UNIVERSAL JOURNAL OF EDUCATIONAL RESEARCH
2960-3714 (Print) / 2960-3722 (Online)
Volume 4, Issue 2, 2025

# Investigating Magnetic Field and Force of Multiple Representation Abilities of High School Students in Cambodia

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## ABSTRACT

This study aims to investigate the ability of Cambodian high school students to understand magnetic fields and forces through multiple representation skills. The survey research design was used to gather data involving 1685 students in grade 12, including 1000 females across 14 high schools in Phnom Penh. As a result, the data was analyzed using descriptive statistics and independent t-tests to explore the level of multiple representations in magnetic fields and forces and the differences in multiple representation abilities based on gender and school locations with multiple representation levels. The findings indicated that students had high proficiency in picture skills but low levels in diagrams, drawings, equations/formulas, symbols, spatial rotations, spatial orientation skills, and very low levels in graph skills. There were significant differences by gender; male students performed better than female students in pictures, symbols, and spatial orientation skills. For school locations, significant differences were in pictures, spatial rotations, spatial orientations, and equations/formulas of multiple representation abilities, and urban schools outperformed suburban schools. Therefore, enhancing students' multiple representation abilities is crucial to help students develop a deeper understanding of abstract and complex concepts, strengthening female students to excel in those skills of multiple representations, and perform an action in suburban schools by providing numerous teaching methods, hands-on activities, and laboratory equipment to support multiple representations abilities for improving students' learning achievement in physics.

**Keywords:**
*Cambodia education, high school students, magnetic field and force, multiple representations abilities, spatial rotation skill*

Suggested citation:

Khek, S. (2025). Investigating Magnetic Field and Force of Multiple Representation Abilities of High School Students in Cambodia. *Universal Journal of Educational Research, 4*(2), 147-157.

## INTRODUCTION

Cambodia's curriculum for general and technical education (CGTE) has been revised several times after the end of the civil war of the Khmer Rouge (1975-1979). First, from 1980 to 1987, it focused on political education (Dy, 2004). Second, from 1987 to 1996, the emphasis was on national identity, culture, preservation, and practical skill development (Chealy et al., 2014). Third, from 1996 to 2005, it focused on recovery and ideological indoctrination to one that increasingly embraced modernization, globalization, and holistic development of students (Chhinh & Dy, 2009). Fourth, from 2005 to 2015, the curriculum focused on the transitional phase, in which Cambodia aimed to align its educational system with international standards, addressing local needs and challenges (MoEYS, 2015). Last, from 2015 until now, the curriculum has emphasized competency-based education, focusing on Science, Technology, Engineering, and Mathematics (STEM) education and global citizenship (MoEYS, 2018; MoEYS, 2015).

Even though CGTE has been changed many times in general education, students' learning achievement has remained low (Bhatta et al., 2022; MoEYS, 2023). Moreover, students' low achievement has been found in physics, specifically magnetic fields and forces, as indicated in various documents and reports. The National Assessment in Grade 11 indicated that students' achievement was below average in physics with 34.5%, which indicated that students still perform poorly (MoEYS, 2019).

The Technical Report of Grade 8 National Learning Assessment Academic Year 2021-2022 showed that the average result in physics was 42.2% of the total students' correct answers. This assessment includes six contents. The content results were as follows: Force and Motion (52.0%); Sound (45%); Energy and Electric Power (44.2%); Work, Energy, and Power (37.5%); Straight Motion (36.9%); and Magnetism (34.5%). Thus, magnetism performed the lowest among those physics contents (MoEYS, 2023). The students had low performance in magnetic fields and forces concerning multiple representation abilities, which various scholars addressed (Sağlam & Millar, 2006; Dimas et al., 2018; Fatmaryanti et al., 2017 ; Fatmaryanti et al., 2018; Theasy et al., 2018; Fatmaryanti et al., 2019; Li & Singh, 2017; Bollen et al., 2017).

Fatmaryanti et al. (2017) students struggle to illustrate the vector nature of magnetic fields, which are characterized by their direction and magnitude. They confuse information in their diagrams because they believe that magnetic fields spread uniformly, and they might fail to draw diagrams to capture variations in field strength and directions. This drawing skill helps students visualize how magnetic fields exist in space and interact with charges and currents (Sağlam & Millar, 2006). Students also had trouble representing equations/formulas, deriving and selecting appropriate mathematical equations when solving problems related to magnetic fields and forces (Fatmaryanti et al., 2018).

