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A Kinesthetic Pedagogical Approach to Teaching Fleming's Left-Hand Rule Using the FLHR Tri-Vector Guide in The Malaysian Matriculation Physics Curriculum

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ABSTRACT: Fleming's Left-Hand Rule (FLHR) is a key concept in understanding the motor effect and magnetic force in the study of electromagnetism. Despite its importance in the Malaysian Matriculation Physics curriculum, many students struggle to visualize and apply the rule correctly due to its abstract and three-dimensional nature. This study introduces the FLHR Tri-Vector Guide, a symbolic and kinesthetic learning tool designed to simplify and concretize the understanding of vector directions in FLHR—force, magnetic field and current. Developed using a design-based research methodology, the guide mimics a 90-degree slingshot structure to represent the spatial relationship between the vectors. The model was validated by matriculation physics lecturers and tested with students through a pre-test, post-test I, and post-test II. Findings indicate a significant improvement in student comprehension and engagement, with learners reporting that the guide was intuitive and helpful in mastering this complex concept. Descriptive analysis of repeated measurements at three time points was conducted to determine the mean scores, standard deviations, minimum and maximum scores. The FLHR Tri-Vector Guide thus presents a promising pedagogical aid that aligns with 21st-century teaching practices and supports more effective physics instruction in Malaysian classrooms.

INTRODUCTION

Students' comprehension of electrical and mechanical systems is greatly influenced by electromagnetic, a fundamental subject in physics education (Serrano et al., 2023). With Fleming's Left-Hand Rule (FLHR) acting as a foundational principle in comprehending the direction of force experienced by a current-carrying conductor in a magnetic field, it is also a basic subject in the Malaysian Matriculation Physics curriculum. Fleming's Left-Hand Rule (FLHR), one of the key ideas in this field, describes the direction of force felt by a current-carrying conductor in a magnetic field, a phenomenon known as the motor effect (Ramful et al., 2023a). However, the abstract nature of vector orientation makes it difficult for many students to understand the spatial relationships between force, magnetic field, and current (Mbonyiryivuze et al., 2019). As a fundamental vector-based principle Bahagian Matrikulasi (2022), FLHR is frequently taught in Malaysian matriculation physics classes. The thumb, forefinger, and middle finger of the left hand, which are all oriented perpendicular to one another, stand for force, magnetic field, and current, respectively (Ramful et al., 2023).

This paper presents the FLHR Tri-Vector Guide, a physical and symbolic model based on the shape of a 90-degree slingshot. Students' understanding of the three orthogonal directions in FLHR is improved by the guide, which is a visual and kinesthetic aid. The abstract and three-dimensional nature

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of vector interactions makes it difficult for many students to visualize and apply the rule, even though it is theoretically clear (Li & Singh, 2017). According to research, learners frequently make mistakes when they try to visualize vector orientation using conventional two-dimensional diagrams or when they only use rote memorization (Ozdemir & Coramik, 2018). According to Ozdemir and Coramik (2018), these difficulties underscore the necessity of more intuitive and embodied teaching methods, especially those based on kinesthetic learning and symbolic modeling.

This work fills this pedagogical vacuum by presenting the FLHR Tri-Vector Guide, a kinesthetic and symbolic tool that concretizes the spatial relationships between force, magnetic field and current in order to improve conceptual clarity. The guide was created, verified, and tested with Malaysian matriculation students using a design-based research (DBR) methodology to ascertain how well it enhanced conceptual comprehension and engagement. This study aims to assess how well the FLHR Tri-Vector Guide, a 21st-century teaching tool that is in line with creative and student-centered physics instruction, improves conceptual understanding and engagement among Malaysian matriculation students in physics.

BACKGROUND OF STUDY

Electromagnetism continues to be one of the most challenging subjects in secondary and pre-university physics courses because of its abstract vector-based concepts and dependence on spatial reasoning. A key principle within this framework, Fleming's Left-Hand Rule (FLHR), is crucial for establishing the direction of motion of a conductor carrying electric current in a magnetic field, particularly in contexts like electric motors (Ramful et al., 2023).

