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AN INVESTIGATION OF FIRST YEAR UNIVERSITY STUDENTS' UNDERSTANDING OF MAGNETIC FORCE RELATIONS BETWEEN TWO CURRENT CARRYING CONDUCTORS A CASE STUDY: BALIKESIR UNIVERSITY, FACULTY OF EDUCATION

ÜNİVERSİTE 1. SINIF ÖĞRENCİLERİNİN AKIM TAŞIYAN İLETKENE ETKİYEN MANYETİK KUVVET KONUSU İLE İLGİLİ KAVRAMSAL ANLAMALARI: BALIKESİR ÜNİVERSİTESİ NECATİBEY EĞİTİM FAKÜLTESİ ÖRNEĞİ

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ABSTRACT: Studies in the area of science education report that children construct alternative frameworks to desribe scientific notions. This study is intended to describe first year university students' ideas, at Balikesir University Necatibey Education Faculty, on magnetic force relations between two current carrying conductors, to offer interpretations of the learning barriers and to reveal the development of students' scientific knowledge on the subject during a period of formal teaching at Balikesir University Necatibey Education Faculty.

In the study, pre, post and delayed post tests were administered to 95 students involved and related lectures were observed using non-participant approach. Finally, semi-structured interviews were conducted with 8 selected students. The analyses of data showed that the majority of the level of students' understanding did not change much over teaching and the detected misconceptions on the learnt concepts before teaching found to be existing after teaching. Implications of the findings are discussed and suggestions are made for teachers and curriculum developers.

Keywords: science education, alternative frameworks, Level of understanding, misconceptions

ÖZET: Fen Eğitiminde yapılan araştırmalar öğrencilerin çeşitli kavramları tanımlamada alternatif kavramlar kullandıklarını göstermiştir. Bu çalışmada, Balıkesir Üniversitesi Necatibey Eğitim Fakültesi Fizik Eğitimi Bölümü 1. sınıf öğrencilerinin akım taşıyan iletkene etkiyen manyetik kuvvet konusunda görüşlerini öğrenmek, konu ile ilgili kavramları anlamalarında karşılaştıkları güçlükleri belirlemek ve öğretim sonrası öğrenmelerindeki değişimin incelenmesi amaçlanmıştır.

Bu amaçla, ön-test, son-test ve gecikmiş son-test söz konusu fakültenin 1. sınıfındaki 95 öğrenciye uygulanmış ve ilgili konuya ait dersler katılımsız gözlem metoduyla izlenmiştir. Ayrıca testleri cevaplayan 95 öğrenci arasından 8 öğrenci ile yarı-yapılandırılmış görüşmeler yapılmıştır. Elde edilen verilerin analizi sonucu öğrencilerin büyük bir çoğunluğunun öğrenme düzeylerinde değişme olmadığı ve konunun öğretiminden önce saptanan kavramsal yanılgıların öğretim sonrası da devam ettiği görülmüştür. Verilerin analizinden elde edilen bulgular tartışılarak öğretmenlere ve program hazırlayıcılarına bazı önerilerde bulunulmuştur.

Anahtar Sözcükler: fen eğitimi, alternatif kavramlar, öğrenme düzeyleri, kavramsal yanılgılar

1. INTRODUCTION

Concern with the nature and development of understanding in physics learners has been of interest to science educators for many years. One prominent dimension of this concern is the consideration of ideas about selected scientific concepts that students bring to classes. These student ideas have been described by a variety of labels: preconceptions, alternative frameworks, misconceptions and naive theories.

Many studies in the area of physics education report that children construct their own ideas of natural phenomena even before formal school teaching takes place (Driver, 1983; Driver & Erickson, 1983). These ideas or '*everyday concepts*' are developed in informal contexts outside of school. Here, children mainly try to make sense of the world around them from their experience, their prior knowledge and linguistic background (Driver, Guesne, Tiberghien, 1985).

One of the main aims of teaching science is to enable students to develop a scientific understanding of the natural world in which they live. Such a development in understanding through schooling can be managed by providing an effective '*learning environment*' (Redish & Stein-

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berg, 1999) involving students in constructing, reconstructing and modifying already existing ideas.

2. AIMS OF THE RESEARCH

The study aims to monitor the learning of first year physics undergraduates as they progress through a taught course on electromagnetism. The aims of the study are:

- To identify the initial ideas held by students before undertaking a course on the topic of magnetic force relations between current carrying conductors;
- To explore shifts in such ideas as the course progresses;
- To evaluate the consistency of these ideas by probing them in different scientific contexts;
- To identify conceptual difficulties or learning barriers encountered by students;
- To consider the implications of the research findings for teaching and learning of electromagnetism.