Theasy et al. (2018) indicated that students find it challenging to solve physics problems related to expressing the mathematical equations that provide a quantitative understanding of forces, leading them to struggle to interpret the physical quantities relationship. For instance, the equation for the magnetic force acting on a moving charge is $F = q(v \times B)$. The formula skill allows students to calculate magnetic forces acting on charges moving within magnetic fields (Fatmaryanti et al., 2018). They also struggle to understand the symbolic meaning because they rely on memorizing formulas without understanding their rationale, and it is challenging to apply them in new or varied contexts (Hau et al., 2018).

Fatmaryanti et al. (2018), Li & Singh (2017), and Hahn & Klein (2023) mentioned that diagrams, graphs, and drawings are crucial for improving students' overall competency in solving the problem of magnetic fields and forces. Students often struggle to link different representations and demonstrate a limited understanding of the physical concepts. They also face challenges with graphical skills of physical quantity relationships, which makes students unable to visualize problems (Bollen et al., 2017).

Li & Singh (2017) addressed that students often struggle to visualize the directions of magnetic forces perpendicular to the magnetic fields and the direction of motion of charged particles. Thus, students are required to understand spatial rotation skills in learning magnetic fields and forces more effectively.

Various scholars mentioned that students have difficulty characterizing the direction and magnitude of magnetic fields, including failing to draw a diagram to capture the field strength and direction to visualize the physical quantities' relationship to clarify the visual images (Fatmaryanti et al.,2018; Li & Singh., 2017; Hahn & Klein.,2023; Bollen et al., 2017; Sağlam & Millar, 2006). Multiple representations mainly focus on drawing, pictures, diagrams, and graph skills.

To solve physics problems related to magnetic fields and forces, symbols and equations/formulas skills are also important because students need to understand physics symbols and write mathematical expressions to enhance calculation procedures (Theasy et al., 2018; Hau et al., 2018) . These skills are mentioned in equations/formulas and symbol representations. Furthermore, some problems are complex, and students require high order thinking skills to visualize and interpret abstract objects (Li & Singh, 2017). Those skills are concentrated on spatial rotation and spatial orientation skills.

Through discussion, in order to improve students' high achievement on magnetic field and force, students require understanding of eight skills of multiple representations, such as drawing, diagram, graph, picture, equation/formula, symbol, spatial rotation, and spatial orientation skills (Fatmaryanti et al., 2017; Fatmaryanti et al., 2018; Hau et al., 2018; Bollen et al., 2017; Li & Singh, 2017; Hahn & Klein, 2023; Sağlam & Millar, 2006).

In this study, drawing skills are freehand or artistic representations, including details about magnetic field lines, poles, and other relevant features. Drawing can serve as a personal interpretation of magnetic concepts. A diagram skill is a schematic representation that illustrates the magnetic field lines around a magnet or the forces acting on a charged particle moving through a magnetic field. Diagrams often indicate the direction of the currents, magnetic field, and force, such as using the right-hand rule. Graph skills can illustrate relationships between the magnetic field and the magnetic force, the magnetic field and distance from a magnet, or the force acting on a charged particle based on its velocity. These graphs assist in visualizing how magnetic forces vary under different conditions. Equation/formula skills describe the mathematical relationships between physics quantities. For instance, the Lorentz force equation $F=q(v\times B)$. Symbol skills represent concepts or quantities in magnetic fields and forces. For example, B represents the magnetic field strength, F represents magnetic force, I represents electric current, and q denotes charge. Picture skills refer to an image or photograph showing magnets, magnetic materials, or actual magnetic experiments, such as visual representations of magnetic field lines as seen with iron filings on paper. Spatial rotation skills involve mental or visual manipulation of a representation to understand how objects, magnetic fields, or magnetic forces behave when viewed from different angles. For example, visualizing how a magnetic field rotates around a wire helps students understand the multidimensional aspects of magnetic phenomena. This enhances their ability to see relationships that may not be immediately clear from a single perspective. Spatial orientation skills involve recognizing the positions of objects in space relative to one another, often highlighting the orientation of magnetic fields and forces, such as the direction of a magnetic field line with a current-carrying wire.

