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# REASONS OF STUDENT DIFFICULTIES WITH RIGHT-HAND RULES IN ELECTROMAGNETISM

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**Abstract.** *In electromagnetism, to determine the direction of the electromagnetic force and magnetic field, the right-hand rule (RHR) is used. Previous researches show that students have difficulty in applying the RHR. This research is aimed to find out the factors which make it difficult for the students to apply the RHR. To achieve this, qualitative case study design is used and 270 students who took Basic Physics II course at university participated. The Right-Hand Rule-Diagnostic Test (RHR-DT) and the unstructured interview were used as data collection tools. In the analysis of the data, firstly, the right-hand types used by the students were determined. Then the right-hand types used by the students in the solution of each task are presented. After that, eight of these students were interviewed about their RHR-DT answers and those interviews were video recorded. Video recordings are divided into three categories according to the level of students: upper, middle and lower. According to the results of this research, it can be said that the conceptual understanding of electromagnetism, the vector algebra and spatial cognition effect the usage of the RHR. In the light of research results, suggestions were made for the teaching of RHR to physics teachers.*

**Keywords:** *magnetism education, right-hand rule, conceptual understanding, vector algebra, spatial cognition.*

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## Introduction

It is claimed that students have difficulty in learning electromagnetism in physics. Most of specialized literature agrees that electromagnetism is the most difficult subject for the students to understand in physics (Chabay & Sherwood, 2006, Houldin, 1974, Loftus, 1996). Students suppose that electromagnetism includes difficult mathematical calculations, and they find concepts relating the topic intangible and cannot directly be associated with daily life (Bagno & Eylol, 1997; Chabay, & Sherwood, 2006; Houldin, 1974; Raduta, 2005; Tanel & Erol, 2008). Electromagnetism includes many intangible concepts such as current, voltage, resistance, charge, magnetic field, magnetic force, induction, and capacitance (Magana et al., 2017). For this reason, it is difficult for students to understand the concepts of electromagnetism and their interrelations, and thus it is difficult to solve problems related to this subject too (Ergin & Atasoy, 2013).

A previous research showed that learning electromagnetism for university students is as difficult as it is for high school students (Demirci & Çirkinoglu, 2004; Tanel & Erol, 2008). Güler & Şahin (2017) stated that university students know the concepts of magnetic effect and magnetic field, but they can inadequately explain the effects of these concepts. Magana et al. (2017) found that university students' knowledge of magnetism was inadequate.

Students have difficulties in applying the right-hand rule (RHR) used in electromagnetism as they have difficulties learning electromagnetism too. RHR is an important mnemonic technique, physics teachers are well-aware of the difficulties of the usage of RHR (Nguyen & Meltzer, 2003). RHR is a method used to show the vector relation between magnetic field, magnetic force and electric current. RHR is most often used to determine the direction of a vector product (Kustusch, 2016). In this rule, right hand thumb, forefinger and middle finger are held 90° angle with each other. Generally, forefinger, thumb and middle finger point in the direction of magnetic field, magnetic force and electric current, respectively. In literature, there are a few studies about the use of the RHR in electromagnetism, although there are many studies on the determination of misconceptions in electromagnetism. The difficulty in implementing the RHR was determined in relation with students' conceptual understanding of magnetism, vector algebra knowledge, and spatial thinking skills in literature (Kustusch, 2016). These factors are explained below.

The understanding of the concepts of magnetism is important for the application of the RHR. The concepts in electromagnetism directly related to the RHR are magnetic field, magnetic force, magnetic flux and electric current. Students have difficulties in learning these concepts on account of the fact that their cognitive complexity, magnetic field, magnetic force and magnetic flux are difficult subjects of physics to learn (Chabay, & Sherwood, 2006). Therefore, there have been several attempts in recent years to develop and validate a conceptual survey of concepts in electromagnetism. Mauk and Hingley (2005) stated that students had difficulty in defining the direction of the magnetic force acting on a wire in magnetic field. In addition to learning difficulty and misconceptions of electromagnetism, students had no idea about how to calculate the magnetic forces between a magnet or two magnets and an iron plate. Furthermore, Guisasola, Almudi ve Zubimendi (2004) showed that when students deal with the concept of lines of field they believe these lines are real. Sağlam and Millar (2006) found that common misconceptions about electric and magnetic field effects are seeing field lines as indicating a flow, using cause–effect reasoning in situations where it does not apply, and dealing with effects associated with the rate of change of a variable. Literature review emphasized that learning of electromagnetism concepts is difficult for students and only a few students could fully understand the concepts of "magnetic force" and "magnetic field" (Rossing, 1995).

