International Journal of Science Education and Teaching
Vol. 2, No. 3, pp. 144-149, Sep. – Dec. 2023
http://doi.org/10.14456/ijset.2023.12

Comparison of Fleming's Right-hand Rule and ijk-Notation in Determining the Direction of Magnetic Force

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Received: 15 Aug 2023 Revised: 27 Dec 2023 Accepted: 30 Dec 2023

Abstract. Fleming's Right-hand Rule (RHR) and ijk-notation are mnemonics that help students identify the direction of magnetic force. Literature has provided successes and limitations of each of these mnemonics, but no literature was found documenting the comparison of these mnemonics used in one Physics concept as these were normally used separately (i.e., RHR for electromagnetism and ijk notation for vectors in Math). This study employed a quasi-experimental one-group posttest-only design and the data were analyzed using Independent Samples t-test. This study underscores that Fleming's Right-hand Rule can better help students in identifying the direction of magnetic force than ijk-notation. The students emphasized that the use of ijk-notation is perplexing particularly when vectors differ in sign conventions, thus the low score using the said mnemonic.

Keywords: Physics Education, Right-hand Rule, ijk-notation, Electromagnetism

INTRODUCTION

Students always find Physics as one of the most challenging subject areas learned in school. The primary reason of their aversion is the fact that Physics entails complex solutions spoken by the intricate language of Mathematics. In the realm of Physics education, a lot of pedagogical innovations were already developed and tested to address this diffident attitude of students towards Physics.

Physics education research has shown that pupils struggle with the concept of magnetic force, which is extremely complicated and challenging (Onorato and Ambrosis, 2014). According to Scaife and Heckler (2010), traditional instruction is fairly effective in teaching magnetic force, but it still buds misconceptions particularly after the instruction. Another reason why students struggle with the concept of magnetic force is the lack of sufficient grasp of the vector algebra (Kustusch, 2016). Because of the previously mentioned learning predicament, teachers and researchers have attempted to innovate and test teaching approaches that would improve students understanding of the magnetic force.

One of the reliable approaches in teaching Physics is doing physical experiments (Trivedi and Sharma, 2013). According to their study, the employment of physical experiments in teaching Physics not only influences the students' attitude towards Physics but also allows them to appreciate its social implications. Suryani et al. (2021) used the R&D model (ADDIE model) in teaching magnetic force. They found out that students understand the concept of magnetic force better by developing a visualization using power generator, tea leaves, two copper wires, two neodymium magnets, and an adjustable

voltage source. If such materials are not available, drawing and mathematical representations can be used as an alternative. Fatmaryanti and Nugraha (2019) emphasized that multiple representation models can effectively improve students' understanding. The same argument was underscored by Onorato and Ambrosis (2014) when they highlighted that effectiveness of multimedia in teaching magnetic force.

Fleming's Right-hand Rule (RHR) has been the staple of Physics teachers in teaching magnetic force. The RHR is a mnemonic that tells us the directions of magnetic force, magnetic field, and the charged particle. According to Deprez, Gijsen, and Deprez (2019), students perform significantly better while using RHR in the context of magnetic force. This mnemonic has been used in teaching, but it also has issues particularly in the student's side. According to Kustusch (2016), there is a direction error which is believed to be implicit. Students are unaware of the direction of the hand especially with reversed direction of one of the vectors. The error of students in using RHR is merely kinesthetic (Kustusch, 2016; Nguyen, 2005; Domelen, 1999).

Another method of identifying the magnetic force is the ijk-notation. This mnemonic is sporadically used in teaching magnetic force. This mnemonic is usually used in Mathematics. Heckler and Scaife (2015) highlighted that students perform typically excellent and often much better using ijk-notation that in the arrow format. They further argued that ijk-notation help students learn physics concepts involving vector addition and subtraction. Furthermore, Buncher and Ph (n.d.) underlined that ijk-notation was effective as their respondents scored higher in post-test than in pre-test.

This foregoing study aimed to compare the use of RHR and ijk-notation in determining the direction of magnetic force. This would examine the students' scores and their response time. Lastly, it is this study's hope to provide Physics teachers an idea of the students' preferences and the difficulties they have encountered using these two different mnemonics.

MATERIALS AND METHODS

This study employs a quasi-experimental one-group posttest-only design. The participants of the study were 17 students of a public secondary school in the province of Phetchaburi in Thailand. They are studying in a program that specializes in Science and Mathematics under a bilingual mode of instruction (English and Thai).

Fleming's Right-hand Rule and ijk notation were both comprehensively taught to the participants. Furthermore, both mnemonics were taught in English and Thai to rule out the possible effects of language barrier in the study's outcomes.