Different skills are indicated in varying levels of students' understanding. The students with high levels of the above eight skills mentioned lead them to get better performance. However, if some of them are low-level, they can lead students to get low performance. For instance, Dimas et al. (2018) mentioned that students have low comprehension of multiple representations, including graphs and equation representations, which showed low performance in problem-solving abilities (Fatmaryanti et al., 2017). In this sense, this study aims to investigate the eight skills of multiple representation by examining student understanding at each level.

On the other hand, there are significant differences between genders in understanding multiple representations, which various scholars identify (MoEYS, 2019; MoEYS, 2023); for instance, MoEYS (2019) reported that Grade 11 students' achievement from the National Assessment in 2018 was 42.2% in physics, with females achieving higher marks than males, particularly in subjects related to magnetism (MoEYS, 2023). This study will compare the significant differences between genders of multiple representation skills.

Moreover, some scholars also mentioned that students' performance can be noted based on the different school locations, which means that the students have opportunities to learn theory and practice. For example, schools well equipped with laboratories, good teaching and learning materials, and diverse instructional methods show students with high performance (MoEYS, 2023; Huh, 2024). This study will compare the significant differences between urban and suburban schools concerning students' understanding of multiple representation abilities.

To achieve the above purposes, two questions will be addressed below.

1. What levels do high school students in Cambodia possess regarding multiple representation abilities in the magnetic field and force?
2. Are there any differences in multiple representations ability levels of magnetic field and force between gender and school location of high school students?

## METHODOLOGY

### Research Design

This study used a survey research design with a descriptive quantitative research design because this research requires categorical levels of students' problem-solving abilities. This approach allows for the validation and triangulation of findings, complements the strengths, and provides practical implications for educational settings (Gay et al., 2012).

### Research Participants

The participants of this study were selected from 14 upper secondary schools in Phnom Penh, Cambodia. The students were chosen from grade 12 during the physical year 2023-2024 based on school principal designation, following a convenience sampling method, where all accessible students at the selected schools were invited to participate in this study while the test was being administered. The selection procedure was based on the class designed by the school principal, which was not intended to create a representative sample of the Cambodian high school student population. The table below shows the number of participants.

Table 1. Number of Participants

| | | N (%) |
|---|---|---|
| Gender | Male | 685 (40.65) |
| | Female | 1000 (59.35) |
| | Total | 1685 (100) |
| | Urban | 853 (50.62) |

| | | |
|---|---|---|
| School location | Suburban | 832 (49.38) |
| | Total | 1685 (100) |

**Research Instrument**

The instruments used in this study are survey tests, which were developed according to the grade 12 physics syllabuses and textbooks (MoEYS, 2018), adapted from (Chandralekha & Jing, 2012).

The test was constructed into two parts: the first part describes demographic information. The second part focuses on magnetic fields and forces topics followed by five subtopics, including (1) the application of the RHR or LHR to determine the magnetic force direction, (2) the magnet, (3) the magnetic field due to a long straight wire, (4) the interaction between two parallel wires, and (5) charged particles moving in a uniform magnetic field. All five subtopics comprise eight multiple-representation abilities: drawings, pictures, diagrams, graphs, equations/formulas, symbols, spatial rotation (3D), and spatial orientation skills. The total number of the tests is 30 multiple-choice tests, which took approximately 50 minutes to complete. Four items were used to measure drawing: three for pictures, five for diagrams, two for graphs, three for equations/formulas, three for symbols, five for spatial rotations, and five for spatial orientation skills. The table below shows the constructed test items.

Table 2. Constructed test items

| No | Multiple Representations abilities | Item Number | Number of Items |
|---|---|---|---|
| 1 | Drawing | 20,21,22,24 | 4 |
| 2 | Pictures | 8,9,14 | 3 |
| 3 | Diagrams | 3,15,16,23,28 | 5 |
| 4 | Graphs | 26,27 | 2 |
| 5 | Equations/Formulas | 19,29,30 | 3 |
| 6 | Symbols | 11,17,25 | 3 |
| 7 | Spatial Rotation (3D) | 1,5,18,4 | 4 |
| 8 | Spatial Orientation | 2,13,6,7,10,12 | 6 |

This survey test was verified with five physics experts to ensure it aligns with Cambodia's existing textbook, curriculum, and grade 12 student level. One expert is from the National Institute of Education (NIE), two are from Phnom Penh Teacher Education College (PTEC), and two are high school teachers who teach grade 12. All experts are majoring in physics. Moreover, the test items were piloted with a coefficient of Cronbach Alpha 0.9, meaning they are reliable for measuring multiple representation skills. The data collection process was the same for all target schools. First, the researcher clarified the purpose of the research and response procedure. Second, tests were distributed to all participants so that they could fill in the information and answer the test items. Finally, all the tests were collected for analysis purposes.