3. RATIONALE OF THE STUDY AND A REVIEW OF LITERATURE

There are several reasons for undertaking this study. Firstly, magnetic force relations is a topic of science which can be demonstrated practically, however, it is an area of physics which contains difficult conceptual ideas due to its abstract nature. Consequently, understanding of the topic can become a source of confusion and memorisation without comprehension.

Secondly, the topic is traditionally covered in the second year (year 10) of secondary schools. This gives the researcher an opportunity to investigate the learnt concepts before the teaching of the subject starts at the university and to monitor students' subsequent progress through their training.

Thirdly, much of the research in students' understanding of scientific concepts has focused on school-age pupils with less attention on university students (Driver, Leach, Millar, Scott, 1996). Therefore, this study is aimed to investigate the ideas students bring to physics classes, what is involved in the teaching of the topic and what the students had learnt after the course at university.

Finally, the relative lack of research into students' understanding of magnetic force relations encouraged the researcher to enter into the study. Additionally, research into the development of ideas in terms of how they change after encountering a structured sequence of physics teaching in a school science course has not been investigated. For these reasons, the researcher is interested in revealing the impact of the taught university course on students' learning of magnetic force relations.

The recent publications in the area that could be traced were that of Galili (1995) and Paulus and Treagust (1991). Galili (1995) administered paper and pencil tests to high school students and prospective teachers aged between 16 and 30. A series of tasks was set in this study and one involved a current carrying wire in the vicinity of two magnetic poles. The students were asked to show all the forces exerted on each component of the system. A striking feature was that only 3% of all students showed correctly a force applied to the magnet. In another study, Paulus and Treagust (1991) found that only 17% of students aged 16 years explained that a current carrying wire can exert a force on another adjacent current carrying wire. Paulus and Treagust (1991) suggest that since the demonstrations of the force on the current carrying conductor in the field of a magnet are performed quickly, students do not have time to register the various directions involved in their mind.

4. METHODOLOGY

Changes in students' understanding of magnetic force relations were monitored during the electromagnetism course using the pre, post and delayed post tets, non-participant classroom observation, and semi-structured interviews

Pre and post tests were administered to measure the growth of understanding during the lecture period while the delayed post test was administered to probe the longer term understanding of the students. The core of data collection lies with the pre, post and delayed post tests. This is where the main body of information was collected.

Most of the questions used in the tests were in the form of a multiple choice question followed by an open ended part which gave students freedom to express their ideas and required an explanation for their predictions to the multiple choice part. All 3 tests were administered to 95 first-year physics students in Necatibey Education Faculty at Balikesir University.

The researcher observed the relevant lectures to learn when and how the main ideas were covered. An observation method was used to detail the nature of the teaching intervention during 12 sessions. The main aim of the observations was to study the interactions between the lecturer and the students to see what teaching activities and learning opportunities were presented and how the students responded to those activities. A simple observation schedule which was easy to code was therefore developed. The class that was involved in the observation included a total of 95 students of mixed abilities.

Finally, semi-structured tape-recorded interviews with selected 4 volunteer students allowed further investigation of depth of student understanding throughout the course.

Students' understandings were probed during interviews with demonstration experiments which were set up beforehand. These experiments were useful to gather information about students' spontaneous reasoning provoked by the visual effect and also to trace progress in students' ideas through discussion with the researcher. Demonstrations first started with students' predictions after introducing the equipment and then continued with their explanations for the phenomena or with working on a piece of paper to depict the related situations.

The lengths of the conducted interviews varied between 25 and 35 minutes, depending on the detail of responses, being largely determined by the students themselves.

5. RESULTS

5.1 Teaching Interactions

A quite detailed record of the teaching processes was collected and it indicated a very clear pattern. This pattern showed that the lecturer was talking many times and there was not much interaction between the lecturer and the students. Additionally, there was no significant difference between the teaching from one lecture to the next for all of the different lectures observed.

In all of the 12 observed lectures, only 3 students interacted with the lecturer by asking questions and this was on only 3 occasions. For most of the 85 minutes of each lecture the students were busy following the lecture and copying notes. When asked to give their opinions about how the lecturers had influenced their understanding of the main concepts all students said they had an average understanding of the lecture. The reasons given ranged from the lack of a link between the abstract physics examples and every day life, low student participation and the balance between theory and experimental work.

