the interviews and complemented where necessary. Additionally, participants' responses during the lecture supported the two other data sets, since some misconceptions that were found were verified in the lecture footage.

For the variation theory analysis, each misconception was considered in light of one or more critical aspects that a participant failed to discern if he or she held that misconception. The results are shown in table 2. The first column provides a short description of the misconception. The second column states how many participants were found to hold that misconception. Some of the misconceptions were detected in the interviews, in which case a 'from interviews' is listed. Finally, the third column indicates which critical aspects were not discerned by the participant with that misconception. Below the table, some of the misconceptions are further discussed and illustrated.

Table 2: Common misconceptions linked to undiscerned critical aspects

	Misconception	**# of participants (total 36)**	**Undiscerned critical aspect(s)**
A	A magnet is made by placing a magnetic material in an electric field.	From interviews	7
	On the source of magnetic fields:		
B	The magnetic field is due to induced charges at the poles of a magnet. The poles carry opposite charges (positive and negative) and thus repel objects of like charges and attract objects of unlike charges.	26	2, 3
C	A steady charge can cause a magnetic field.	11	1
D	A moving point charge cannot cause a magnetic field.	From interviews	1
E	A steady current cannot cause a magnetic field.	30	1

F	Only a *changing* current can cause a magnetic field.	9	1, 4
G	Magnetic fields can be caused by other magnetic fields (steady or changing).	17	4
	On the source of currents:		
H	A steady current can cause another, external current to arise.	7	12, 15
I	A changing current can cause another, external current to arise.	20	12, 15
	On the source of electric fields:		
J	Electric fields are only due to *moving* charges.	From interviews	1
K	A current-carrying wire has an electric field around it.	From interviews	15
	On the effects of electric and magnetic fields on materials:		
L	All metals will be affected by a magnet.	13	11
M	The exact same materials that are affected by electric fields are also affected by magnetic fields	8	11
	On electric and magnetic forces:		
N	The magnitude of the electric force is always smaller than that of the magnetic force.	From interviews	10
O	A magnetic field will exert a force on a steady charge.	31	12
P	A charged object will not cause a force to be exerted on a steady charge.	6	12
	On the direction of the electric and magnetic forces:		
Q	The direction of the magnetic force aligns with the magnetic field, in the same way as the direction of the electric force is aligned to that of the electric field.	12	16
	General:		
R	Electric and magnetic fields cannot exist without one another.	From interviews	5

Instead of correctly discerning critical aspect 1, 4 and 15 (table 1), regarding the source of the fields, some participants reasoned that a magnetic field can be caused by a steady charge (misconception C, table 2). This view was verified in both the interviews and questionnaires. Participants also thought that magnetic fields can be caused only by a *changing* current (F) or by other magnetic fields (G). The lack of discernment also caused some participants to explicitly deny that moving charges (D) and steady currents (E) give rise to a magnetic field. Also related to these critical aspects were the misconceptions that concerned the source of electric currents and electric fields (H, I, J and K).

Interestingly, misconception K, which was detected in interviews and validated in the lecture, could possibly be a consequence of misconception J. If *only* moving charges give rise to an electric field, a current-carrying wire could have an electric field around it because the positive charges in the wire are immobile and the moving electrons would thus give rise to the field (similarly to the magnetic field). Two of the three participants who were interviewed strongly supported the view that a current-carrying wire would have an electric field around it, both when they were asked explicitly ("We shall have a clockwise electric field around the conductor.") and when it was asked what would happen to a current-carrying wire in an external electric field ("It will experience a force because there is going to be interference between its electric field and the electric field that is already there.").

Other critical aspects that participants did not seem to discern were those that concerned the effect of the fields on materials and charges (11 and 12). This lead to the misconceptions that all metals will be affected by a magnet (L), the same materials will be affected by both fields (M), and that a magnetic field will exert a force on a steady charge (O). Again, these results of the questionnaire were verified by the interview responses. The misconception that a charged object will not exert a force on a steady charge (P) also occurred.

Misconception M was recognized due to the analysis of answer patterns in the questionnaires. Participants were asked what would happen to a variety of materials that were put in an electric or a magnetic field. It was then analysed how many participants gave similar answers for the electric and magnetic field, for each material, when different answers would be correct (average 21 participants). Finally, it was analysed how many participants gave the exact same answer pattern for *all* materials (8 participants).

Misconception L was probably related to the confusion between electric and magnetic fields. From the questionnaire, it followed that most participants did not recognize the effect that electric fields can have on insulators. The effect of an electric field on metals was attributed to the conducting nature of the material. That is also the case when participants speak of magnetism. As one interviewee stated: "I think what happens is that… these ones" [metals] "are good conductors. Their charges are more easily picked and they're free to move. More than the insulators, so *they* cannot be attracted."

A large number of the participants (26 out of 36) also showed confusion between electricity and magnetism in their view of how a magnet works, which can be attributed to critical aspects 2 and 3. The common view was that a magnet works because either pole of the magnet carries a different charge, as is illustrated in figure 2, which shows a sketch from one of the interviews.

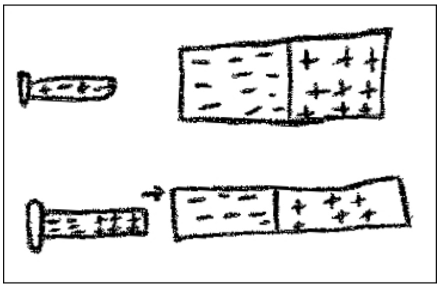

Figure 2: A participant's sketch of a magnet and its effect on charges in an iron object

This participant explained her view that "Poles are just opposite sides. What happens is, on one side of the magnet there are more positive charges and on the other we have the negative charges. So it means [that if] one is the negative pole, the other one is going to be the positive pole."