**Data Analysis**

The data was analyzed based on the scoring provided by each test item. Scores were provided for each skill, categorized as ‘1’ meaning correct response and ‘0’ meaning incorrect response. All the scores were input into Microsoft Excel and cleaned. IBM SPSS Statistics Data Editor, version 26, was used as the tool to analyze the data. The data analysis was done to measure the level of student understanding of magnetic fields and forces through the eight multiple representation abilities as follows:

First, identify the level of multiple representation in each skill. The data were investigated the mean score, standard deviation, percentage of correct answers, and criteria level to identify multiple representation ability. The skills of multiple representation were evaluated based on the following percentage of correct responses. The table below shows the categories of the level.

Table 3. Level of Multiple Representation

| Categories | Percentage (%) |
|---|---|
| High | >76 |
| Moderate | >51 |
| Low | >26 |
| Very low | < 26 |

Sources. (Im et al., 2024).

Secondly, the independent t-test examined the difference between males' and females' performance in multiple representation ability.

Thirdly, mean scores were analyzed to identify the differences between urban and suburban schools' performance regarding students' understanding of multiple representation abilities.

Finally, this research identified the level of multiple representation ability and compared the performance of gender and school location to investigate magnetic field and force through the multiple representation ability of high school students in Cambodia.

## RESULTS

The results of this analysis are as follows: The level of multiple representation ability in graphs is very low. Six skills are categorized as low: drawings, diagrams, equations/formulas, symbols, spatial rotations, and spatial orientations skills, while only one skill performs well in pictures. The table below shows the level of multiple representations in each skill.

Table 4. The level of Multiple Representation in each skill

| Multiple Representation Skills | Mean (N=1685) | SD | Percentage of correct responses | Criteria Level |
|---|---|---|---|---|
| Drawing | 1.32 | 0.96 | 33 | Low |
| Pictures | 2.40 | 0.79 | 80 | High |
| Diagrams | 1.38 | 1.01 | 27.6 | Low |
| Graphs | 0.39 | 0.55 | 19.5 | Very Low |
| Equations/Formulas | 1.47 | 0.87 | 49 | Low |
| Symbols | 0.91 | 0.83 | 30.33 | Low |
| Spatial Rotations | 1.22 | 1.16 | 30.5 | Low |
| Spatial Orientations | 2.46 | 1.09 | 41 | Low |

Table 4 shows that high school students performed best in using pictures to learn the magnetic field and force, with a high percentage of correct answers (80%). Following that, students also had low levels of all other skills, such as Equation/Formula (49%), Spatial Orientation (41%), Drawing (33%), Spatial Rotation (30.5%), Symbol (30.33%), and Diagram (27.6%). The percentage of correct answers for Graphs was the lowest (very low = 19.5%). This result suggested that students were required to strengthen the seven skills of multiple representation ability, excluding pictures, which is high performance.

Table 5 compares multiple representation abilities between male and female students, as assessed through various skills, including drawing, picture, diagram, graph, equation/formula, symbol, spatial rotation, and spatial orientation skills.

Table 5. Gender comparison in terms of Multiple Representation skills

| Skills | Mean | | t |
|---|---|---|---|
| | Male | Female | |
| Drawings | 1.31 | 1.32 | 0.168 NS |
| Pictures | 2.49 | 2.35 | -3.884*** |
| Diagrams | 1.40 | 1.37 | -0.678 NS |
| Graphs | 0.39 | 0.40 | 0.577 NS |
| Equations/Formula | 1.49 | 1.45 | -1.053 NS |
| Symbols | 0.98 | 0.86 | -3.131** |
| Spatial Rotations | 1.22 | 1.23 | 0.132 NS |
| Spatial Orientations | 2.53 | 2.41 | -2.085* |

*: p<0.05; **: p<0.01; ***: p<0.001

The analysis revealed that independent t-tests showed significant differences in three specific skills: pictures, symbols, and spatial orientations. For pictures, male students (M=2.49) outperformed female students (M=2.35), with a statistically significant t(1683)= -3.884 (p<0.001). In terms of symbols, male students (M=0.98) again showed higher performance compared to female students (M=0.86), with t(1683)= -3.13 (p<0.01). Furthermore, for spatial orientations, male students (M=2.53) performed better than female students (M=2.41), with t(1683)= -2.085 (p<0.05).