Questions asked by the lecturer did not promote students' interaction with the lecturer, the blackboard or the textbook. However, the strengths of the interaction patterns can be summarized as follows:

- Teaching was carried out systematically and there was a careful build up of the concepts,
- The lecturer reviewed the topics covered earlier and made links with the recently taught ideas. In doing this he also set the target in terms of learning objectives for topics to be taught.

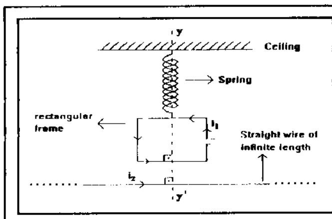
On the other hand, the most obvious weakness of the lecture events was the lack of involvement of the students. The missing thing about the lectures was that the lecturer did not really ask questions, give opportunities and encourage students to negotiate or discuss ideas between themselves. Students had few chances to ask their own questions. Apart from these;

- Most of the lecture time was spent on solving abstract problems which were nothing more than using related equations with given numerical values.
- The lecturer attempted to make links between concepts or subtopics but not adequately to influence meaningful learning.
- Although the language used was clear, the lecturer was most of the times facing the blackboard rather than addressing the students.
- The lecturer did not give any assignment to evaluate the students' learning.

In the following section, the extent of the students' learning which followed from these lectures will be examined in detail.

5.2 The Analysis of Students' Responses to Tests

Students' explanations concerning the magnetic forces between two current carrying conductors were analysed. The same question was used through all the 3 tests and responses to the question were again in two parts. In part (a), students were asked to predict the correct option and in part (b) they were asked to write their explanations for their predictions. Figure 1 shows the question used in pre, post and delayed post tests.



A suspended rectangular wire frame and straight wire of infinite length are in the same plane as can be seen in the figure above. The frame is stationary. Current intensities are i_1 (produced by the battery on frame) for the frame and i_2 for the straight wire. If the intensity of current i_2 is increased the frame moves.

a) Which one of the following sentences best describes the movement of frame?

A. Moves up
B. Moves down
C. Moves in the direction of i_2
D. Remains stationary
E. Rotates around yy' axis

Letter

My selection is:

b) My reason for choosing this answer is because:

Figure 1. A suspended rectangular wire frame above a current carrying straight wire of infinite length.

This question was used for two purposes. The first one was to find out whether students were able to define the magnetic field of a current carrying straight conductor and whether they were aware of the varying strength of the field with distance. Secondly, it checked whether students recognised mutual magnetic forces between current carrying conductors.

The analysis was carried out in two phases: Firstly, the distribution of the number of students selecting each of the options in the multiple choice part and the nature of students' explanations of their predictions were analysed.

5.2.1 Responses to Multiple Choice Items

Table 1 shows the number of students predicting the options in response to the multiple choice part.

First of all, the number of students selecting the correct option increases slightly after instruction. In fact, this option was the second most common option in the pre and post tests. However, in the delayed post test there is a 50% increase in the number of students who predicted the correct option which became the most common alternative.

Table 1. Distribution of predictions.

Pre, post and delayed post Instruction	Pre	Post	Del. Post
A. Moves up	48	39	33
B. Moves down	27	32	48
C. Moves in the direction of i_2	1	4	0
D. Remains stationary	5	11	2
E. Rotates around yy' axis	14	9	12

* Shaded row shows the correct option

As can be seen in Table 1, option A is chosen most often in the pre and post tests, the numbers decreasing after instruction.

5.2.2 Analysis of Students' Explanations

The following section examines students' reasoning in response to the open ended part of the question. The complete list of the students' reasoning and the number of students in each response category are shown in Table 2.

The first analysis of the students' responses

Table 2. Summary of forms of arguments given in response to "*magnetic force relations*" question