More confusion between the fields was detected in misconception Q, where participants considered the direction of the magnetic force to be comparable to the alignment of the electric force to its field. This view was present in both questionnaires and interviews. Also, some participants thought that electric fields and magnetic fields cannot exist without one another (R)[3]. Two of the three interviewees were convinced of their view. As one of them stated, "They're like friends. I think when one is there, the other one must be there. Yes. If one is not there, the other one will not be there."

Overall, it should be noted that a large number of participants (10 out of 36) used the terms of electric and magnetic field, or electric and magnetic force, interchangeably in both questionnaires and interviews. For instance, a participant may recognize that an electric field occurs between two charges plates, but will later speak of a 'magnetic' force that causes a particle to move within this field. This certainly seems to validate the hypothesis that the participants commonly confuse the two concepts, and that a clear distinction is not present in their conception.

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[3] From a relativistic point of view, electric and magnetic fields actually cannot exist independently. An electric or magnetic field in one intertial frame of reference will appear as a mixture of the two fields in another frame of reference. However, the Sediba programme does not consider relativistic effects and it is assumed that the participants here refer to a dependent existance within a single frame of reference.

In general, *all* participants showed confusion between electricity and magnetism at some point in the questionnaire. The number of times that they showed such confusion ranged between one and seven occurrences in 13 questions.

It should be noted that the participants did not always show a consistent view throughout the questionnaire. The majority of the participants that held misconception C seemed to deviate from their ideas when the situation varied. However, 11 participants expressed this view at some point in the questionnaires. Similarly, conception E was expressed by 30 participants in the questionnaire, but only eight of these participants consistently answered the questions according to this view. For instance, of the 23 participants who stated that a current will influence a compass, only four answered, in another question, that a current will have a magnetic field around it. Inconsistent views were also detected amongst the notably large number of participants (31 out of 36) that held the view that a magnetic field will exert a charge on a steady charge (misconception O), when compared to the (still large) number of 11 participants who believed that a steady charge can *cause* a magnetic field (C). Similarly, this seems to be the case for misconception P.

Summarizing these results, it follows that the participants seemed not to discern the basic critical aspects that differentiate magnetic and electric fields. The most problematic aspects appear to be the sources of the electric and magnetic field and the effects that the fields have on charges and materials. Confusion between the fields is commonly the case.

Finally, some misconceptions were found that were unrelated to the confusion of electricity and magnetism. Although they are not the focus of this study and will not be subjected to further analysis, the most important are the following. Eight out of 36 participants held the misconception that 'only metals can be affected by an electric field'. It is noteworthy that even amongst the participants that did recognize that insulators (such as paper shreds) would be attracted to a charged object, *none* of the participants could give an adequate explanation as to *why* this would be the case, so polarization in insulators was not recognized by any of the participants. Another example is the misconception that related magnetic strength to the magnet's size. Six of the 36 participants believed that a physically bigger magnet *must* be the stronger magnet, and another six participants thought that the area of the magnetic poles was the decisive factor of the magnet's strength. Another misconception was about the electric and magnetic field lines: seven out of 36 participants expressed the view that field lines are real entities, which function as active agents that can "cause forces", which can "clash" and "be cut". It should be noted that this conception was not addressed explicitly in the questions, but just 'showed up' in the participants' answers. Consequently, we can only be sure that *at least* seven participants hold this view. The misconception that 'a current does not consist of moving charges' was detected similarly. This misconception was recognized when participants mentioned that a current *could* cause certain effects (such as generate a magnetic field), but that moving charges could *not*. Six participants expressed this view. Unfortunately, the scope of the interview did not allow insight in the participants' alternative conception of current, so it is unclear what these six participants considered current to be, or to consist of.

Lecture

In the following section, the introductory Sediba lecture on electric and magnetic fields is analysed so that a judgement can be made whether the potential learning space was established that allowed participants to newly distinguish critical aspects, and thus improve their conceptual ideas about the electric and magnetic field. The lecture footage, the researchers' field notes and the interview with the lecturer form the data sets used to determine the pattern of variation that occurred during the lecture. It should be noted this description does not include all the variations that took place in class, but only those which are relevant to the problematic critical aspects listed in table 2. Below, the relevant critical aspects are referred to numerically in brackets.

The most prominent variation that occurred during the lecture was that of the explicit comparison of different fields. The focus was on the variation of the electric and magnetic field, where the gravitational field sometimes served as a third example. During the comparison, the critical aspects that were varied were the source of the field (1, 15) and the objects which the electric or magnetic force acts upon (11, 12). While variations occurred in these critical aspects, others were kept invariant so that discernment was possible. Variation for critical aspect 1 (table 1) occurred, for example, when the lecturer encouraged the participants to identify the different sources of different fields. However, the actual learning result of this effort, and the potential discernment, may differ for some students. Critical aspect 1 identifies the source of the fields to be charges, whereas the magnetic field is induced *only* by moving charges. In the lecture, the source of the magnetic field was stated to be ‘magnets’ and ‘currents’. However, since some participants did not seem to relate currents to moving charges (see the analysis on misconceptions), these participants may not see the essence of critical aspect 1. Thus, while the lecturer may be justified to claim he has adquately addressed this point, the participants may lack the required conceptual tools and consequentally fail to discern critical aspect 1. Something similar holds for critical aspect 15, which states that a constant current will induce a magnetic, but not an electric field outside the wire. The fact that a magnetic field will emerge was introduced with several variations. One of these was a variation in practical demonstrations. It was discussed whether a current diverts a compass needle, and demonstrated that a bar magnet affected a current-carrying wire. Another variation for this critical aspect was to regard the wire only in terms of magnetic field, and only in terms of electric field. Although these variations would most likely establish a successful method to allow participants to discern the critical aspect, the *content* of the discussion that followed possibly undermined the learning potential. A discussion was held during the lecture, on whether a current would trigger both an external electric and magnetic field. It appeared that the discussion lead the class and lecturer to agree that *both* fields would occur around a current-carrying wire. The fact that a wire carries both positive and negative charge, and an electric field would thus not occur, was not adressed and participants who were not aware of it before may not have newly discerned this aspect as a result from the lecture. Consequently, critical aspect 15 *was* addressed, but what was discerned may not have resulted in the full scientific view.