FLHR requires students to spatially align three vectors: current, magnetic field, and force, using the thumb, forefinger, and middle finger of the left hand, which should be positioned at right angles. As shown in **Figure 1**, the FLHR visually represents the perpendicular relationship among force, magnetic field and current. While it may seem straightforward in theory, this representation of the three vectors presents considerable cognitive difficulties, particularly for learners who tend to rely on memorization or have trouble with spatial visualization. The abstract and three-dimensional aspect of the rule frequently results in misunderstandings, especially when conventional teaching methods, such as textbook illustrations or memory aids, fail to encourage a true understanding of the concepts (Lederman & Klatzky, 2009; Ramful et al., 2023).

This issue is well-recognized within the Malaysian Matriculation Physics curriculum, where FLHR is classified as a fundamental learning standard. Although significant focus is directed towards it during teaching sessions, both assessment results and classroom observations consistently show that numerous students struggle to utilize the rule properly, despite being able to articulate its elements. This discrepancy between recalling knowledge and applying concepts highlights a larger educational challenge: the difficulty of teaching three-dimensional scientific concepts using two-dimensional formats (Lederman & Klatzky, 2009).

In recent years, teaching methods based on constructivism and kinesthetic learning have become increasingly popular in tackling challenges, especially in physics topics that require intricate spatial reasoning. Educational studies emphasize the importance of using physical tools and symbolic representations to connect abstract concepts with concrete understanding (Cordeiro et al., 2023). Specifically, models that cater to kinesthetic and visual learning preferences are crucial (Nordin, 2019) for promoting meaningful learning and memory retention in the context of electromagnetism education.

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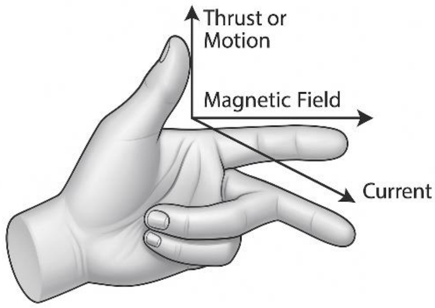

Figure 1. Fleming Left Hand Rule

In line with contemporary educational trends, this research presents the FLHR Tri-Vector Guide, a symbolic, physical model resembling a 90-degree slingshot that illustrates the perpendicular arrangement of the vectors in FLHR. Based on a design-based research approach, the guide was collaboratively created with subject-matter specialists, validated through expert evaluations, and assessed using pre- and post-tests among Malaysian Matriculation students.

The study responds to an urgent need in physics education to provide students with interactive, visual tools that enhance spatial reasoning and conceptual clarity. By addressing the common pitfalls in applying FLHR, the FLHR Tri-Vector Guide supports the shift toward student-centered, multimodal instruction advocated by 21st-century educational reforms in Malaysia and globally.

METHODOLOGY

Research Design

This study employed a design-based research approach, which enabled the iterative development, expert validation and classroom testing of the FLHR Tri-Vector Guide as a pedagogical tool for improving students' conceptual understanding of Fleming's Left-Hand Rule (FLHR). DBR was selected because it allows for iterative refinement of educational interventions through systematic cycles of design, expert validation, classroom implementation and empirical testing in authentic learning contexts.

Two DBR cycles were conducted:

(1) Design and expert validation, and
(2) Classroom implementation and evaluation

Participants and Context

A total of 30 students enrolled in a physics course at a Malaysian matriculation college participated in the study. The participants, aged between 18 and 19 years, were recruited through an open invitation following approval from the college director. The sample consisted of an equal gender distribution (50% female, 50% male).

Second-semester students were selected because Fleming's Left-Hand Rule (FLHR) is formally introduced at this stage of the matriculation physics curriculum. Purposive sampling was employed to ensure that participants had prior exposure to the FLHR concept. Although these students had previously learned FLHR through conventional instructional approaches, they continued to exhibit persistent conceptual difficulties, particularly in relation to vector orientation and the coordination of magnetic field, current and force vectors.