However, no significant differences were found for the remaining skills: drawings, diagrams, graphs, equations/formulas, and spatial rotations. The p-values were higher than 0.05, all categorized as not significant (NS).

Table 6 summarizes the comparison of multiple representation abilities between students from urban and suburban locations. The analysis indicates significant differences in each skill, while others do not show statistically considerable variability.

Table 6. Comparison of Skills by School Location

| Skills | Mean | | t |
|---|---|---|---|
| | Urban | Suburb | |
| Drawings | 1.32 | 1.32 | 0.044 NS |
| Pictures | 2.56 | 2.29 | 7.42*** |
| Diagrams | 1.39 | 1.37 | 0.337 NS |
| Graphs | 0.41 | 0.39 | 0.835 NS |
| Equations/Formulas | 1.53 | 1.42 | 2.47* |
| Symbols | 0.93 | 0.89 | 0.783 NS |
| Spatial Rotations | 1.35 | 1.14 | 3.59*** |
| Spatial Orientations | 2.55 | 2.39 | 3.103** |

*: p<0.05; **: p<0.01; ***: p<0.001

The results indicated that urban students performed significantly better than suburban students in several skill areas. For example, in the skill of picture, urban students had a mean of (M=2.56) compared to (M=2.29) for suburban students, yielding a highly significant t-value of 7.42 (p<0.001). Similarly, urban students performed better in spatial rotations (M=1.35, t=3.59, p<0.001) and spatial orientations (M=2.55, t=3.103, p<0.01). In the case of equations/formulas, urban students (M=1.53) still outperformed their suburban students (M=1.42), demonstrating significant differences, with a t-value of 2.47 (p<0.05).

However, no significant differences were noted in drawing, diagram, graph, and symbol skills, as these comparisons yielded non-significant results.

The level of multiple representation ability consisted of pictures performing at a high level while the others were low and very low. Furthermore, the results emphasized that gender differences in multiple representation ability are inconsistent, with males showing outperformance in female students in specific skills, particularly in image, symbol, and spatial orientation skills. These findings suggest that students in urban settings tend to perform better in particular representation skills than those in suburban areas for understanding magnetic field and force through the multiple representation ability of high school students in Cambodia.

## DISCUSSIONS

This study examined the level of multiple representation ability among high school students. The results revealed that students performed highly in picture skills and could improve their multiple representation abilities. However, they acquired low levels in drawing, diagram, graph, equation/formula, symbol, spatial rotation, and spatial orientation skills in physics, specifically in magnetic field and force, due to a lack of skills in multiple representation ability. This research aligns with the study by Pebriana et al. (2022), which investigated the multiple representation abilities of high school students regarding linear motion in Indonesia. They found that students' verbal, graphical, equation, diagram, and table skills are at a low level, suggesting that students need to strengthen their knowledge and skills related to verbal, graphical, equation, diagram, and table to perform better understanding in magnetic field and force.

Similarly, this finding is also supported by AM and Istiyono (2022), who studied the components of multiple representation ability in learning physics. They mentioned that students have low levels of various representation abilities in graphical, image, and verbal skills and found that students' lack of opportunities to practice and integrate multiple representation abilities in problem-solving may prevent their ability to develop these skills. To address these issues effectively, various representations in teaching methods are employed by integrating multiple representation abilities to enhance students' abilities in physics. Li & Singh (2017) and Sağlam & Millar (2006) studied the assessment of physics students' understanding of magnetism. They found that students struggle to visualize the directions of magnetic force perpendicular to the magnetic field and the direction of motion of charged particles in three dimensions. Students also struggle to create and integrate diagrams, particularly in understanding the forces exerted by magnets and the interactions between bar magnets.