The other critical aspects mentioned above concerned ‘that which the field exerts a force on’: number 11 and 12. Again, the lecturer encouraged participants to identify what would be affected by the different fields. The participants successfully discerned that charges would be affected by electric fields and magnets by the magnetic field. Additionally, the lecturer contributed with a variation that allowed participants to discern that all ‘magnetic materials’ would be affected by the magnetic field. The latter was subject to a second variation when an example of a magnetic material, a compass needle, was used in a variety of experiments. The reaction of a compass needle to a few magnetic fields (that of the earth, a bar magnet, and a wire) was discussed, and thus another dimension of variation opened that allowed the participants to discern that ‘a magnetic field will exert a force on magnetic materials’. Although these variations certainly contributed to the discernment of critical aspect 11, full discernment might not have occurred for all students. It would be advisable, here, to address the issue that electric fields, unlike ferromagnetism, can affect *all* materials. No variations occurred that established the possible discernment of this fact. This provides an example of the potential contribution of a variation theory perspective. Similarly, part of critical aspect 12 (‘electric forces act on charges’) was addressed in accordance to the variation theory strategies, but another part (‘magnetic forces act only on moving charges’) was not subject to variations, and thus not part of the established space of learning. The crux here is that most of the critical aspects in the list contain two ‘sub-aspects’, one for each type of field. To achieve a greater learning effect in conceptuel development, the strategies of variation theory suggest that *both* aspects must be addressed through variation, so that discernment, and consequentially successful distinction of the two fields can be achieved.

Some more critical aspects were addressed in the lecture through variation, such as critical aspect 10. In fact, several variations occurred in the lecture that concerned field strength. One example is that two magnetic north poles (of equal size) were drawn on the blackboard, one with three magnetic field lines emerging from it, and the other with six magnetic field lines emerging from it. Similarly, two point charges were drawn with respectively six and twelve electric field lines around them. Although this does not fully establish the space of learning that is required to discern that ‘the force on a charge in an electric field is proportional to the magnitude of the field strength and the magnitude of that charge’ and ‘the force on a charge in a magnetic field is proportional to the magnitude of the field strength, the magnitude of that charge *and* the magnitude of its velocity’, it *does* allow participants to discern that the strength of the field can vary and consequently, that an electric force can be stronger than a magnetic force or vice versa.

Finally, a space of variation was opened that allowed participants to discern critical aspect 5. The variation entailed two situations, that of an isolated bar magnet, and that of an isolated point charge. By varying between these two situations, participants were offered the potential learning space to discern that electric and magnetic fields can exist independently. Moreover, the lecturer brought this to their awareness explicitly.

A number of variations allowed other critical aspects (9, 19 and 20) to be discerned by the participants, but these were not related to the common misconceptions that were found. Also, a number of critical aspects were addressed which were related to the concepts ‘field’, ‘electric field’ or ‘magnetic field’, but not to the distinction between the two. Since they are not the focus of this study, these variations are not discussed further.

In the interview with the lecturer, it was confirmed that the lecturer did not know of the variation theory of learning when the lecture took place. This seems to verify the assumption that even teachers who are unfamiliar with the theory sometimes tend to use the strategies intuitively (Marton & Pang, 2006). During the interview, the lecturer even stressed the importance of keeping the situation invariant, while one aspect was to be focused on: "When I treated electric field now, I try to strictly stick to the electric field. You know, reduce it to electric field only, and then look at the point charges and so on. […] So that when I come to magnetic field, I only draw that." Furthermore, the lecturer specifically chose to incorporate a number of variations in the lecture because he was aware of the problems that participants encounter: "Although the focus was on magnetic field, the reason that I started with the electric field [is that] I wanted to get the comparison between the two. Because there are similarities and major differences. And students have, in most cases, problems in mixing the two up. And not really understanding the one from the other." However, concerning misconceptions, there were some discrepancies between the lecturer's view and the results from the questionnaire and interview data. For example, the lecturer held the view that electric fields were better understood than magnetic fields, and acknowledged that he was not fully aware of the conceptual difficulties that participants encounter when learning about the magnetic field: "I think the misconceptions in magnetic field are not as prominent as the ones in electric field. I think they understand the magnetic field fairly well, compared to the electric field. Maybe it's because of the fact that they are used to magnets, rather than charges. I mean, they can hold magnets, they cannot hold a charge. […] The conceptual problems… there's not one that comes to mind now. But one does not rule out the possibility that there are." The fact that the lecturers view is not consistent with the data that was gathered in this study, only illustrates the difficulty that teachers face in being fully aware of their students' conceptual understanding.

<u>Discussion of results</u>

During the lecture, a space of learning was established that allowed a number of critical aspects to be newly discerned by the participants. These critical aspects were number 1, 5, 10, 11, 12 and 15. It should be noted, however, that only number 5 was fully dealt with in the lecture, while the others were treated only partially. Consequently, the following conclusion is both based on *which* critical aspects were addressed and *how* they were addressed, in order to determine which misconceptions could possibly be altered towards a more scientific view.

From the discernment of critical aspect 1, the misconceptions that could undergo a change were C, D (but only by those participants who recognize the relation between moving charges and current), E, F and J. From the discernment of critical aspect 12 and 15, one might expect that misconceptions H, I and K could be altered. However, since it did not become clear that a constant electric current does not create an external electric field, changes in these misconceptions are unlikely. The way that aspect 12 was addressed allowed participants to discern that 'electric forces act on charges'. Consequently, the potential for alteration in conception P was realized. Because a distinction was made between what was affected by the two fields, and 'steady charges' were not part of the magnetism discussion, discernment of critical aspect 12 also allowed for a change in conception O.