Prior to data collection, five physics lecturers, who voluntarily participated in the study, attended a 60-minute online briefing session with the researcher. The session aimed to familiarize the lecturer with the study instruments and the online administration procedures, including the data collection process. The lecturer also piloted the instruments to evaluate their content, layout clarity and data collection schedule. All data were collected **fully online** in April 2025 using smartphones. Instruction was conducted **entirely online**, and all research instruments were administered online. Pre-test and

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post-test were delivered via **Google Forms** and completed by students using their own devices under supervised conditions.

Data Collection Instrument: FLHR Concept Test

The FLHR Concept Test, a researcher-developed tool given as a pre-test, post-test I, and post-test II, was used to gauge students' conceptual grasp of Fleming's Left-Hand Rule.
The test consisted of 25 items, comprising:

- 20 multiple-choice questions, and
- 5 short-answer questions

The test examined students' use of a tri-vector spatial framework to recognize, coordinate, and apply the three mutually perpendicular vectors in FLHR: force (F), current (I) and magnetic field (B). The test used a comparable coordinate-frame approach to reduce dependency on memorization and terminology:

- forefinger → north (N) –south (S) axis (magnetic field),
- middle finger → x–y axis (current),
- thumb → resultant direction (force).

Content Coverage

The FLHR Concept Test assessed four key content areas:

1. Identification of individual vectors (B, I, F),
2. Spatial orientation and perpendicularity of vectors,
3. Application of FLHR to current-carrying conductors in magnetic fields, and
4. Interpretation of physical scenarios involving relative motion and field direction.

Example item:

Students were asked to determine the direction of the resulting force from the given magnetic field and current orientations using Fleming’s Left-Hand Rule.

Validity and Reliability

Content Validity

Content validity was established through expert review by three physics lecturers with experience in electromagnetism instruction. Each item was assessed by experts for:

- conceptual accuracy,
- alignment with learning outcomes,
- clarity of representation, and
- suitability for assessing spatial reasoning related to FLHR.

After receiving input from experts, a few minor changes were made, especially to make items involving three-dimensional vector orientation less ambiguous.

Pilot Testing

A small group of matriculation students who were not included in the study sample participated in a pilot trial of the FLHR Concept Test prior to the main study. Student input and pilot data were utilized to:

- refine item wording,
- confirm students’ interpretation of the coordinate-frame analogy, and
- ensure appropriate difficulty and completion time.

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Reliability

Cronbach's alpha was used to evaluate the reliability of internal consistency. The test's overall reliability (α =.82) showed acceptable internal consistency for assessing conceptual understanding over several administrations.

Design-Based Research (DBR) Cycles

DBR Cycle 1: Design and Expert Validation

In the first DBR cycle, the FLHR Tri-Vector Guide and the accompanying FLHR Concept Test were designed based on:

- documented student misconceptions in electromagnetism,
- difficulties with vector coordination in FLHR, and
- principles of multimodal and kinesthetic learning.

The initial prototype of the guide was reviewed by three physics lecturers, who provided feedback on:

- content accuracy,
- representational fidelity of vectors,
- instructional clarity, and
- pedagogical suitability.

Vector orientation, visual signals, instructional sequencing and test item clarity were all improved as a result of feedback from this cycle.

DBR Cycle 2: Implementation and Evaluation

In the second DBR cycle, the revised FLHR Tri-Vector Guide was implemented in an authentic classroom setting. Students interacted with the guide by:

- lecturer demonstrations,
- guided hands-on activities, and
- small-group discussions focused on applying FLHR to conceptual problems.

The effectiveness of the refined design was evaluated using the FLHR Concept Test administered at three time points:

- pre-test (prior to intervention),
- post-test I (immediately after intervention), and
- post-test II (delayed measure).

Quantitative test data, supported by classroom observations, were used to examine learning gains and identify remaining conceptual challenges.