The RHR is closely related to vector product. Cross product of two vectors is equal to a vector quantity and the direction of this vector can be determined by using RHR. Use of the RHR in a correct way is directly related to the understanding the vector product for the students. Barniol & Zavala (2013) investigated misconceptions and difficulties with graphical representation of components of magnetism. They found that even after three introductory physics courses, student still had difficulties with vectors. They emphasized that the students thought that a component of a vector was equal to the magnitude of the vector. Furthermore, the students had difficulties in calculating products and interpreting the scalar nature of the dot product and the vector nature of the cross product. Scaife and Heckler (2010) revealed that the students had difficulties in defining the direction of magnetic force on a charged particle in a magnetic field. This research indicated that the students did not recognize the noncommutativity of the cross product. Barniol & Zavala (2013) found that the electric field was not well understood by the students. Heckler & Scaife (2011) explained that students had difficulties with arrow representation itself, rather than the physics behind it.

RHR contains three-dimensional and kinesthetic ability (Kustusch, 2016). Klatzky & Wu (2008) signified practical difficulties of RHR. According to Klatzky & Wu (2008), students have difficulty to point the vector directions by using their fingers in RHR applications. In general, it is believed that use of the body (fingers in our case) may often facilitate cognition (Alibali, 2005). In some works, it is found that kinesthetic effects may play a role using RHR; for example, student may have physical disability to use hands or fingers (Nguyen & Meltzer, 2003). According to Kustusch (2016) the use of a RHR is more difficult when the vectors are not aligned with the axes of the paper or when the axis of rotation is vertical. Çoramık, Kocakülah & Özdemir (2010) indicated that these difficulties are caused by the complexity of spatial thinking.

*Research Focus*

Given the complexities associated with RHR, this research is aimed to find out the factors which make it difficult for the students to apply the RHR. This aim was addressed through the following research question: Why is it difficult for university students to comprehend and use RHR in electromagnetism?

It is considered that determining the reasons for the difficulty in practicing the RHR for the students will contribute to the teaching of the RHR. There are only a few studies on the RHR. Therefore, it is expected that this research will contribute to filling this gap in the literature.

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## Methodology of Research

### *General Background*

In this research, university student's skills in practicing RHR related to electromagnetism in Basic Physics II at university level are investigated. Qualitative studies typically focus in depth on relatively small samples that selected purposefully (Patton, 1990). Qualitative case study research design was used for detailed identification of RHR types which are used by students (Glesne, 2006). Research sample was determined according to purposeful criterion sampling method. Criterion sampling involves reviewing and studying cases that meet predetermined criterion of importance (Patton, 1990). For this purpose, the following criteria were used in the selection of the students for the study group:

a) being a student at science or mathematics education department,
b) to have taken Basic Physics II course for the first time in the last 2 years,
c) want to be a participant in this research.

In this research, data were collected with an open-ended diagnostic test and video recorded unstructured interviews. Descriptive analysis was used in the analysis of the data.

In the following sections, participants, data collection tools and procedures and data analysis are explained in detail.

### *Sample Selection*

The research sample consists of 270 second year students (pre-service teachers) at the faculty of education of a state university located in the west of Turkey at the fall term of 2015-2016 academic year. Departments of the students are physics education, science education, chemistry education and mathematics (elementary and high school) education. The sample is composed of 132 (48.9%) men and 138 (51.1%) women and age range of the sample is 18-20. All of the students participating in this research took the Basic Physics II course which includes electricity and magnetism. Third and fourth year students who had taken the Basic Physics II course more than one were not included in the research. In order to make an in-depth analysis of their right-hand rule usage, eight participants were randomly selected among 270 students. Interviews were held with them and were video recorded with the permission of the students.