Likely, Sağlam & Millar (2006) studied to explore the understanding of fundamental ideas in electromagnetism of high school physics students. They found that students observed difficulties with spatial orientation tasks that required the direction of the magnetic field to originate from different views. Students were challenged to misuse the right-hand rule when viewed from different positional points, leading to the wrong interpretation of the force acting on the moving charge particles or the current passing through wires. Then, students draw the field lines incorrectly, fail to identify the direction of magnetic field vectors, or misunderstand the significance of field strength as represented by line density (Hau et al., 2018). Fatmaryanti et al. (2017) indicated that students were challenged to write down the equations related to the magnetic field or only attempt to use numbers without a clear understanding. They rely on memorizing formulas without knowing when or how to apply them. This finding further supports the idea that for students in the low category of symbols, there are common mistakes in writing known symbols, such as neglecting to indicate vector quantities properly. Equally, Harra Hau et al. (2020) studied to describe the multi-representation ability of students in solving physics. This study found that students have low skills in graphs and drawing due to their inability to create or interpret graphs, which can check their understanding of complex concepts. They showed a slight inclination to use drawings but still lacked the skill to represent concepts visually effectively.

According to the gender comparison findings regarding multiple representation abilities, there are significant differences in picture, symbol, and spatial orientation skills. The current results are consistent with those of Apata (2022), who found that male students outperformed females in mathematics and graphical skills. This finding supports that males generally possess superior visual representation and interpretation abilities when understanding physics concepts. Similarly, Edelsbrunner et al. (2023) explored how multiple representational skills in vector fields relate to the conceptual understanding of electromagnetism in both genders.

The above study revealed that male students outperformed female students in spatial orientation and graphic skills. In contrast, female students struggled more with symbol, picture, and spatial orientation skills, which was associated with a lesser understanding of physics concepts, particularly those related to magnetic field and force. The research highlighted the importance of proficiency in using multiple representation abilities to develop a deeper understanding of physics.

However, these results differ from the findings of Li and Singh (2017), who noted that while females typically perform better in verbal tasks, they tend to score lower than males in spatial orientation skills. This difference in spatial reasoning skills can hinder their understanding of complex physics concepts, such as those related to magnetic field and force.

An analysis of multiple representation ability based on school location revealed notable differences between Cambodia's urban and suburban high school students. In addition, urban schools perform better than suburban schools in pictures, equations/formulas, spatial rotation, and spatial orientation skills. The current study aligned with the Ministry of Education (2023), which found that students from urban areas generally performed better than rural students because of educational resources and quality teaching. However, MoEYS (2019) found that rural students performed better than urban students in about 2% of physics subjects. This suggests unique advantages in rural schooling contexts and potential for improvement in rural areas, challenging general assumptions that urban areas provide better educational resources than rural areas.

This research suggests that Cambodian students should receive sufficient training on using multiple representation abilities effectively in the classroom, particularly in drawing, diagram, graph, equation/formula, symbol, spatial rotation, and spatial orientation skills, to enhance their high-order thinking skills. In addition, implementing hands-on activities can engage students in the physics learning process. Providing professional development for teachers who effectively utilize multiple representations can further improve student learning outcomes. Therefore, immediate action is required to integrate multiple representation abilities in their teaching and learning process.

## CONCLUSIONS

This research revealed that picture skills are highly proficient because students are familiar with picture skills that the teacher draws on the whiteboard and many pictures in the physics textbook. While drawing, diagram, symbol, equation/formula, spatial rotation, and spatial orientation skills are low, graph skill is very low among the eight skills of multiple representation abilities. However, the analysis showed significant differences between genders in three skills of multiple representations in magnetic field and force. Male students performed better than female students in picture, symbol, and spatial orientation skills. Furthermore, urban and suburban schools are significantly different in picture, equation/formula, spatial rotation, and spatial orientation skills among those school locations. These results suggested that Cambodian high school students must strengthen their drawing, diagram, graph, equation/formula, symbol, spatial rotation, and spatial orientation skills in multiple representations of magnetic fields and forces to improve student learning achievement in physics. It is crucial to help high school teachers develop a deeper understanding of numerous representation skills, integrate those skills in instructional methods, conduct experiments, integrate multiple representation abilities in the learning process, and revise curriculum design and textbooks to address these low skills of multiple representation abilities to improve multiple representation levels in their learning physics.

The current study has only used descriptive statistics to examine the level of multiple representation skills, gender, and school location. Further research should concentrate on interviewing high school students to obtain more information about students' difficulty understanding multiple representation skills and the effectiveness of intervention strategies to improve them in magnetic field and force. Additional research should investigate the level of multiple representation skills in mechanics, thermodynamics, and waves.

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