Design Principles of the FLHR Tri-Vector Guide

The three mutually perpendicular quantities of Fleming's Left-Hand Rule, force (F), magnetic field (B) and current (I) were represented by the FLHR Tri-Vector Guide, a visual-kinesthetic 90-degree "slingshot" structure.

The associated test and educational activities used an equivalent coordinate frame that purposefully avoided using explicit physics vocabulary in order to promote spatial reasoning and encourage students to concentrate on directional relationships rather than memorization. The design was influenced by research on:

- kinesthetic learning,

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- embodied cognition, and
- symbolic and spatial representation in physics education.

Expert Reviewers

A total of five physics lecturers participated in the expert validation process across the two DBR cycles:

- During Cycle 1, three lecturers evaluated the initial prototype with an emphasis on conceptual integrity and instructional efficacy.
- During Cycle 2, two lecturers examined the updated prototype, assessing its applicability for a variety of learners, pedagogical coherence, classroom usefulness, and alignment with learning objectives.

Revisions were implemented after each cycle, resulting in a classroom-ready instructional guide.

Design and Development of the Guide

The FLHR Tri-Vector Guide was constructed using tinsel wire and pen components, arranged in a Y-shaped configuration with 90-degree angles between arms. Each arm was colour-coded to represent a vector:

- blue → magnetic field,
- green → current,
- red → force.

Labels, proportional lengths, and orientation were designed to align with standard FLHR hand gestures, reinforcing the connection between physical movement and vector direction.

Implementation of the FLHR Tri-Vector Guide

Throughout the intervention, a systematic educational sequence introduced the revised guide to the students. Students used the guide to use FLHR during guided practice and group problem-solving exercises following a lecturer demonstration. Figure 2 shows the application in the classroom.

Figure 2. Lecturer guide students to learn FLHR Tri Vector

Data Analysis

A repeated-measures design was employed to evaluate the effect of the FLHR Tri-Vector Guide on students' understanding of Fleming's Left-Hand Rule. Descriptive statistics were used to compute the mean and standard deviation of students' scores at three time points: pre-test, post-test I, and post-test II.

Inferential analysis was conducted using a repeated measures ANOVA to assess statistically significant differences across time points. Mauchly's test of sphericity was applied to test the assumption of sphericity and where violated, the Greenhouse–Geisser correction was used. Besides that, pairwise comparisons were conducted to determine the specific points of significant improvement in performance.

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DISCUSSION AND CONCLUSION

This study aimed to examine the effectiveness of the FLHR Tri-Vector Guide in improving students' conceptual understanding of Fleming's Left-Hand Rule (FLHR) within the Malaysian Matriculation Physics curriculum. Using a repeated-measures design, students' performance was assessed at three intervals: pre-test, post-test I, and post-test II. The descriptive statistics indicated a progressive increase in mean scores across these time points, reflecting a positive learning trend. To determine the statistical significance of these changes, a Repeated Measures ANOVA was conducted. The results revealed a significant effect of time on student performance, suggesting that the intervention using the Tri-Vector Guide contributed meaningfully to students' ability to grasp and apply the principles of FLHR. This section presents the findings in detail, followed by a discussion of their implications in the context of physics education and instructional design.

Descriptive Analysis of Repeated Measurements

This study measured students' physics test scores at three different time points: Pre-test (Week 0), post-test I (Week 2) and post-test II (Week 4) to observe any trends in academic performance over time. However, inferential analysis (e.g., repeated measures ANOVA) was conducted, and the analysis focused solely on descriptive statistics. Table 1 presents the descriptive statistics of FLHR score over time

Table 1. Descriptive statistics of FLHR score over time (N=30)

Time point	Mean	Standard Deviation	Minimum	Maximum
Pre-test	54.80	20.99	8.00	76.00
Post test I	82.00	3.28	76.00	88.00
Post test II	91.73	3.14	88.00	100.00

The finding indicates a distinct rising trend in students' scores across the three time points. Students performance average improved from the pre-test (M = 54.80, SD = 20.99). Whereas, post-test I (M = 82.00, SD = 3.28), indicating a progressive increase in achievement throughout the intervention period. Besides, post test II shows (M = 91.73, SD = 3.14) The descriptive results show a consistent increase in test scores across the three time points. The mean score increased from 58.40 in the pre-test I to 82.00 in the post-test I and 91.73 in post test II. This indicates a positive trend in student performance, which may reflect learning progress throughout the intervention.