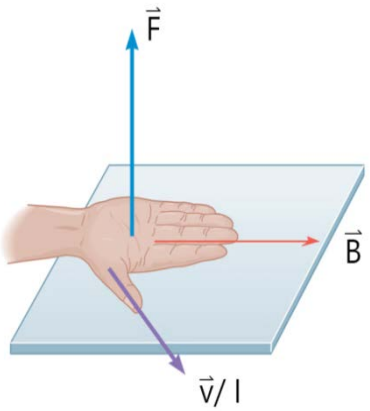


Figure 1. Fleming's Right-hand Rule

Fleming's Right-hand Rule can be used to determine the directions of the magnetic force on a moving charge in a magnetic field or a current in a magnetic field. The fingers point to the direction of the magnetic field. The thumb points the direction of the charge's motion or the current flow. Lastly, the palm of the hand points to the direction of the magnetic force. The ijk-notation and its sign conventions were taught using the illustration shown above. This mnemonic is deemed useful in determining the direction of a vector cross product.

The instrument used in this study is a 15-item test on determining the direction of the magnetic force. In the first part of testing, the participants were asked to identify the direction of the magnetic force using the Fleming's

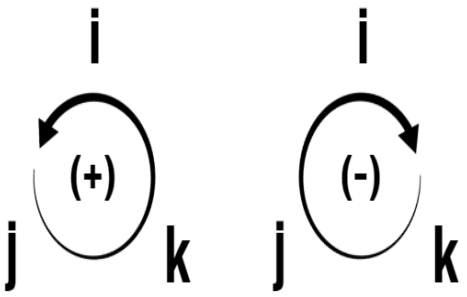
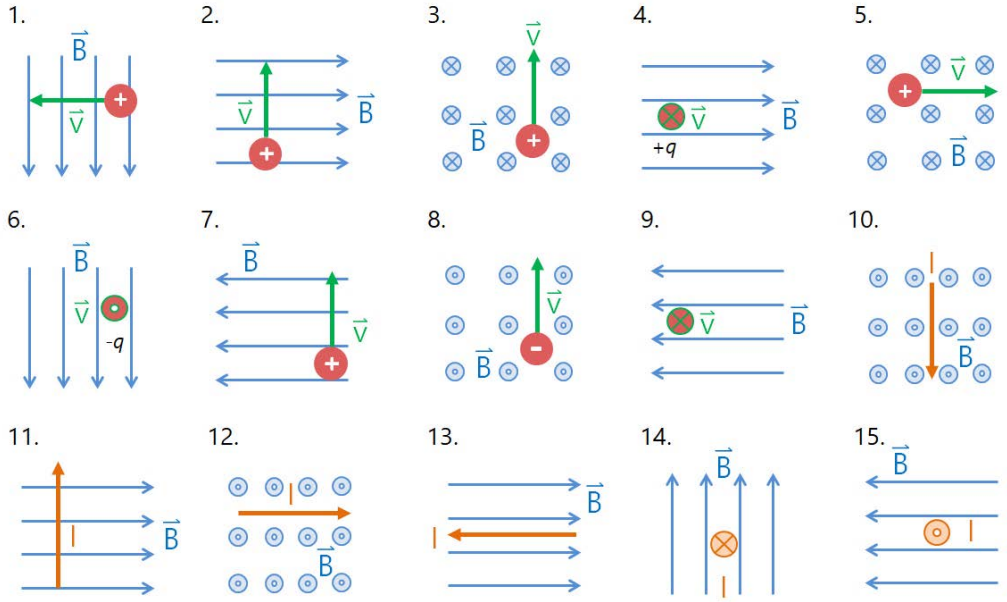


Figure 2. ijk-notation

Right-hand Rule. The respondents were also asked to submit their papers once done. The researcher recorded the time elapsed to answer the test. In the second part of testing, the same data collection method was employed but in this part the participants were only allowed to use the ijk-notation.

This study utilized descriptive statistics to analyze the data collected. The scores from two tested mnemonics were analyzed using Independent Samples t-test. The same statistical tool was used to analyze the time taken to complete each test using two different mnemonics.



RESULTS AND DISCUSSION

Table 1. Independent Samples t-test Result on the Mean Scores of Fleming's Right-hand Rule and ijk-notation

Mnemonics	Mean Score	SD	Statistic	df	p
Fleming's Right-hand Rule	9.71	1.86	8.71	32.0	< 0.001
ijk Notation	3.71	2.14			

*used $\alpha = 0.05$

Table 1 shows the mean scores of students using Fleming's Right-hand Rule (RHR) and ijk-notation. The mean score using RHR is 9.71 while the mean score using ijk-notation is 3.71. There is a huge difference between the mean scores using the two mnemonics. Since $p < 0.001$, the null hypothesis is rejected. Therefore, there is a significant difference between the students' mean scores using Fleming's RHR and ijk-notation.

Table 2. Independent Samples t-test Result on the Time Spent using Fleming's Right-hand Rule and ijk-notation

Mnemonics	Mean Time (s)	SD	Statistic	df	p
Fleming's Right-hand Rule	438	227	-1.85	32.0	0.074
ijk Notation	559	148			

*used α= 0.05

Table 2 shows the mean time spent by the students in using Fleming's Right-hand Rule (RHR) and ijk-notation. The mean time spent using RHR is 438 s. On the other hand, the mean time spent by the students using ijk-notation is 559 s. Since p= 0.074 is greater than α= 0.05, the decision is to fail to reject the null hypothesis. Therefore, there is no significant difference between the time spent by students in using Fleming's Right-hand Rule and ijk-notation.