Since critical aspect 11 could be partially discerned, misconception L could possibly be altered, but there was no incentive for a change in misconception M because the effect of electric fields on materials could not be readily discerned from variation. Although variation allowed only the basis of critical aspect 10 to be discerned, that strengths *can* vary, the relevant misconception (N) is such that a change of this conception can be expected. Finally, the successful discernment of aspect 5 might allow for a change in conception R.

The misconceptions that relied on critical aspects that could not be discerned from the lecture at all were misconception A, B, D (by those who do not relate current to moving charges), G and Q.

In short, a space of learning was opened that allowed the necessary discernment of critical aspects related to ten conceptions (C, D, E, F, J, O, P, L, N, R). Consequently, according to variation theory, the necessary condition for potential conceptual change was achieved for these ten misconceptions. The critical aspects related to the other nine misconceptions (A, B, D, G, H, I, K, M, Q)[4] were not part of the learning space.

[4] Misconception D is mentioned twice because it depends on the students knowledge of current as moving charges.

Limitations

Firstly, since the space of learning was determined from the lecture discourse, any conclusion in this study only reflects which *potential* of learning was offered to the participants. No conclusions can be drawn about the actual learning effect for individual participants. This is also the case because ‘the space of learning’ that is described here refers to the pattern of variation that occurred in this particular lecture only, as in agreement with Marton and Tsui (2004). However, “someone whose past experiences are sufficient for perceiving the necessary pattern of variation can experience variation without that space being constituted in the immediate situation” (Marton & Tsui, 2004). The participants may have had earlier experiences that allowed them to experience variation which was not fully constituted in the lecture itself, and thus could not be measured. It could be worthwhile to investigate the learning effect for individual participants in a follow up study by considering these two aspects and using a different methodology.

It should also be noted that only one lecture of the Sediba programme was considered, and it could not be expected that all misconceptions that participants may have were addressed in this short amount of time. The subject of electricity and magnetism is treated more elaborately during the rest of the programme, through the use of additional lectures, but also through practical work. It should be considered that a lecture is only one of the many methods to achieve effective conceptual development. For more insight in the learning potential of the whole programme, additional research would be required that considered variations in the other aspects of the programme. Therefore, the recommendations following from this study concern only this particular lecture.

Conclusion

A number of 18 common misconceptions was detected amongst the Sediba participants. It can be argued that the lack of an adequate understanding of 11 critical aspects, which a learner requires to discern to distinguish between electric and magnetic fields, could have given rise to these misconceptions. The majority of the conceptual difficulties involved the source of the electric and magnetic field and the effect that the fields have on charges and materials.

During the lecture, a space of learning was established that allowed six critical aspects to be newly discerned by the participants. Consequently, potential conceptual change was established for ten of the eighteen misconceptions.

During this study, the possibility to link misconceptions and conceptual confusions to the inadequate understanding of a number of subject-based critical aspects was investigated. The fact that such an analysis could be made supports the validity and applicability of the variation theory. Specifically, it supports the notion that the theory is applicable in the field of physics education.

Recommendations

In order to further enhance the potential learning effects of the Sediba lecture, a number of considerations follow from the application of variation theory to the students' prior knowledge and the current content of the lecture. Firstly, it is advisable for the lecturers to develop a more detailed understanding of the conceptual problems that participants might have. Little research was done for this specific group, but it seems that some misconceptions that the teachers hold are comparable to those that secondary science students were found to have in prior research. Additionally, it may be worthwhile to measure the conceptions of the Sediba participants in the successive years to validate the results of this study for a larger group size.

The conceptual problems that were detected in this study mostly involved the source of electric and magnetic fields and the effects that the fields have on charges and materials. To solve these problems, discernment of their relevant critical aspects must be made possible for the participants. According to variation theory, this can be achieved through variation. Whereas some variations were already used accordingly in the lecture, it seems the complete discernment of the aspects that allows participants to make a *distinction* between the fields is not consistently realized. That is to say, the learning potential is established for learners to become aware of a critical aspect of *one* field, but not for the counterpart of the other field. Secondly, some critical aspects were not yet addressed in the lecture. Amongst these was the issue of 'how does a magnet work' and 'how is a magnet made'. Since many misconceptions seem based on an insufficient knowledge of the cause of polarity of magnets, it seems worthwhile to introduce variations in the lectures that allow participants to discern the critical aspects which are relevant to this notion.

Overall, the teaching of the Sediba lecturer is to a certain extent (intuitively) congruent with the variation theory of learning. However, by explicitly considering the problematic critical aspects and introducing variations that allow these to be discerned, the learning effect of the study may be further enhanced. A possible practical way to achieve this is to let participants solve a number of similar problems in which all aspects but one, the problematic aspect, are kept invariant.

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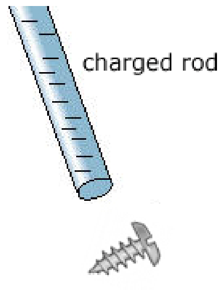
APPENDIX 1

QUESTIONNAIRE ON ELECTRICITY AND MAGNETISM – PART 1

QUESTION 01

A few objects are placed near a rod with a large negative charge (as in the image on the right). Answer for each object: will it be attracted, repelled, or not affected by the charged rod? Circle your choice.



a) An iron screw will be attracted / repelled / not affected
b) An aluminium plate will be attracted / repelled / not affected
c) A wooden block will be attracted / repelled / not affected
d) A copper coin will be attracted / repelled / not affected
e) A plastic ring will be attracted / repelled / not affected

For each case where an object is attracted or repelled (if any), explain:
i) What type of force is it?
ii) What *causes* this force?

