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Multirepresentation in Physics Learning to Reduce Students' Misconceptions About Circular Motion Concepts

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Abstract

Physics education faces significant challenges in addressing students' misconceptions, particularly regarding the concept of circular motion. This article raises this issue by proposing the application of a multi-representational (MR) approach as an effective solution. A descriptive research method was used to analyze the MR abilities of 36 eleventh-grade students, consisting of 12 males and 24 females. The results indicate that before the implementation of this approach, students' abilities to understand the concept of circular motion were very low, with an average percentage of only 28.70%. However, after the application of MR, this percentage significantly increased to 70.59%. Furthermore, when examining gender aspects more closely, the highest achievements in students' MR abilities related to the concept of circular motion occurred across all types of representations. This indicates that students are now capable of understanding and communicating physics ideas through various types of representations. These findings suggest that the use of different forms of representation, such as verbal, graphical, image, and mathematical, not only enhances students' conceptual understanding but also helps them identify and correct existing misconceptions. In conclusion, the integration of a MR approach into the physics curriculum is crucial for improving students' understanding and reducing conceptual errors. This study recommends ongoing training for teachers in using various representations for instruction, as well as the development of learning modules that include different types of representations to support better student comprehension.

Keywords: Multirepresentation; Misconception; Concept understanding, Physics Learning

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INTRODUCTION

Physics has become the most prestigious field compared to other sciences, as the representation gap for women and marginalized groups is still more pronounced than in other fields. Physics is also a subject sought after by students with certain profiles, who are perceived to be more interested in this subject compared to students in other fields. Physics has a reputation as a pure science about nature, rather than about humans or culture. Concepts in physics such as time, space, and mass are often considered independent of socio-political concepts such as democracy and capitalism (Gray & Scherr, 2025). Physics also plays a crucial role in fostering knowledge of natural sciences and building a foundation for logical and scientific methods. In order to understand and solve physics problems accurately, students must be able to visualize concepts in a comprehensive physics language to facilitate understanding for others (Zeidan et al., 2023). For example, in the field of medicine, students recognize the importance of studying physics (Hsu & Hsu, 2012). Physics has a significant impact on the advancement of a country. Nature published a list in 2020 of the top 10 countries in the field of physics: 1) United States of America - This country has maintained its position as the largest producer of high-quality articles in this field. Its top three institutions are Harvard University, Stanford University, and MIT; 2) China; 3) Germany; 4) Japan; 5) United Kingdom; 6) France; 7) South Korea; 8) Switzerland; 9) Italy; and 10) Spain. Five European countries are among the top ten in the field of physics (Nature Idex, 2020; Bitzenbauer, 2021). Although the motivation to study physics in high school and college may vary and is related to the general motivation for studying science (Johansson et al., 2023). In March 2024, Nature Physics published a Focus issue highlighting the importance of physics education research. The physics curriculum and education system have largely remained unchanged for decades, and there is much that can be done to improve it. For example, the well-documented lack of diversity in physics begins at the undergraduate level. As a result, many potential talents are overlooked, and the lack of representation of minority groups increases at every stage of their careers. Furthermore, the goal of many physics courses still tends to be training students to work in academia, which leaves graduates less prepared for careers in industry. Today's students are unlikely to be satisfied with traditional teaching styles and require an educational structure that allows them to take responsibility for their own learning with the assistance of digital technology. This approach will not only benefit students' understanding of physics but also help them influence change in the world around them (Nature, 2024). The unimpressive trend that stakeholders attribute primarily to the ineffectiveness of teachers in using innovative strategies to teach the subject (Kilpeläinen-Pettersson et al., 2025). Physics is often considered one of the most difficult subjects to learn. Therefore, it is crucial to have good physics teachers to teach the subject. However, looking at the statistical data, about 67% of high school physics teachers did not major in physics. Physics is taught by teachers who have expertise in various subjects, mostly in science and mathematics. Additionally, two-thirds of the 27,000 physics teachers teach subjects other than physics (Uran, 2015). Other reports have shown that academic performance in science, particularly physics, among students is below average (Akanbi et al., 2018). Students' performance in physics exams is on a downward trend compared to other science subjects such as biology and chemistry (Ugwuanyi et al., 2020). The main cause of students' low academic performance in physics can be attributed to teachers' inability to use innovative teaching models in 21st-century classrooms (Ugwuanyi et al., 2023). These studies show that traditional teaching methods are ineffective in reducing misconceptions.