One-Way Repeated Measures ANOVA

A one-way repeated-measures ANOVA was conducted to examine changes in students' FLHR test scores across three measurement points. Table 2 shows the result for the test of sphericity. Mauchly's Test of Sphericity indicated that the assumption of sphericity was violated, $\chi^2(2) = 93.66$, $p < .001$. Therefore, the Greenhouse–Geisser correction was applied ($\varepsilon = .51$).

Test of Sphericity

Table 2. Result for the Test of Sphericity

Within Subject Effect	*Mauchly's W*	Approx.Chi-Square	df	Sig	*Epsilon*[b]		
					Greenhouse-Geisser	*Huynh-Feldt*	*Lower-Bound*
Time	.984	93.659	2	<.001	.509	.510	.500

Test of Within Subject Effect

Table 3 shows the result for the test of within subject effect. The results of the corrected repeated-measures ANOVA revealed a statistically significant effect of time on FLHR test scores, F(1.02, 29.52)

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= 96.29, $p < .001$, with a large effect size (partial $\eta^2 = .769$). This indicates that approximately 76.9% of the variance in FLHR test scores was attributable to changes over time following the FLHR intervention.

Table 3. Result for the test of Within Subject Effect

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	*Observed Power*
Masa	*Greenhouse-Geisser*	21986.489	1.018	21598.852	96.29	.001	.769	1.000
Ralat	*Greenhouse-Geisser*	6621.511	29.520	224.302	-	-	-	

Comparison of Mean Score Pairs for the FLHR Concept Test

Table 4 presents the overall pairwise comparison of mean scores for FLHR test between post-test I and pre-test, post-test II and pre-test, and post-test II and post-test I. Overall, there were significant differences in the mean scores of tests between post-test I and pre-test, post-test II and pre-test, and post-test II and post-test I. These findings indicate that the mean scores for the FLHR Concept Test increased as a result of the FLHR Tri Vector-Guide intervention implemented in this study.

Table 4. Result for One-Way Repeated Measures ANOVA

Comparison of Mean Score Pairs	Mean Difference	Std. Error	Significant
Post test I – Pre-test	27.200	3.373	.000
Post test II – Pre-test	36.933	3.364	.000
Post test II – Post test I	9.733	.368	.000

The mean scores increased significantly from pre-test to post-test I (M difference = 27.20, SE = 3.37, p <.001) and from pre-test to post-test II (M difference = 36.93, SE = 3.36, p <.001), according to pairwise comparisons in Table 5. The difference between post-test I and post-test II scores were also considerably higher (M difference = 9.73, SE = 0.37, p <.001).

The results of the pairwise comparisons show that participants' scores improved consistently and statistically significantly at every time point. Pre-test and post-test, I showed a significant difference (M difference = 27.20, p <.001), indicating that the instructional technique or intervention used prior to the first post-test had an immediate favorable impact on students' performance or comprehension.

Furthermore, a sustained and potentially cumulative improvement is highlighted by the additional increase from pre-test to post-test II (M difference = 36.93, p <.001), indicating that the learning benefits were not only maintained but also continued to expand following the initial post-test I. Reinforcement, prolonged learning exercises, or ongoing exposure to the teaching approach may be the cause of this.

Students continued to gain from the continuous learning process after the initial post-test, as evidenced by the statistically significant difference between post-test I and post-test II (M difference = 9.73, p <.001). High consistency in the observed improvement is suggested by the comparison's minimal standard error (SE = 0.37).