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……………………………………………………………………………………………
……………………………………………………………………………………………
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QUESTION 02

Which of the options below cause an *electric current*? Please check the box in front of each correct answer. More than one answer may be correct.

	Another steady electric current
	Another changing electric current
	A magnetic field
	A changing magnetic field
	Other……………………………………………………………… ………………………………………………………………

QUESTION 03

Which of the options below cause a *magnetic field*? Please check the box in front of each correct answer. More than one answer may be correct.

	A magnet
	A charge at rest
	A steady current
	A changing current
	Another magnetic field
	Other…………………............…………………..................... ……………………...................……………………......................

QUESTION 04

See the figure. A sphere with a large positive charge is hanging above the table. On the table there is a heavy weight, with another sphere attached to it by a string. This second sphere has a small negative charge. The spheres are attracted to each other *just* enough so that the second sphere floats in the air. You then move a piece of wood (an insulating material) in between the spheres. Will the negatively charged sphere fall? Explain your answer.

The negatively charged sphere will / will not fall,
because ……….……….……………….
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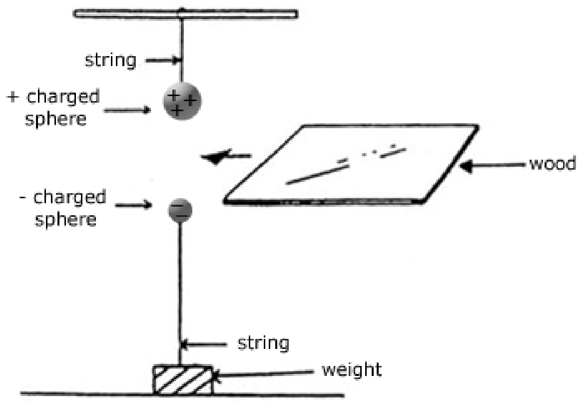
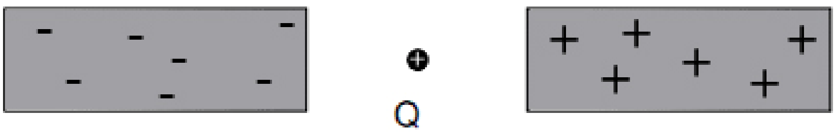


QUESTION 05

A particle with a positive charge Q is placed between two pieces of plastic, as shown in the figure. The one on the left is negatively charged. The one on the right is positively charged. Will these exert a force on the particle? Will the particle move? Explain your answer.



Answers:
The plastic pieces will / will not exert a force on the particle.
The particle will / will not move.
Explanation: ……………………………………………………………………………………
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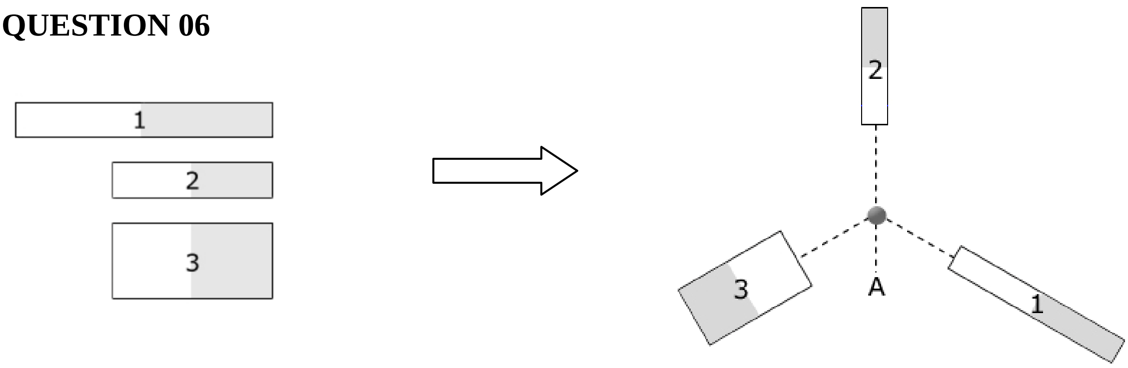
QUESTION 06

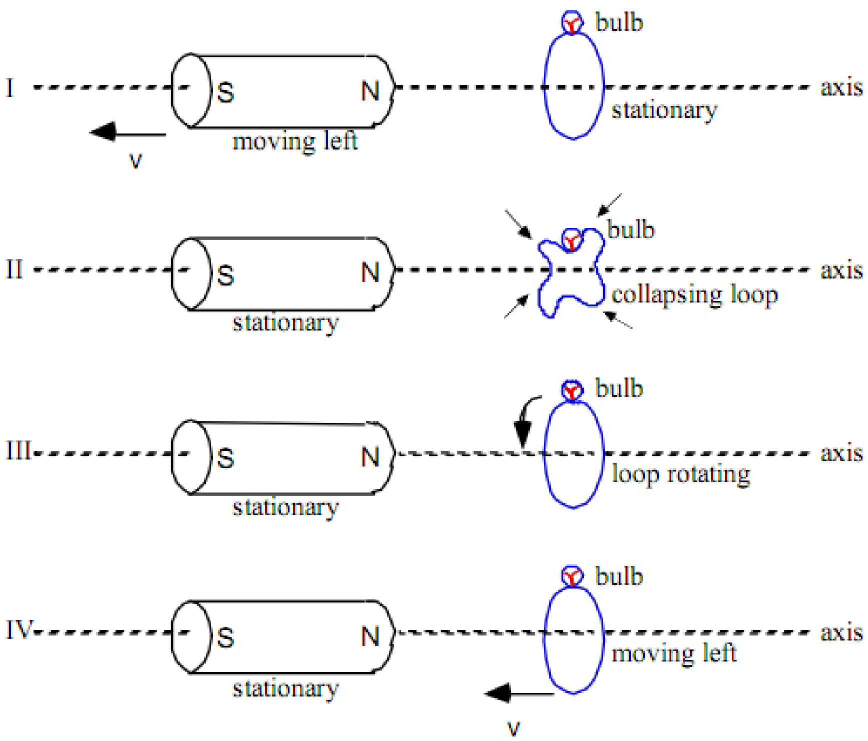


Three *different* bar magnets (left image) are placed around an iron marble as shown on the image on the right. The initial distance between the marble and each magnet is the same. In which direction will the marble move?