One effective approach to addressing this challenge is the implementation of multi-representation (MR), which combines various forms of representation to convey abstract concepts in a more concrete manner and enhance understanding (Munfaridah et al., 2021). The most commonly used representations in the discipline include formulas, graphs, tables, diagrams, and verbal descriptions. Each can have many variations, and each difference can influence the final solution and the strategies to obtain it (Ceuppens et al., 2018). Furthermore, by using diverse representations, students can choose and utilize the representation that best suits their learning style, enabling them to connect ideas and concepts more intuitively (Khemmani & Isariyapalakul, 2018; Wu & Liu, 2021). The use of multi-representation has proven to be an effective teaching method in deepening conceptual understanding (Hahn & Klein, 2023) and improving problem-solving in physics (Marshman et al., 2024). A learner equipped to think in more than one representation can reason more flexibly when studying new material or solving problems (Wong et al., 2011). By integrating various forms of representation, students can experience physical phenomena or concepts in a more holistic way (Danday & Monterola, 2019). Therefore, the application of multi-representation contributes to the understanding of abstract concepts, facilitates knowledge transfer, and supports problem-solving abilities (Hansen & Richland, 2020). Thus, the use of MR in physics is not only effective in concretizing abstract concepts but also enhances understanding and supports students' problem-solving abilities. On the other hand, the application of MR in physics is effective in both concretizing abstract concepts and improving understanding while supporting students' problem-solving skills. Additionally, effective application requires students to possess the ability to interpret and assimilate various forms of representation (Treagust, Duit & Fischer, 2017). Students' understanding of physics is influenced by their ability to translate knowledge through various types of representation (Bakar et al., 2020). The ability to understand, interpret, and communicate complex physics concepts effectively through various forms of representation is known as MR skills (Guentulle et al., 2024). These skills are crucial in learning, problem-solving, and communication in science, particularly in physics, where dual representations often serve as the foundation for understanding phenomena (McPadden & Brewe, 2017). To develop MR skills, students require structured practice and guidance, which enables them to achieve a deeper understanding of the concepts being studied (Riechmann, Koenig & Rexilius, 2022). The utilization of MR skills significantly supports students in understanding and reinforcing their knowledge of physics concepts.

Students do not enter the classroom with empty minds. They often have different ideas about things, which is referred to as naive knowledge (Asgari et al., 2018). Students' personal experiences, the language used, textbooks, and even teachers are primary sources of misunderstanding (Hammer, 1996). Teachers' mistakes in teaching, incorrect conceptions held by teachers, and inadequate understanding by teachers can lead to misconceptions among students. Misconceptions caused by teachers' errors are often difficult to correct because students feel confident that the concepts presented by teachers are correct. Previous analyses have revealed difficulties in various introductory and intermediate physics courses (Mashood & Singh, 2015; Resbiantoro et al., 2022). This serves as a precedent for creating an inventory of circular motion concepts that will help assess the effectiveness of strategies aimed at enhancing conceptual understanding among school students. Circular motion is part of circus tricks and presents a challenging topic for both students and teachers. Prior research by Volfson et al. (2020) has shown misconceptions about forces acting on rotating objects. A common demonstration used by physics teachers involves spinning a bucket of water vertically to illustrate why the water does not spill when the bucket is inverted. One major misconception is the assumption of centrifugal force, where students believe that a real force pulls objects outward from their path. Consequently, they assume that the gravitational force mg is balanced by the centrifugal force at the peak of the trajectory, thus keeping the water inside the bucket. Furthermore, Taibu & Mataka (2025) indicate that students face various challenges in understanding the dynamics of circular motion. One difficulty arises from the use of centrifugal force in free-body diagrams when solving dynamics problems from an inertial observer's perspective. This is due to students' physical experiences being directly related to circular motion. To apply Newton's Second Law, students need to accurately identify all the forces acting on an object so they can determine the net force and calculate the object's acceleration. Errors in free-body diagrams can lead to incorrect solutions. Canlas (2016) highlights the challenges students encounter when solving a series of mathematical problems. As many as 19% of respondents did not have the opportunity to study circular motion while taking physics courses at university and general education in high school, while others had a limited understanding of these concepts. This research analyzes how students discuss forces in circular motion, uncovering common misconceptions and difficulties in understanding the underlying physics concepts. Therefore, this study presents a unique perspective by integrating a MR approach specifically designed to address students' misconceptions regarding circular motion. Unlike previous research that broadly examined the effectiveness of MR strategies, this study focuses on the nuanced application of these strategies in the context of students' understanding of circular motion. By emphasizing the cognitive and pedagogical implications of MR approaches, this study aims not only to enhance conceptual understanding but also to empower students with the skills necessary to navigate and correct their own prevalent misconceptions in physics education. This targeted approach is expected to make a significant contribution to the discourse on physics teaching methodologies, particularly in the Indonesian educational landscape, which is still underrepresented in the existing literature.