Levels	TYPE OF RESPONSE	Test Type (N = 95) Pre Test	Post-Test	Delayed Post Test.
	A. Scientifically Acceptable Arguments			
	1. Full Argument			
6	Increase in current → increase in B field Right – hand rule → direction of B field Current carrying frame in a B field → experience magnetic forces Right – hand rule → direction of forces B field intensity reduces with distance → force on lower side is bigger	1	1	2
	2. Part of Argument **a. Response refers to full explanation of Right – hand rule**			
5	Increase in current → increase in B field Right – hand rule → direction of B field Current carrying frame in a B field → experience magnetic forces Right – hand rule → direction of forces	0	1	0
4	**b. Response refers to increase in B field and linking that increase to magnetic forces on the frame**			
	Increase in current → increase in B field Right – hand rule → direction of B field Current carrying frame in a B field → experience magnetic forces	2	5	4
	c. Response refers to increase in B field and the direction of that B field using Right – hand rule			
3	Increase in current → increase in B field Right – hand rule → direction of B field	3	3	3
2	**d. Response refers to only increase in B field**			
	Increase in current → increase in B field	4	2	3
	B. Scientifically Unacceptable Arguments	**10**	**12**	**12**
	1. Response Related to Magnetic (B) Field and Forces			
	Response such as those relating the movement direction of frame to:			
	● B fields' directions or mutual interactions between B fields which were produced by frame and/or straight wire in wrong directions	27	28	18
	● mutual/balancing magnetic forces which have unknown source and/or wrong directions for frame and wire	23	27	32
1	● unbalanced B field lines or flux passing through the centre of frame	8	6	11
	● no magnetic effect of straight wire or no function of increased field	3	1	2
	2. Response Related to Other Ideas	**61**	**62**	**63**
	Response such as those relating the movement direction of frame to:			
	● balancing currents and their directions flowing in the conductors	10	10	13
	● E field or E force produced by wire and frame	8	3	3
	● directions of balancing currents and mutual electric forces	6	8	4
		24	**21**	**20**

was in terms of whether they suggested scientifically acceptable arguments in response to this question. The scientifically acceptable arguments are coded into five different levels in terms of their level of sophistication. Levels 2 to 6 are allocated for scientifically acceptable arguments with increasing completeness and the full argument in level 6 involves all the steps as shown in Table 2.

The lowest level (Level 1) represents the scientifically unacceptable explanations given by students. Responses in this level were divided into two groups. The first group comprises the ideas referring to magnetic fields and forces but are judged scientifically unacceptable in response to this question. The second group consists of the responses involving ideas about electricity.

While 27 students predicted the correct option in the multiple choice part, only 10 students gave scientifically acceptable explanations prior to instruction. In addition, there is little change in the number or level of students' scientifically acceptable responses with instruction (from 10 to 12). After teaching, one student, but not the same student as in the pre test, gave a full explanation of the phenomenon. While nobody made the full explanation of right hand rule (Level 5) in the pre test, 1 student gave this level of explanation.

Prior to teaching, 85 students suggested scientifically unacceptable arguments of which 61 referred to magnetic fields and forces ideas whereas 24 students related their ideas to electric concepts (Table 2). In responses related to magnetic fields and forces group, the most frequent response category (27 students) is the one which explains the movement direction of the frame in terms of magnetic fields' directions or mutual interactions between the straight wire's and the rectangular frame's fields. For example:

"*Both rectangular frame and the straight wire produce magnetic fields out of paper plane. Increase in current intensity in the straight conductor also increases straight wire's field on the frame. Since both fields are in the same direction, increased current destroy the balance between two fields. The frame will encounter with more repulsive force and be moved upwards*" (Student 34)

The same resultant motion of the frame was explained in a different way by some students in this category. They answered the question in terms of the straight wire's magnetic field direction rather than the interaction between two conductors' fields. A typical response of these students would be:

"*Magnetic field due to current i_2 will be upwards. When we increase this current, the frame will move in the direction of the straight conductor's field, so it moves up*" (Student 25)

As can be seen from these two examples, students were focusing on just one part of the system by referring only to current i_2 and the field around the straight wire produced by current i_2. There is no reference to interaction between the straight wire's magnetic field and the electric current carrying frame in that field to identify the force on the frame.

23 students provided explanations in terms of magnetic forces which have an undefined source or wrong directions, without making reference to magnetic fields. They mixed up the field and force and responded that conductor follows the direction of magnetic field:

"*Here, an upwards magnetic force is applied by current i_2 on the frame and a downwards force is applied by current i_1 on the straight wire are equal initially thus the frame is stationary. If the current i_2 is increased, the balance of these forces is ruined. Since we ruined this balance by contributing the force produced current i_2, rectangular frame will move in the direction of magnetic force applied by straight wire. Therefore, the frame moves up by dominated force on itself*" (Student 61)

This suggests that students do not differentiate magnetic field and force.

After completion of the electromagnetism unit 83 students' responses were classified as containing scientifically unacceptable explanations. Of the 83 students (87%), 62 students proposed scientifically unacceptable ideas related to magnetic fields and forces (Table 2). In the first response category of this group, which refers to magnetic fields' directions, students were basically unable to conceptualise the formation of magnetic field around the current carrying straight conductor and the responses fell into the same pattern as were exemplified in the pre instruction data.