### *Instrument and Procedures*

In this research, *Right Hand Rule Diagnostic* (RHR-DT) and unstructured interviews were used as data collection tools. These measurement tools are explained below.

#### *Right Hand Rule Diagnostic Test (RHR-DT)*

RHR-DT was used as data collection tool. At the development stage of RHR-DT, firstly a draft version was created for a RHR-DT. Then, this RHT-DT draft was evaluated by two physics teachers and it was applied to 20 university students who are outside of this sampling. RHR-DT was revised by taking into account the opinions and suggestions of the teachers and the students about the draft form. There are four tasks in RHR-DT given in below (Figure 1). These tasks include the physical conditions about the magnetic field and magnetic force. Students were asked to explain these physical conditions by using RHR.

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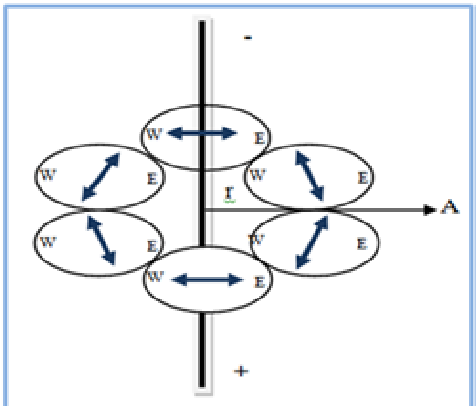
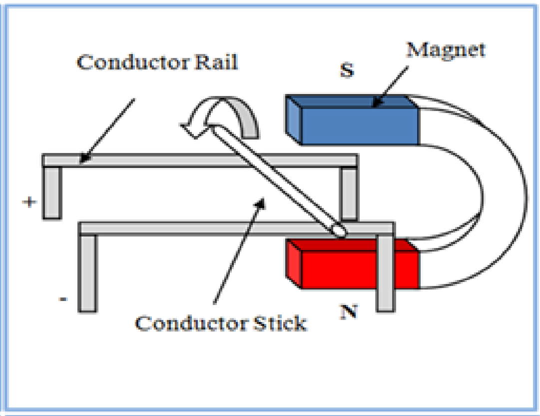
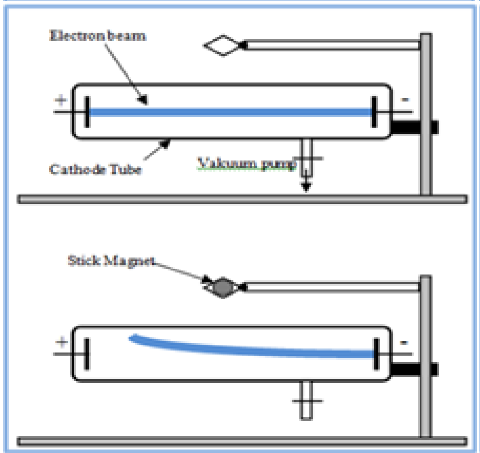
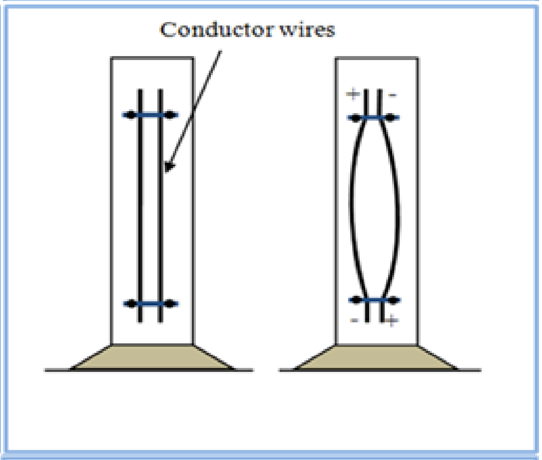



**Task1**
Information: The compasses tended in the north-south direction when not receiving any electric current on conducting wire. After the electric current started to flow on the conducting wire, the compasses tended to a shape shown at Figure.