Figure 3. Direction of Magnetic Force using Fleming's Right Hand

	v/l x B	Direction of magnetic force
1.	$-\hat{\imath} \times -\hat{\jmath} = +\hat{k}$	out of the page
2.	$+\hat{\jmath} \times +\hat{\imath} = -\hat{k}$	into the page
3.	$+\hat{\jmath} \times -\hat{k} = -\hat{\imath}$	left
4.	$-\hat{k} \times +\hat{\imath} = -\hat{\jmath}$	down
5.	$+\hat{\imath} \times -\hat{k} = +\hat{\jmath}$	up
6.	$+\hat{k} \times -\hat{\jmath} = +\hat{\imath}$	Right *(left for –q)*
7.	$+\hat{\jmath} \times -\hat{\imath} = +\hat{k}$	out of the page
8.	$+\hat{\jmath} \times +\hat{k} = +\hat{\imath}$	Right *(left for –q)*
9.	$-\hat{k} \times -\hat{\imath} = +\hat{\jmath}$	up
10.	$-\hat{\jmath} \times +\hat{k} = -\hat{\imath}$	left
11.	$+\hat{\jmath} \times +\hat{\imath} = -\hat{k}$	into the page
12.	$+\hat{\imath} \times +\hat{k} = -\hat{\jmath}$	down
13.	$-\hat{\imath} \times +\hat{\imath} =$	no magnetic force
14.	$-\hat{k} \times +\hat{\jmath} = +\hat{\imath}$	right
15.	$+\hat{k} \times -\hat{\imath} = -\hat{\jmath}$	down

Figure 4. Direction of Magnetic Force using

This is because when one of the two vectors differs in sign, the cross product should bear the opposite sign indicated by the ijk-notation.

Apart from the statistical findings, the students underscored that they were having difficulties using the ijk-notation. Their main problem is the sign conventions assigned to the vectors. Furthermore, they emphasized that the ijk notation only becomes convenient if the velocity of the particle, magnetic field, and current all have the same sign. The students found it difficult to identify the direction of the magnetic force using the ijk-notation especially when one of the two vectors differs in sign.

Figure 5 shows the comparison of RHR and the ijk-notation in determining the direction of magnetic force. For instance in item 10, RHR can immediately determine the direction of the magnetic force by looking at the direction at which the palm is facing. In this particular example, it is directed towards the left. If ijk-notation will be used in this item, it is confusing. In this item, I x B is counterclockwise (j^ x k^) in the ijk-notation, thus the direction should be positive (+): up; right; or out of the page. However, the current and magnetic field have different sign conventions: the current is going down (-j^) and the magnetic field is directed out of the page (+k^). In this condition, the sign suggested by the counterclockwise ijk-notation should not be followed. The sign of the cross product should be the opposite of the indicated sign convention by the ijk-notation. For illustration

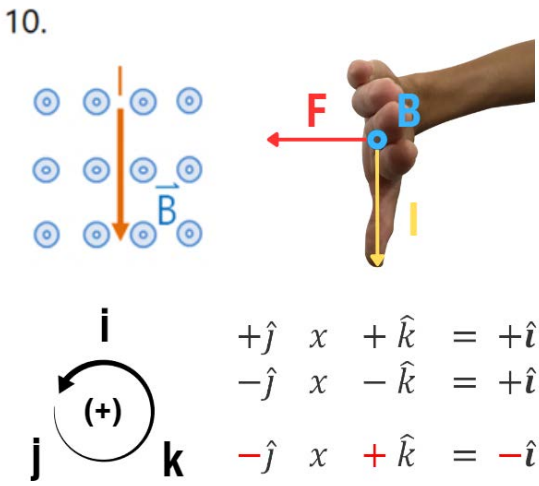


Figure 5. Comparison of RHR and ijk-notation in determining the direction of magnetic force in item 10

purposes, +jˆ x +kˆ= +(i)ˆ, -jˆx -kˆ= +(i)ˆ, but -jˆx +kˆ = -iˆ. The same should be observed in the clockwise ijk-notation.

The comparison of RHR and ijk-notation was inspired by the researcher's observation when his students were unaware of the direction of their hands. The ijk-notation was meant to solve the abovementioned problem. However, the data of this study revealed that the use of ijk-notation, as a mnemonic in determining the direction of magnetic force, entails a robust background in vector algebra.

CONCLUSION AND RECOMMENDATION

After deliberate analysis of results, this study strongly underscores the following:

1. Fleming's Right-hand Rule can better help students in identifying the direction of magnetic force than ijk notation ($p < 0.001$).

2. There is no significant difference between the time spent by students in using Fleming's Right-hand Rule and ijk Notation.

3. The main problem encountered by the students using the ijk notation is when vectors differ in sign conventions.

The magnetic force's direction can be determined using either mnemonic. Additionally, it is advised that both be introduced to the students. Students should be encouraged to practice RHR in order to prevent direction error. To identify the direction of magnetic force, vector algebra and sign rules should be taught as prerequisites for the use of ijk-notation.

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