Some students also justified themselves by referring to different magnetic force(s) ideas from the pre test responses. For example:

"*If current i_2 is increased, magnetic forces applied by straight wire to the frame increases. If we apply right hand rule to the frame, we see that net force on the frame is zero due to upwards force on upper side, downwards force on lower side and leftwards and rightwards forces on the left and right sides of the frame respectively. Although increase in current i_2 will increase the value of magnetic forces on each side of the frame, resultant force will be zero. Thus, the frame stays stationary*" (Student 42)

In this extract application of the right hand rule to the question was correct but the student did not analyse the variation of the magnetic field and hence the force with distance. Similar sorts of ideas, as those which were exemplified in the analysis results of the pre test question, came up in the rest of the students' responses in this category.

Almost the same number of students (63) responded in the delayed post test compared to the post test (62 students) in terms of unacceptable magnetic fields and forces ideas. Students explaining the movement of the frame in terms of mutual or balancing magnetic forces increased by 5 to 31 and made this category the most common category in the delayed post test.

The most common response category which includes magnetic fields' directions or mutual interactions between these fields in pre and post tests was the second most common (18 students) category in delayed post test. A different response from the pre and post test responses appeared:

"*Current in the frame produces a magnetic field into paper plane between the frame and straight conductor. Current flowing in the straight wire produces a magnetic field out of paper plane above itself. If initially the frame is stationary then the values of inwards and outwards magnetic fields are equal. When we increase the intensity of current i_2, outwards magnetic field due to the straight conductor will increase and move the frame up*" (Student 55)

Although the directions of the fields were correct, the student adopted the unacceptable idea of fields' interaction.

Pre instruction, ideas are drawn upon from the concept area of electricity by 24 students. In this group, the most common category relates the movement direction of the frame to the currents' directions flowing in the straight wire and in the rectangular frame. For example:

"*Conductors carrying currents in the same direction repel each other whereas conductors carrying currents in opposite directions attract each other. Currents i_1 and i_2 balance themselves while the frame is stationary. When the current i_2 is increased mutual magnetic forces between the conductors increase and the repulsive force on the frame becomes superior to the attractive force. Thus, the frame moves up*" (Student 17)

Students following this line of argument mainly assumed that the currents in the lower section of the frame and in the straight wire are in the same direction thus they repel each other.

An interesting kind of reasoning in this category was given by another couple of students who used the term '*current*' instead of magnetic field by applying the right hand rule to two conductors:

"*Straight conductor of infinite length produces a current which is out of paper plane and can be found by using right hand rule. On the other hand, rectangular frame also produces a current into the paper plane. Since these current flow in opposite direction both conductors will repel each other*" (Student 69)

These references to the word '*current*' could be made unconsciously however several students responded in the same way referring to the pattern of '*outwards/inwards current*' in their responses.

In the post test, the same pattern of responses as pre test responses appeared. Once again, most of the students referred to current in the bottom section of the frame and in the straight wire with their directions. On the whole, after instruction 21 students responded with ideas in this group which represents a slight decrease by 3 students compared to pre test results (Table 2).

Delayed post instruction, 20 students proposed ideas related to electricity and there was no particular response including a different idea from the pre and post test results.

The main points emerging from the analysis of students' responses to all 3 tests are:

1. The number of students giving scientifically acceptable responses did not change much with instruction. Indeed, 2 students were added to this group in the post test and these 12 students comprised 12% of the whole sample. After teaching, the quality of the responses did not change in terms of the number of elements contained and students gathered in the lower levels of the scientifically acceptable arguments group.

2. In both tests, a large proportion of students (89% in the pre test and 87% in post test) suggested scientifically unacceptable ideas related to magnetic and electric concepts. In observing the pre and post test data, recurring problems identified from students' responses were those of:

   i) single field model in which most students focus on only current i_2 and explain the movement of the frame in terms of the direction of magnetic field produced by current i_2,

   ii) confusion of magnetic field with magnetic force,

   iii) correctly applying flux linkage arguments,

   iv) basing explanations solely on the relative directions of currents in both conductors to each other,

   v) confusion between current and field in terms of the terminology used.

3. In this question, both the directions of magnetic field and forces are required but students often failed to describe the direction of magnetic forces on the frame. Although, some students in scientifically acceptable arguments identified the direction of magnetic field, they found difficulty in using this knowledge to specify the magnetic force's direction using the right hand rule.