**Task2**
Information: Task 2 is comprised of horseshoe magnet, conductor rails and a conductive metal stick which was placed between the poles of magnet




**Task 3**

Information: There are cathode ray tubes in the tables above. Electron beams became visible at the tube's (+) and (-) edges shown at the table. When a magnet (source of magnetic field) was put closer to the electron beam observed in Figure, a deflection was seen at the electron beam.

**Task 4**

Information: The Task of two conductors named number 1 and number 2 which were totally parallel to each other when there was no current is seen in Figure of Task 4 current flowed into it.

**Figure 1:** **Task of RHR-DT.**

There are 4 tasks in RHR-DT. In Task 1, students are asked to determine the magnetic field around a current carrying wire by using RHR. In Task 2, students were asked to determine the direction of the magnetic force acting on a current carrying wire in a magnetic field by using RHR. In Task 3, students are asked to determine the direction of the magnetic force acting on a charged particle moving in magnetic field by using RHT. In Task 4, students are asked to determine the direction of the magnetic force on parallel conductors by using RHR. Participants were asked to respond to each task by filling in the form given in Figure 2.

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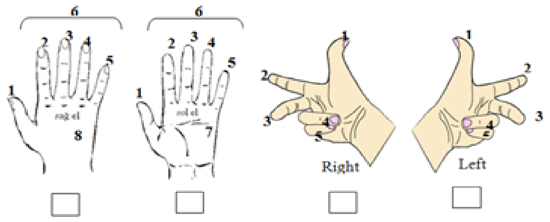


1 st Finger indicates the direction of……………………………………
2nd Finger indicates the direction of……………………………………
3th Finger indicates the direction of……………………………………
4th Finger indicates the direction of……………………………………
5th Finger indicates the direction of……………………………………
Four finger (6) indicates the direction of ………………………………
Palm (7) indicates the direction of…………………………………………
Out of hand (8)……………………………………………………………………
If you use a different right hand type you can explain in this section. ………………………………

**Figure 2: RHR-DT explanation form.**

The answers given by students who participated in the research about each task in RHR-DT were examined. The types of RHR used by the students were determined. Then, two researchers grouped the answers independently in accordance with the types of RHR. It is found that consistency percentage changes between 70 and 100% for each task.

*Unstructured Interviews*

Interviews were held with eight students. These students are selected randomly from 270 students. Interview data were also evaluated independently of RHR-DT. Student interviews were video recorded and evaluated by two researchers separately according to assessment scale given in Table 1.

**Table 1. Assessment scale used to evaluate video records.**

| Score | Category | Explanation |
|---|---|---|
| 3 | High Level | The student could express a vector frame. The student could easily keep his/her hands and fingers in the appropriate position to vectors in the frame that he/she stated. |
| 2 | Medium Level | The student could express a vector frame incompletely. The student could partially keep his/her hands and fingers in the appropriate position to vectors in the frame that he/she stated or could keep them by spending many time. |
| 1 | Low level | The student could not express a vector frame. The student could not keep his/her hands and fingers in a position that he/she could express a vector frame. |

Categories of groups are defined as high level, medium level and low level. This research showed 73% consistency in students grouping.

*Data Analysis*

The following steps were done in the descriptive analysis of the data.

1) In the analysis of the data, the answers given by the students to the tasks and the video records were examined and the right-hand types were determined as given in Figure 3.
2) The groups, which are defined according to the right hand types used by the students, and the frequency ratios of the groups are given in Table 2.
3) The answers given in Table 2 were then evaluated separately for each tasks by being associated with the student interviews.
4) Student skills in practicing RHR were eximined in three caegories. Finally, interview records are presented by categorizing and given in Table 3.

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**Results of Research**

*RHR-DT Data*

The prominent types of RHR used by the students obtained from the RHR-DT and video records are given at Figure 3.