Overall, the results provide strong evidence that the intervention was effective in enhancing students' performance over time. The progressive increase in scores across the three assessments demonstrates not only the effectiveness of the instructional approach but also its retention and reinforcement effects. These outcomes support the integration of such instructional strategies in future implementations, particularly in contexts requiring conceptual understanding and retention over time.

https://doi.org/10.37134/ejoss.vol12.sp.3.2026

Profile plot

Figure 3 shows the profile plot demonstrates a clear upward trend in students' scores changed over time throughout the intervention. The sharp increase from pre-test to post-test I suggests that the use of the FLHR Tri-Vector Guide or related symbolic strategies was highly effective in addressing students' initial misconceptions and facilitating conceptual learning. The continued improvement from post-test I to post-test II indicates that the students were not only able to recall the rule but were also able to apply it more effectively over time. This trend supports the pedagogical value of integrating symbolic visual tools in teaching abstract electromagnetism concepts, particularly within the Malaysian Matriculation Physics curriculum.

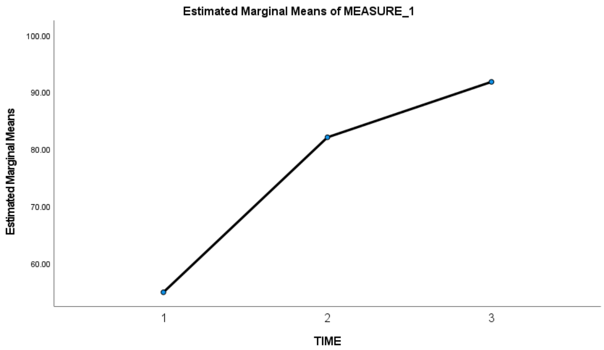

Figure 3 Students' scores changed over time throughout the intervention

CONCLUSION

The results of this study show that the FLHR Tri-Vector Guide has a great deal of short-term promise as a teaching tool to help students grasp Fleming's Left-Hand Rule in electromagnetism. The visual and kinesthetic aspects of the guide may help students understand and apply the directional relationships among magnetic field, current, and force, according to the repeated-measures results, which demonstrated statistically significant improvements in students' FLHR Concept Test scores across the three measurement points. These improvements show that the guide was successful in encouraging short-term conceptual understanding rather than rote memorization of the rule within this group.

Notwithstanding these encouraging results, a number of caveats need to be noted. The study's limited sample size (N = 30) from a single matriculation school restricts how broadly the findings may be applied. Furthermore, the last measurement was carried out just one week following the intervention, which was carried out over a brief instructional session. As a result, the study offers no proof of sustained conceptual change, learning transfer to other electromagnetic topics, or long-term retention. These limitations imply that the findings should be regarded as preliminary and situation-specific.

Therefore, rather than being a final answer for teaching Fleming's Left-Hand Rule, the FLHR Tri-Vector Guide should be seen as exhibiting significant short-term conceptual benefits in this sample. The applicability of this method to additional physics topics requiring vector interactions, as well as its efficacy across various institutions and student groups, require more investigation. In addition to comparing the Tri-Vector Guide with other teaching strategies like inquiry-based learning or simulations, future research could examine other outcomes like student motivation, confidence, and engagement. A more thorough grasp of the guide's pedagogical value and its place in larger electromagnetic training cycles would result from such study.

ETHICAL CONSIDERATIONS

The ethical standards for educational research were followed in the conduct of this study. The participating matriculation college's relevant institutional authorities granted permission to carry out the

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study. Prior to data collection, informed consent was obtained from each participant after they were made aware of the study's objectives and methods. Students were given the assurance that their answers would only be utilized for research and participation was completely voluntary. To preserve participant privacy, all information was anonymized, safely kept and analyzed collectively.

DECLARATION OF GENARATIVE AI

During the preparation of this work, the author used [Scribbr] to enhance the clarity of the writing. After using the [Scribbr], the author reviewed and edited the content as needed and take(s) full responsibility for the content of the

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