a) Towards magnet 1. It pulls harder than the other magnets because it is longer.
b) Towards point A. Magnet 1 and magnet 3 both pull harder than magnet 2, because they are bigger.
c) Towards magnet 3. It pulls harder than the other magnets because the area of the poles is larger.
d) Towards another point P (please draw this point), because …………………………..
……………………………………………………………………………………………….
……………………………………………………………………………………………….
e) The marble will not move because each magnet must pull equally hard.
f) It is impossible to answer, because the strength of a magnet cannot be predicted by its size.

QUESTION 7

The five separate figures below involve a cylindrical magnet and a tiny light bulb connected to the ends of a loop of copper wire. The plane of the wire loop is *perpendicular* to the reference axis (see image). The magnet can stand still, or move to the right or left. The wire loop can also stand still, or move to the right or left. It can also collapse (move inward). The arrow in the pictures show which of these are the case for each scenario.



In which of the above figures will the light bulb be glowing?

a) I, III, IV
b) I, IV
c) I, II, IV
d) IV
e) None of these

QUESTIONNAIRE ON ELECTRICITY AND MAGNETISM – PART 2

QUESTION 01

A few objects are placed near a bar magnet (as in the image on the right). Answer for each object: will it be attracted, repelled, or not affected by the magnet? Circle your choice.

a) An iron screw will be attracted / repelled / not affected
b) An aluminium plate will be attracted / repelled / not affected
c) A wooden block will be attracted / repelled / not affected
d) A copper coin will be attracted / repelled / not affected
e) A plastic ring will be attracted / repelled / not affected

For each case where an object is attracted or repelled (if any), explain:
i) What type of force is it?
ii) What *causes* this force?

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QUESTION 02

A magnet creates a magnetic field around it because:

a) In a magnet there is a part where positive charges accumulate and another where negative charges accumulate.
b) Inside the magnet there exist currents of electrons that lead to the creation of a magnetic field.
c) A different answer (please explain in detail), ……………………………………………
……………………………………………………………………………………………
……………………………………………………………………………………………
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QUESTION 03

See the figure. A magnet is hanging above the table. On the table there is a heavy weight, with a paperclip attached to it by a string. The paperclip is floating in the air, attracted to the magnet by *just* enough force to make this happen. You then move a piece of wood (an insulating material) in between the paperclip and the magnet. Will the paperclip fall? Explain your answer.

The paperclip will / will not fall,
because ……….……….……………………...
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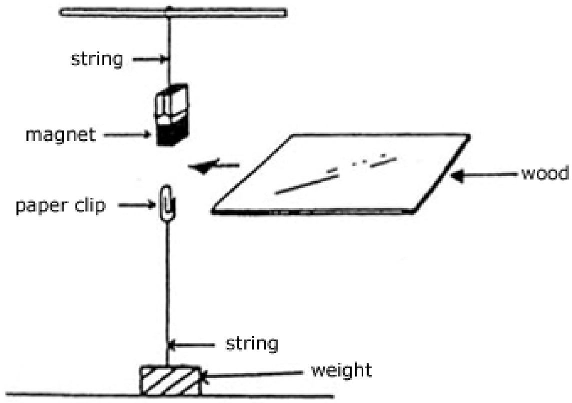

QUESTION 04

Consider a compass, which points to the magnetic north pole of the earth (see image). A number of objects is then brought near to the compass. Which of these can cause the compass needle to change direction? Circle the correct option(s) (more than one answer may be correct), and explain your answer below.

a) A bar magnet
b) A large charge at rest
c) A electric wire with a current
d) None of these because the Earth's magnetic field is much stronger

Explanation: ……………………………………………………………………………………
…………………………………………………………………………………………….
…………………………………………………………………………………………….
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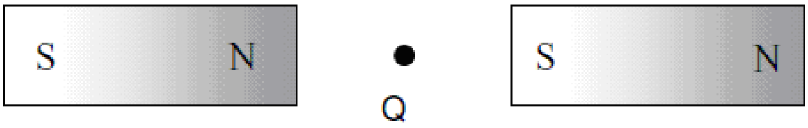
QUESTION 05

A particle with a positive charge Q is placed between two magnets, as shown in the figure below. Will the magnets exert a force on the particle? Will the particle move? Explain your answer in detail.



Answers:
The magnets will / will not exert a force on the particle.
The particle will / will not move.
Explanation: ……………………………………………………………………………………
……………………………………………………………………………………………...
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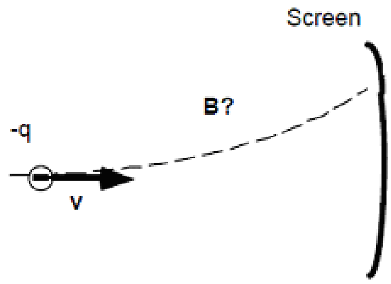
QUESTION 06

An electron moves horizontally toward a screen. The electron moves along the path that is shown because of a magnetic force caused by a magnetic field. What is the direction of this magnetic field?

a) Towards the top of the page
b) Towards the bottom of the page
c) Into the page
d) Out of the page
e) The magnetic field is in the direction of the curved path.