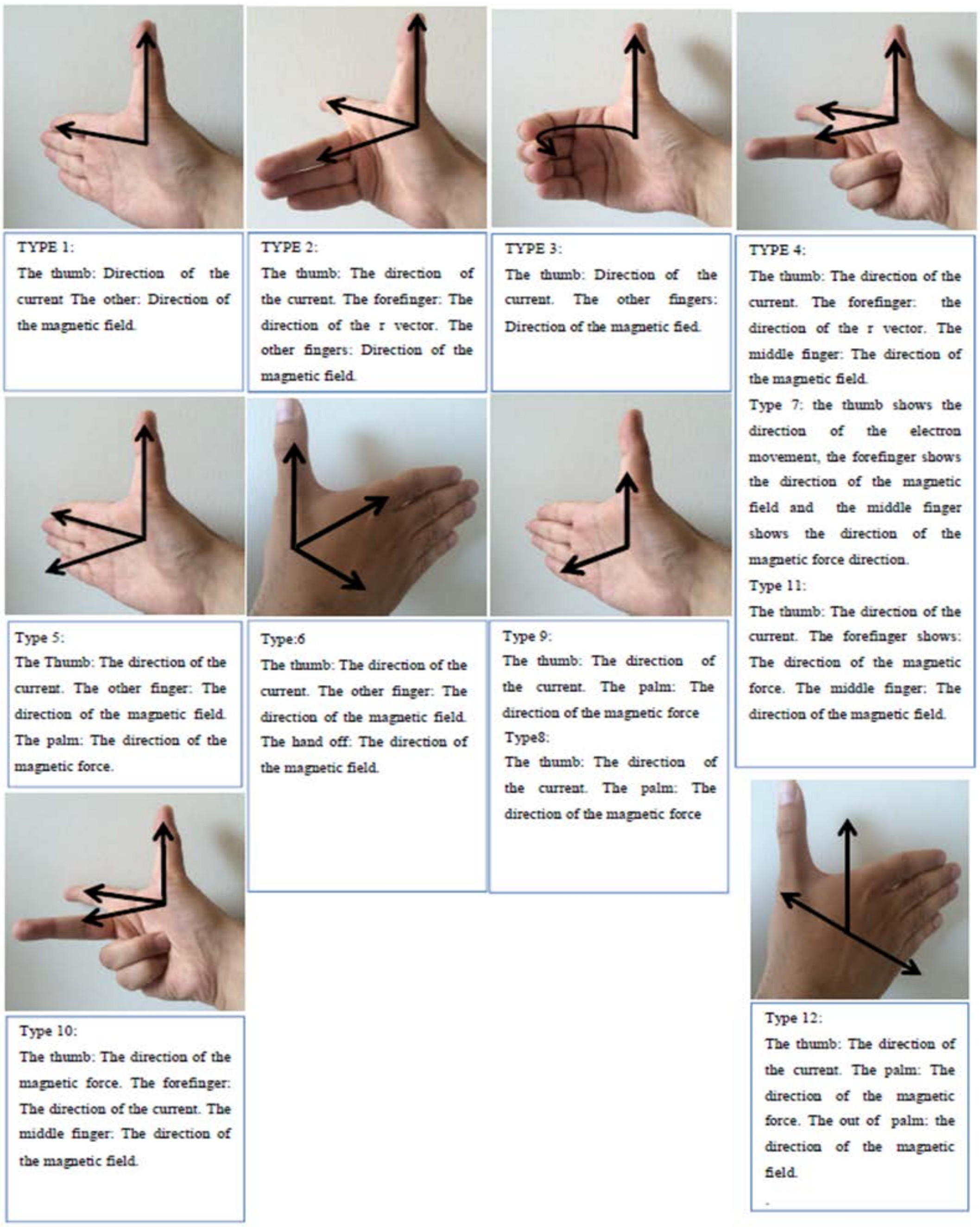


**Figure 3: Types of RHR used by the students.**

Types 2,3,4,5 and 11 are appropriate for RHR but Type 1,6,7,8,9,10 and 12 are not appropriate for RGR in Figure 3. Types of RHR used by the students obtained from the RHR-DT and their percentages are given in Table 2.