5.2.3 Progress in Learning of Individuals: Analysis of Changes in Individuals' Ideas

So as to examine the changes in students' ideas between pre to post and post to delayed post tests, changes between levels for individual students were examined. Figure 2 shows the shifts in the explanations of 95 students across the six levels for pre, post and delayed post instructions.

The main feature of the representation in Figure 2 is that 85 students proposed scientifically unacceptable responses (Level 1) in pre test and 79 students were still responding in the same level without apparently being affected by instruction. It is also striking that 77 students did not change their unacceptable ideas from post to delayed post teaching. For example, student 46 wrote in her pre test:

"*Frame remains stationary since electric fields produced by both conductors are parallel to each other and outwards*" (Student 46)

After instruction her response was:

"*As the current i_2 is increased, magnetic force surrounding the straight wire increases which rotates the frame around yy' axis*" (Student 46)

Here, she refers to magnetic field as magnetic force and refers to the same concept in the delayed post test:

"*According to right hand rule, magnetic force encircles the current carrying straight conductor. Thus, the frame rotates around yy' axis*" (Student 46)

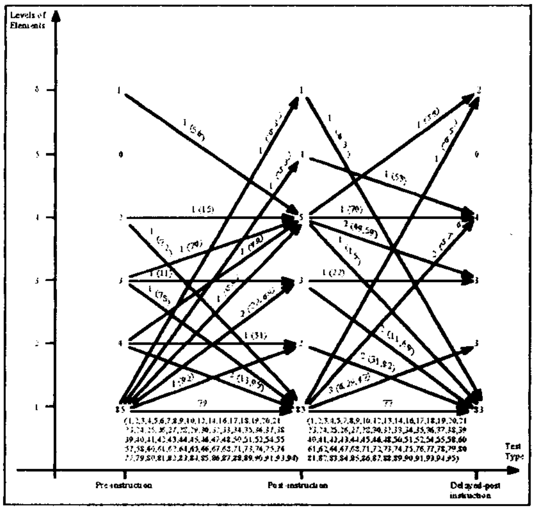


Figure 2 Analysis of changes in respondents' ideas. Movement across levels of responses of individual students to the question.

It is noticeable from Figure 2 that instruction caused 8 (1+2+1+1+1+1+1) students to make progressive shifts. Apart from the movement made by 2 students (22 and 69) from level 1 to level 3, all progressive shifts from level 1 to all other higher levels involve one student. For example, student 63, who made significant progress from level 1 to 6, wrote in his pre instruction test:

"*Wires carrying currents in the same direction attract each other whereas they repel themselves if they carry currents in opposite directions. Here, the lower side of the frame, which carries current in the same direction with straight wire, is closer to this wire than the upper side. Since the attractive force on lower side is dominated on repulsive force on upper side, it moves the frame down*" (Student 63)

After teaching his response was:

"*Current i_2 constitutes a magnetic field out of paper plane where the rectangular frame is located. In this magnetic field each side of the frame experiences magnetic forces which can be found using right hand rule. Since the leftwards and rightwards forces on the left and right fragments of the frame respectively are equal and in opposite directions, they cancel each other. Downwards force on the lower section is bigger than upwards force on the upper section of the frame. This is because the magnetic field's intensity decreases as the distance from the current carrying conductor increases. This will also cause the decrease in the strength of the magnetic force. By taking into account these points and considering the net force on the frame, it should move down*" (Student 63)

However, like the other 9 (1+1+2+1+2+2) regressing students he reverted to level 1 in the delayed post test.

"*Magnetic field produced by current i_2 in the straight wire is out of paper plane above the wire and into the paper plane below the wire. In addition, the lower side of the frame produces inwards magnetic field where the straight wire is located. Since these two fields between the frame and wire are opposite to each other, they attract themselves and the frame moves down*" (Student 63)

There were 5 (1+1+1+2) students showing lower level responses after teaching than before teaching. For example, student 72 gave a response referring to increase in magnetic field and linked that increase to magnetic forces on the frame (Level 4) in the pre-test but she regressed to presenting scientifically unacceptable arguments at Level 1 with instruction. The picture is one of the instability and uncertainty of understanding of these concepts.

It is interesting that there is a progressive shift over the time of post to delayed post testing performed by 7 (1+1+2+3) students. Apart from these, the majority of the students responded at level 1 through all 3 tests.