APPENDIX 2

INTERVIEW SCHEME FOR INTERVIEW WITH SEDIBA PARTICIPANTS
Subject: misconceptions

- *Welcome participants, introductions, and thank them for their cooperation.*
- *Purpose: to get an idea what is understood of electricity and magnetism and which concepts are difficult.*
- *Grades: this interview will not affect the participants' performance in the Sediba programme. The researcher will use the results of the interview only for the research itself.*
- *Privacy & permission to film: the teachers will not be named in final product, video only for research purpose.*
- *Feel free: if a question is unclear, if you want to add something, or if you want to elaborate your views, feel free to interrupt at any time. This is not a test, so please feel free to share your thoughts at any time.*
- *Questions?*

N.B. Relevant critical aspects are listed between brackets.

A: CAUSE OF MAGNETIC FIELDS

Question 01: Can you explain what a magnet is? (2)
    What do magnets do? (8, 9)
    Can you explain how it works? (2)
    What makes a magnet do that? (What makes a material magnetic?) (1, 2, 8)
    If necessary: can you explain what a magnetic field has to do with this? (2)
        What causes the magnetic field?
        What causes a magnetic force?

Question 02: Will a magnet attract…
…A small piece of iron? (8)
    If yes, why is the iron attracted to the magnet?
        How does it work / what happens? (2)
        Will aluminium be attracted to the magnet? (8)
            If no, why are some materials attracted and others not? (8)
                Which other materials act like iron near a magnet? (8)
                What do these materials have in common? (2)
            If yes, will all metals be attracted? (8)
                If yes, why are metals attracted? (2, 3, 8)
                If no, why are some materials attracted and others not? (8)
                    What are magnetic materials? (8)
                    What do these materials have in common? (2)

    If no, what *will* be attracted to a magnet and why? (8)
        What is the difference between iron and that material? (8)
        How does it work / what happens? (2)
        What do magnetic materials have in common? (2)

…a small piece of wood / wood splinters?
    If yes, why is the wood attracted to a magnet? (2)
    Do magnets attract all materials? (8)
        Are there non-magnetic materials? (8)
            If yes, what is the difference between mag./non magn. materials (8)

If no, why not?
What is the difference between wood and iron? (8)
Why is one attracted while the other is not? (8)
What makes a material magnetic? (2)

Question 03: Explanation of models

In case of **magnetism explanation** (i.e. poles, magnetic moments, currents):
Do charges have something to do with magnetism?
Does the motion of the charges in the magnet have anything to do with the magnetic field / force? (1)
Will it still be a magnet if the charges in the magnet are stationary? (1)
In case of **electric induction explanation** (i.e. one pole is negative, one positive):
Can you explain how the charges in the magnet cause the magnetic field? (3)
Can you draw where the charges are situated in the material and/or magnet? (2)
Does it matter whether the charges in the magnet move or not? (1)
Please explain, using charges, how a magnet can stick to a fridge door.

Question 04: We've seen that a permanent magnet has a magnetic field. What else can cause a field like that? (4)
Steady / moving charges? (1)
Currents? (1)
Changing E-fields? (4)

B: CAUSE OF ELECTRIC FIELDS

Question 05: Do you know how a plastic rod may be given an electric charge? (2)
What can an electrically charged rod do when objects are brought near? (8, 9)
Can you explain how it works? Examples? (2)
If necessary: can you explain what an electric field has to do with this? (2)
What causes the electric field?
What causes an electric force?

Question 06: Will a charged rod attract…
…a small piece of iron (foil)?
If yes, why is the iron attracted to the rod? (2)
How does it work / what happens? (2)
What happens inside the iron when a charged object is brought near? (8)
Can you draw where the charges are situated in the rod and iron? (2)
Does it matter whether the charges in the rod move or not? (1)

Will other materials be attracted as well? Which? Why? (8)
What do these materials have in common?
Are there also materials that cannot be picked up this way? Which? Why? (8)
(Even if they're very small?)
What makes them different from the materials that can be picked up?
Carry on with wood if it hasn't come up yet.
If no, *carry on with next question.*

…a small piece of wood (splinters)?

If yes, what causes the wood to be attracted to a charged rod? (2)

What happens inside the wood when a charged object is brought near? (8)

Can you draw where the charges are situated in the wood and rod? (2)

Is it different for insulators / conductors? Why? (2, 8)

Does it matter whether the charges in the rod move or not? (1)

If no, what is the difference between wood and iron? (8)

Why is one attracted while the other is not?

Does it make a difference whether the material is an insulator / conductor?

or: What *will* be attracted to a charged rod (if anything) and why? (8)

How does it work / what happens? (2)

What is the difference between iron/wood and that material? (8)

Can you draw where the charges are situated in the rod and material...? (2)

Question 07: We've seen that a charged object has an electric field. What else could cause a field like that? (4)

Steady/moving charges? (1)

Changing B-fields? (4)

C: INTERACTIONS

Question 08: Suppose a steady charge would be placed near a bar magnet, would the charge be attracted to the magnet?

Does a magnetic field exert a force on a steady charge? (9)

Question 09: A piece of electric wire is placed in a magnetic field. (9, 12)

a) The piece of wire is not connected to anything.

Will the magnet exert a force on it? Explain?

b) Now we use a piece of wire connected to a battery: it conducts a current.

Can it be attracted to the magnet now? Explain?

Is it different for a separate moving charge?

Question 10: A steady charge is placed in an E-field. Will a force act on it? (9)

Does an electric field exert a force on a steady charge?

Question 11: A piece of electric wire is placed in an electric field. (9, 12)

a) The piece of wire is not connected to anything.

Will a force act on the wire? Explain?

b) Now we use a piece of wire connected to a battery: it conducts a current.

Will a force act on the wire now? Explain?

D: POLES

Question 12: What is a magnetic pole? (2, 3, 14)

Or: magnets have a north and south pole. What can you tell me about them?

What happens when you cut a magnet in half? Can you separate the poles? Explain?

Question 13: Do charged rods have similar poles? (14)

Or: a charged rod has plus charges at one end, and minus at the other.