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**Table 2. Types of RHR used by the students and their percentages.**

| Type Number | 1st TASK | | 2nd TASK | | 3rd TASK | | 4th TASK | |
|---|---|---|---|---|---|---|---|---|
| | True**/False*** | f* | True/False | f | True/False | F | True/ False | f |
| 1 | False | 127 | | | | | | |
| 2 | True | 16 | | | | | | |
| 3 | True | 25 | | | | | | |
| 4 | True | 11 | | | | | True | 33 |
| 5 | | | True | 28 | True | 36 | True | 28 |
| 6 | | | False | 53 | | | | |
| 7 | | | | | False | 45 | | |
| 8 | | | | | | | | |
| 9 | | | | | False | 34 | | |
| 10 | | | | | | | | |
| 11 | | | True | 32 | | | True | 9 |
| 12 | | | | | | | False | 19 |
| Total True | | %19 | | %22 | | %13 | | %26 |
| Total False | | %47 | | %20 | | %30 | | %7 |
| Null/Nut evaluating | | %34 | | %58 | | %57 | | %67 |

*f*: frequency, True**: The type is appropriate for RHR. False***: The type is not appropriate for RHR.*

Table 2 gives the frequencies of RHR types used by students for each task. For Task 1 and Task 4, the students were concentrated on the fourth type. Task 2 and Task 3 used three RHR types in general. It is also given on the same line whether the types used by the students were described correctly.

When the percentage values in Table 2 are examined, it is seen that the students' proper use rates of RHR are low. It is seen that the students' answers are false, empty or cannot be collected in a particular category.

The students' answers for each task in RHR-DT are examined with the data obtained from the interviews held with the students and the results are given below.

*Task 1 Data Analysis*

When the answers about Task 1 in the Table 2 are examined, it is seen that the majority of the students (False, Null/Not evaluating) who participated in the research could not apply to determine the direction of the magnetic field formed around a current carrying wire.

When the types of RHR used by the students for Task 1 in the Figure 3 are examined, it is seen that Type 2, Type 3 and Type 4 are correct to the vector product while Type 1 is not.

In Type 1, it is seen that the magnetic field formed around a wire points outward (in the radial direction of the wire). This behavior is similar to that of the electric field around a positive charge. The fact that electric field analogy is used to structure magnetic field concept might have an effect on the usage of this RHR type. The opinion of one of the students used this RHR type is given in the section on Task 3 below. Type 3 does not contain triad structure of vector product; however, the direction of magnetic field can be found correctly with Type 3. This RHR type is generally recommended in physics books for finding the magnetic field formed around a current carrying wire (Fishbane, Gasiorowicz & Thornton, 2004; Keller, Gettys & Skove, 1992; Serway & Beichner, 2000).

In the interviews about the students' answers for Task 1, none of the eight students interviewed could explain what the unit vector means physically. One of these students' expressions about unit vector is given down.

***Researcher:*** *There is a vector expressed by r in the figure. What does it mean?*
***Student 3:*** *I don't know.*

*Task 2 Data Analysis*

When the answers about Task 2 in the Table 2 are examined, it is seen that the majority of the students (False, Null/Not evaluating) participating in the research could not apply the RHR to determine the direction of the magnetic force acting on a wire in a magnetic field (Mauk & Hingley, 2005).

When the RHR types about Task 2 in the Figure 3 are examined, it is seen that Type 5 and Type 11 are appropriate to the vector product while Type 6 is not.

Type 5 and Type 11 are appropriate for the RHR because they include the orientation of the current, the magnetic field and the magnetic force. The opposite of the magnetic force's direction can be found by Type 6. The usage of Type 6 could be affected by the fact that vector product has not commutative property. In an interview of a student who used Type 6 for the solution of Task 2, he/she was asked that whether the vector product had commutative property or not. One of these students' expressions about vector product is given below.