5.3 A Case Study: Investigating The Status of One Student's Ideas

In this part, an individual interview will be used to uncover one student's ideas at different stages of the teaching. Since it would not be possible to report data gathered from all 4 students only 1 student, Seda, who did not progress with instruction has been selected to examine changes in her thinking.

Seda almost always revealed scientifically unacceptable ideas despite teaching. She used the idea of fields' interaction during the interview which is conducted to analyse her representation of the forces on currents. A foil about 1 cm wide and 1 m long was cut and its ends were secured to two clip component holders. Two magnets were held above and below the centre of the foil strip with a mild steel yoke. A current of about 2A was passed in the east-west direction and the foil is moved northwards.

I: *How do you explain the movement of the foil when I switch on the d.c supply?*

S: *This is also related to the directions of magnetic and electric fields. When magnets are stuck inside the U shaped steel yoke, magnets' field flows in the yoke. Moreover, there is an electric field produced by current carrying foil. This can be found by using right hand rule while the thumb shows the direction of current flow, curled four fingers shows the electric field's direction. In sum, there is an interaction between the two fields and electric field producing foil, which is tensed northwards, tries to go away from the magnets' magnetic field.*

In order to probe what she meant by the interaction between two conductors, discussion continued on another demonstration where two parallel aluminium foils are connected in series and carry currents in opposite directions when the switch is on.

I: *What happens when I switch on the d.c voltage supply?*

S: *Foil on the right carries a current downwards and produces an inwards electric field on its left side according to right hand rule. On the other hand, an upwards current passes in the foil on the left which also creates an inwards electric field on its right side. Since both produced fields are in the same direction, foils attract each other.*

I: *Would you say that the foils attract one another if two fields are outwards between two?*

S: *Yes, I would. If one field is inwards and another is outwards however they repel each other. I imagine each foil as a magnet. The flow direction of currents in the foils corresponds to the currents flowing inside parallel placed two magnets whose opposite positive and negative poles faces each other. Since the opposite poles attract, these foils should get closer.*

Later on the interviewer switched on the power and demonstrated that two parallel foils repelled each other. She then explains that field lines produced in the same direction by both foils repel each other since they cannot intersect between the foils.

Despite teaching Seda still argues that a current carrying foil produces an electric field and she likens inwards field lines to the current of water in a waterfall. According to her, in order to allow the water (electric field lines) to flow, the foils should move apart to provide enough space for water to be poured. She then makes a generalisation using the waterfall analogy that conductors carrying currents in opposite directions never attract each other. During the interview, Seda has not recognised that a force on the foil is created due to the presence of that foil in the magnetic field of the other adjacent coil. Here, she concentrates on the region between two conductors.

As a final part of the interview, Seda was interviewed about another demonstration experiment based around a conducting rod, which is placed at right angles onto two parallel wires and two magnets held above and below the parallel wires with a steel yoke in between the parallel wires. When the current flows through the parallel wires, the rod conductor moves along a pair of conductors as long as it is situated between the magnets since a magnetic force will act upon it. The equipment used was introduced to Seda and the interview starts with Seda's prediction.

I: *What do you expect to see if a d.c current is given to the conductors?*

S: *Movable conductor and the other parallel wires produce electric fields since they carry a current. Magnets also create a magnetic field.*

I: *OK. Go on.*

S: *Both electric and magnetic fields interact. If the small rod is inside the magnetic field, it may be forced to move upwards or downwards. For example, if the magnetic field is directed from up to down, then the rod moves in the magnetic fields direction but if it is out of magnetic field area there will be no interaction and the rod stays stationary.*

When asked about the function of the current driven from the d.c voltage supply she comments that current's direction defines the orientation of the electric field produced by the rod conductor and if the magnets' magnetic field occurs in the same direction as the electric field then the rod is thought to be moving in the field's direction as in the case of a charged particle moving in the electric field's direction. However if two fields are in the opposite directions, she considers them to be cancelling each other and leave the rod motionless.

The interviewer switched on the voltage supply and the rod placed between the magnets moved along the parallel wires contrary to what she said. The interviewer turns to Seda and asks:

I: *The rod did not move upwards but rolled leftwards. What do you reckon?*

S: *Because there is an interaction between the electric field produced by the current and magnetic field due to magnets. Rod wants to move to a point where there is no such an interaction. Thus, it tries to escape from the magnetic field.*

I: *Do you think the rod moves when I put it out of magnets?*

S: *No. Because in the lack of magnetic field there will not be an interaction between those two fields and hence the rod remains stationary.*

As can be seen from Seda's responses, she cannot offer a further explanation except the interaction between two different fields. From what she has written, there is a suggestion here that she imagines magnetic field lines as having a reality of their own and can cause an interaction with each other.