What happens when you cut a rod in half? What happens to the charges? Why? (2, 3)

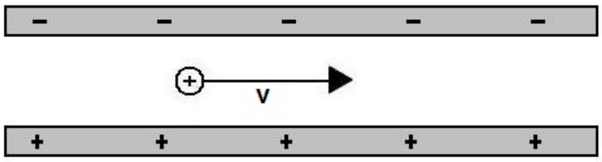
Question 14: The E-field

Show drawing on separate paper

A moving positive charged is placed in an E-field as shown in the drawing.

In what direction is the E-field? Could you draw it on the image? (13)

In what direction will the charge experience a force? Could you draw this? (13)



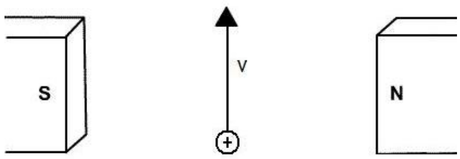
Question 15: The B-field

Show drawing on separate paper

A moving positive charged is placed in a B-field as shown in the drawing.

In what direction is the B-field? Could you draw it on the image? (13)

In what direction will the charge experience a force? Could you draw this? (13)



<u>H: GENERAL</u>

Question 16: Can a B-field and an E-field exist without one another? Example? (5)

- *Are there any questions?*
- *Would the participants like to add anything?*
- *Thank participants again for their cooperation.*

APPENDIX 3

INTERVIEW SCHEME FOR INTERVIEW WITH PROGRAMME LECTURER
Subject: lecture on electric and magnetic fields

- *Thank lecturer for cooperation*
- *Purpose: (1) to get insight in the didactical methods used in the Sediba program (2) to compare the methods to a theory of how people learn (variation theory) to see whether the used methods can be expected to be efficient and whether theory could show where there is room for improvement.*
- *Privacy & permission to film*
- *Feel free: if a question is unclear, if you want to add something, or if you want to elaborate your views, feel free to interrupt at any time.*
- *Questions?*

A: DIDACTICAL APPROACHES

How have you explained the concept of the electric field to the students?

Could you describe the didactical approach that you followed in the lecture?
Why did you choose this approach (didactical reasons)?
Do you think the approach you used was effective? Why / why not?
Do you always use this approach always / often / occasionally?

Does the *textbook* do it the same way?

If not, where do you divert from the book? Why did you decide to do it your way?
If yes, are you happy with this explanation? Why?

Do you use *examples* in class to teach the concept of the electric field?

Example? Why do you think these specific examples are useful?

Do you use *assignments / group discussions / problem solving* in class to teach the concept?

Example? Why do you think these specific assignments are useful?

Do you use *practical work* to explain the concept?

Example? Why do you think these tasks are useful?

Do you think students have *conceptual problems* about the electric field?

Can you give an example?
Is your textbook useful in addressing these problems?
How do you deal with these problems?

How have you explained the concept of the magnetic field to the students?

Could you describe the didactical approach that you followed in the lecture on this topic?
Why did you choose this approach (didactical reasons)?
Do you think the approach you used was effective? Why / why not?
Do you always use this approach always / often / occasionally?

Does the *textbook* do it the same way?

If not, where do you divert from the book? Why did you decide to do it your way?
If yes, are you happy with this explanation? Why?

Do you use *examples* in class to teach the concept of the magnetic field?

Example? Why do you think these specific examples are useful?

Do you use *assignments / group discussions / problem solving* in class to teach the concept?

Example? Why do you think these specific assignments are useful?

Do you use *practical work* to explain the concept?

Example? Why do you think these tasks are useful?

Do you think students have *conceptual problems* with the concept of the magnetic field?

Can you give an example?

Is your textbook useful in addressing these problems?

How do you deal with these problems?

<u>Distinction of E&M:</u>

From prior research, it appears students sometimes confuse aspects of electricity and magnetism with each other. Have you noticed confusions of that kind? Example(s)?

In your teaching, how do you help the students to distinguish electricity and magnetism?

Can you describe / characterize your didactical approach on this?

Do you think it is an effective approach?

Have you ever used different approaches?

Lecture: there was a focuss on similiarities and differences between E&M. Reasons?

Which do you think are the critical differences and similarities between E & M?

How do you explain the difference and similarities between the two fields to the students?

Which aspects do you make explicit (i.e. source, strength, effect etc)?

Similar to text book? Yes/no, why?

Do you use examples or assignments in class to handle the distinction/similarities?

Do you use examples? Why?

If nothing comes up: an example is that students seem to think that magnetism is due to induced charges which form the poles of a magnet. How would you deal with this?

<u>B: VARIATION THEORY</u>

Have you heard about the 'variation theory' of learning?

If yes, can you explain what the theory says?

If no: the researcher briefly summarizes the basics of variation theory.

What do you think of this theory? Does it seem credible? Usable?

Would you say you have used this theory before (knowingly or instinctively) in your teaching (do you think your teaching reflects some of the aspects suggested by variation theory)?

If yes, how would you say this was the case? Can you name an example of this?

Had you planned it that way, or did it just happen?

Do you always/often/occasionally use it in your classes?

Do you think it could be useful to take this theory into account (more) in your teaching? Why (not)?

Back to the physics subject of interest:

Of course, the aspects we deal with in electricity and magnetism are very different from those of a chair or table. I'm trying to find the critical aspects a student has to know, to distinguish between a magnetic and an electric field.

So what do you think are some main characteristics of electricity that distinguishes it from other phenomena?
And what do you think are some main characteristics of magnetism that distinguishes it from other phenomena?
In your view, what are the most important aspects of the electric and magnetic field? How are the two to be distinguished?
And how about the electric and magnetic forces?

Any ideas on how variations could be used to teach about these main characteristics? Examples?

- Any other questions / input / contribution that he would like to make? Anything to add?
- Thank lecturer again for cooperation