> ***Researcher:*** *Please, compare the direction of* $\vec{A} x \vec{B}$ *with the direction of* $\vec{B} x \vec{A}$*?*
> ***Student 5:*** *They are in the same direction.*

In the interviews for Task 2, two of the eight students gave the right answer on the source of the magnetic force.

*Task 3 Data Analysis*

When the answers about Task 3 in the Table 2 are examined, it is seen that the majority of the students (False, Null/Not evaluating) participating in the research could not apply the RHR in determining the direction of the magnetic field.

When the RHR types about Task 3 in the Figure 3 are examined, it is seen that Type 5 is correct to the vector product while Type 7 and Type 9 are not.

In Type 7, the thumb points in the direction electron moves. Therefore, the opposite direction of the magnetic field is found with Type 7. In Type 9, the directions of the current and the magnetic force are shown with fingers, but the direction of the magnetic field is not shown. Electric force analogy to explain the magnetic force might have an effect on using these RHR types.

In the interviews for Task 3, three of the eight students said that magnetic force and magnetic field had the same direction. One of these students who used Type 9 explained his idea as indicated below:

> ***Researcher:*** *What is the reason for the deviation at electron beam when the magnet comes closer to the tube?*
> ***Student 8****: Electron goes from (-) to (+). If electrons go upwards, it means that upper part of magnet is positively charged. We could think this like an N pole. In this task, the magnetic field pulls towards these particles.*

*Task 4 Data Analysis*

When the answers about Task 4 in Table 2 are examined, it is seen that the majority of the students (False, Null/Not evaluating) who participated in the research could not apply the RHR to determine the direction of the force applied to each other by parallel wires.

When the RHR types about Task 4 in the Figure 3 are examined, it is seen that Type 4, Type 5 and Type 11 are appropriate to the vector product while Type 12 is not.

According to the interviews, it could be said that the idea that the source of the magnetic force was the magnetic field formed by the wire itself had an impact on using this RHR. According to the interviews, 5 students out of 8 ones thought that magnetic force acting on wires is a result of the magnetic field formed by the wires themselves for the Task 4 in RHR-DT. One of these students explained his idea as indicated below:

> ***Researcher:*** *For Task 4, you said that the magnetic force affects the first wire and the second wire. Could you explain the source of this force?*
> ***Student 5:*** *The current in the first wire forms a magnetic field. It deviates under the effect of this magnetic field.*
> ***Researcher:*** *Could you show this task with the right-hand rule?*
> ***Student 5:*** *The thumb indicates the current direction; the middle finger indicates the direction of the magnetic field (formed by itself) and the fore finger is the magnetic force.*

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Another result of the interviews is that the magnetic field and the magnetic force are thought of as being in the same direction. Similar ideas were found in the interviews held for Task 3. One of these students explained his idea as indicated below:

> ***Researcher:*** *For Task 4, you said that the magnetic force affects the first and the second wire; could you explain the source of this force?*
> ***Student 1:*** *The thumb shows the direction of the current, the other four crimped fingers show the direction of the magnetic field and the palm shows the direction of the force.*

The idea of the students that the magnetic force and the magnetic field are in the same direction and the wire moves with the effect of the magnetic field resulting from the current on the wire itself might cause difficulty in using RHR in Task 4 by students.

*Video Recording Data*

Video recording interviews were scored according to evaluation scale given in Table 1. Results are given in Table 3.

**Table 3. Video recording interview categories.**

| Student Number | Task 1 (Score) | Task 2 (Score) | Task 3 (Score) | Task 4 (Score) | Average Score | Category |
|---|---|---|---|---|---|---|
| 1 | 3 | 2 | 1 | 1 | 1.75 | Low |
| 2 | 3 | 3 | 2 | 1 | 2.25 | Medium |
| 3 | 3 | 3 | 3 | 3 | 3.00 | High |
| 4 | 3 | 1 | 1 | 2 | 1.75 | Low |
| 5 | 3 | 2 | 2 | 1 | 2.00 | Medium |
| 6 | 3 | 2 | 3 | 3 | 2.75 | High |
| 7 | 3 | 1 | 1 | 1 | 1.50 | Low |
| 8 | 2 | 1 | 1 | 1 | 1.25 | Low |
| Average Score | 2.88 | 1.87 | 1.75 | 1.67 | 2.03 | Medium |
| General Category | High | Medium | Medium | Medium | 2.29 | Medium |

When the answers in Table 3 are examined, it is seen that the students are generally in the medium level category. This can be interpreted as they had difficulty in using the RHR to find the direction of the magnetic field and the magnetic force.