5.3.1 Outcomes for Seda's Learning

There were some confused situations about electric and magnetic fields. Indeed, throughout the interviews there is clear evidence that Seda associates an electric field with an electric current and she associates a magnetic field with magnets.

Seda drew upon a range of ideas to help her make sense of '*her own*' model after teaching and during this process a number of alternative conceptions were generated. The most striking feature of Seda's thinking after teaching was her use of a waterfall analogy which explains that parallel two current carrying conductors' fields interact with each other. This shows her struggle to make sense of the right hand rule to explain the magnetic force on a current carrying conductor. Like many students Seda was still not able to respond with scientifically acceptable arguments after teaching.

6. DISCUSSION AND IMPLICATIONS

From the analysis, there was a wide range of incorrect reasoning in response to this question and it has been possible to identify a number of difficulties which come forward. A significant obstacle for the conceptual understanding of the phenomenon is that students found only one magnetic force on the frame in fact there has to be 4 different forces in terms of their directions and strength. In addition, students mainly accepted magnetic field lines as a source of force. They used the single field model based on current i_2 only and referred to term '*magnetic force lines*' which indicates that the field's direction gives the direction of force. This led them to conclude that the frame would move in the direction of the magnetic field lines. This sort of confusion of magnetic force with magnetic field was very common. Students neglected the fact that according to electromagnetic theory field and force vectors are perpendicular to each other and both cannot be in the same direction.

Some students referred to the reality of magnetic field lines and tried to make the idea of magnetic interaction between the frame and the straight wire concrete by saying things like "*fields in opposite directions between the frame and straight wire apply repulsive forces to each other and the frame moves up*".

Responses framed in terms of electricity were interesting. Students decided the movement of the frame in terms of the current's directions in two conductors. These students might have been prompted by thinking in terms of an algorithm in which currents repel each other if they are in opposite directions but attract if they are in the same direction. Furthermore, this idea may have come from secondary school teaching. The students know by heart a short cut solution without assimilating the reasoning behind that solution. In other words, the question of why current carrying conductors in the same direction attract each other cannot be answered by these students.

The confusion of ideas in electricity with electromagnetism was evident from the students' responses. They thought that conductors produce an electric field or electric force and interpreted the frame's movement in terms of the direction of electric fields or forces.

In the light of the overall findings from students' responses, there seems often to be a serious discrepancy between students' concepts and the accepted scientific point of view. Alternative frameworks detected in this study and other research might be used as a starting point and as an effective foundation for teaching. In some cases, it may be necessary to reveal students' previous experiences with the topic to make teaching and learning processes effective in modifying students' alternative frameworks.

The researcher believes that students should be made aware of their scientifically unacceptable ideas involving confusions. For example, when students are taught how a magnetic force acts on a current carrying conductor, it can be shown that the magnetic field of another adjacent current carrying conductor will not rotate it but it will apply a magnetic force in one direction which can be found using the right hand rule. In this strategy, students are exposed to a situation where their alternative frameworks are confronted with scientific concepts which in turn are supported by evidence through experimentation. This may put students in a position where they have to defend their ideas against the conflicting scientific observation or modify or replace their ideas.

The findings of the study suggest that curriculum developers in Turkey might be advised to take students' alternative ideas into consideration when planning and developing science curricula. In designing the science curriculum the areas of conceptual barriers to learning should be identified and more time should be allocated to focus on those identified conceptual difficulties and to practical activities (Woolnough, 1991). This will help teachers to monitor the changes in students' ideas and to diagnose the meanings constructed by the students through sharing of ideas.

The lectures in universities are mainly based on chalk and talk teaching and the solving of theoretical problems. On the other hand, the secondary school curriculum requires the teaching of the topic with explanations based on practical work. This shows that there is little coherence between the teaching goals of secondary schools and universities. Therefore, there is a need for university lectures to be organised in a way that builds more effectively on the secondary science curriculum. A combined approach, which provides the links between the same topics, would hopefully serve to better student understanding of the area. In this sense, what is contained in the university curriculum and what should be rejected have to be examined carefully by comparing the secondary school and university curricula. This will help secondary science teachers to improve the design and implementation of their own teaching strategies gained during their pre-service training.

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