It is seen that the students are located at high level category for Task 1, but they are located at medium level category for the other tasks. The reason of this situation can be explained by the fact that RHR type 3 has two components and the other RHR types have three components.

In tasks except the first one, it is seen that the students had difficulty in creating a vector frame and fitting their fingers into it. The students got the lowest score for the Task 4. The low score for Task 4 can be explained with the fact that the students have difficulty to apply RHR for the components pointed into the page and out of page.

## Discussion

According to the results, the students had difficulty in using the RHR to find the direction of the magnetic field and the magnetic force; therefore, their average marks were low. With the complete analysis of the results, it can be said that the students had difficulty in using the RHR in electromagnetism.

The research results show that the conceptual understandings related to magnetism influence the use of the RHR. Magnetic field, magnetic force and magnetic flux are difficult concepts to teach for physics teachers (Chabay, & Sherwood, 2006). It is seen that the students who participated in this research explained the magnetic field with likening it to the electric field and they explained the magnetic force with likening it to the electrical force. This result is in good agreement with the ones obtained in other studies. Scaife and Hecker (2010) expressed that students believe that charges are attracted to the magnetic poles and then pushed along magnetic field lines. In this research, it is found that students believe that the magnetic field lines and magnetic force point in same direction. This idea that students have, consistently with literature, is effective on how they use the RHR types (Çoramık, Kocakülah & Özdemir, 2010). Another misconception that makes the RHR more difficult is that the directions of the current flow and the electron movement are the same. This idea of the students causes to find the direction of magnetic field/ force wrong by using the RHR. Another misconception is that the electrons are affected by the magnetic field formed by it. The students structure the RHR according to this idea while determining the direction of the force applied by the parallel wires to each other.

In the research, it is seen that the students could find the direction of the magnetic field correctly although they could not understand the physical meaning of the unit vector and the relationship between the unit vector and the vector product. It is understood that the standard type in which the thumb shows the current and the crimped four fingers show the direction of the magnetic field made contribution to this situation (Kustusch, 2016). It is seen that this type was explained in many college textbooks while studying the magnetic field formed around a current-carrying wire (Serway & Beichner, 2000; Keller, Gettys & Skove, 1992; Fishbane, Gasiorowicz & Thornton, 2004). It is found that the RHR type, Type 3 cannot type the vector product. However, it helps students reach the correct results.

In this research, it is seen that the students had difficulty in bringing their fingers into the proper position while using the RHR. Similar results were also obtained by Nguyen and Meltzer (2003). Because of the fact that it was not necessary to keep their fingers in a position showing three separate components, it is seen that they could apply the standard type (Type 3) more comfortably than the other types. In addition, results show that there is a close relation between spatial thinking and use of RHR. These results agree with the literature; (Çoramık, Kocakülah & Özdemir, 2010; Kustusch, 2016). Students have more difficulty to apply RHR for the components pointed into the page and out of page.

## Conclusions

The aim of this research was to determine why the students have difficulty in applying the RHR in electromagnetism. As a result, it is seen that the students' difficulties in applying the RHR are due to the misconception of magnetism in accordance with the literature, the effect of vector algebra and spatial thinking. It is suggested that physics teachers should consider these factors when they are designing the teaching of electromagnetism. During the teaching of the RHR, the misconceptions of the students need to be eliminated. In addition, establishing a relation between the RHR and the vector product can help students. Finally, considering that the students' spatial thinking skills might be low, it can be useful to use concrete materials during the teaching of the RHR.

This research is important because a few studies have been performed to determine the factors which make it difficult to apply the RHR. It is believed that this research will guide future works related with applying the RHR in physics teaching.

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