In 1986, they interviewed Harvard University graduates, their professors, and several high school students about the causes of seasons and moon phases. They found that both Harvard graduates and high school students held misconceptions about these concepts—misunderstandings that remained ingrained in their minds despite their time in school. After being re-taught these concepts, only a few demonstrated a better understanding, and many retained some of their incorrect beliefs. Some even reverted to their initial misconceptions, indicating that once information is learned—whether correct or incorrect—it is difficult to edit or erase (Gooding & Metz, 2011). Research in Bhutan and Iran also found that diagnostic items designed to identify student misconceptions and classroom activities aimed at addressing these misconceptions were effective and efficient. Therefore, a similar approach can be taken to tackle common misconceptions and help students build scientific conceptions in other content areas within science education (Dorji, 2021). In the 21st century, researchers have identified many innovative tools to evaluate conceptual understanding, problem-solving, beliefs, and attitudes toward physics. However, there is still a lack of various assessment instruments related to problem-solving in physics (Musengimana et al., 2025). This indicates that the approaches, methods, or teaching strategies used by lecturers have not been effective in enhancing conceptual understanding and reducing misconceptions among students. Therefore, there is a need for alternative approaches or teaching methods to address these issues. One alternative that can be used to reduce misconceptions among prospective physics teacher students, particularly in the topic of kinematics, is the MR approach.

The first semester physics course in college introduces physics students not only to fundamental principles of physics but also to new problem-solving, mathematical, and representational skills. Each of these skills is refined over time (Bego et al., 2018). The effective use of MR is considered key to learning physics, and there is therefore significant motivation to study how students utilize various representations when solving problems and to learn the best ways to teach problem-solving using MR (Kohl et al., 2007). The MR approach refers to learning that presents the same concept in different formats or forms (Munfaridah et al., 2022). MR means representing the same concept in different formats (such as visual, verbal, graphic, and mathematical) to enhance students' problem-solving abilities (Niyomufasha et al., 2024). The goal of using MR in presenting a physics concept is to clarify that concept, which in turn can further enhance students' understanding of it (Pierson et al., 2023). The use of representations to improve learning is particularly important because different representations yield varying capabilities or potentials for communication and learning (Simayi & Lombard, 2019) Furthermore, Lin et al. (2016) explain that the ability to connect information and ideas across different representations for a specific concept is a more meaningful indicator of understanding than merely manipulating symbolic notation. Students often struggle to interpret, translate, and connect the three levels of representation, and this has been identified as a major barrier to student learning (Adadan & Ataman, 2021). Additionally, findings from other research highlight the importance of teachers developing content-pedagogical representation competencies to select representations that align with the targeted content knowledge, student profiles, learning environments, and the nature of science (Yeo et al., 2020). Empirical research related to the use of a MR approach in enhancing students' conceptual understanding has been conducted previously. The results McNeal et al. (2008) indicate that the application of a MR approach in physics education can improve students' conceptual understanding. Therefore, this study aims to analyze the MR approach in reducing students' misconceptions about circular motion concepts.

METHOD

Research Design

The research method applied in this study is a descriptive research method, designed to capture and analyze phenomena and events occurring within a specific context. The primary objective of this approach is to provide an accurate and detailed description of the research object, allowing researchers to understand and depict complex situations and express nuances that may not be detected in more structured quantitative research. In the context of physics learning, particularly regarding the concept of circular motion, descriptive research serves as a tool to identify and analyze misunderstandings experienced by students. This method enables researchers to explore how students understand the concept of circular motion and the factors influencing that understanding. For instance, descriptive research can be used to investigate students' experiences while learning about circular motion, which is often influenced by various pedagogical aspects, such as the use of MR in teaching (Yildiz, 2012; Canlas, 2016b). As an illustration, a study by O'Neill & Mcloughlin (2021) demonstrates how descriptive methods can be employed to explore students' experiences in the context of physics learning. In that research, the researchers conducted in-depth interviews with students to gather qualitative data that depicts their understanding of the concept of circular motion. The findings from this study provide valuable insights for developing more effective teaching strategies and demonstrate how the use of MR can help reduce students' misunderstandings (O'Neill & Mcloughlin, 2021). Thus, descriptive research plays a crucial role in providing a more holistic and in-depth picture of students' understanding of the concept of circular motion. This method allows researchers not only to collect data but also to analyze and understand the broader context in which these misunderstandings arise. This approach is particularly useful in situations where researchers aim to gain a deeper understanding of students' behaviors, attitudes, and experiences, as well as how these factors interact within the larger context of physics learning (Ibrahim et al., 2022). Overall, descriptive research is an invaluable tool in the field of education, especially in physics learning, as it offers researchers the freedom to explore and delve into the complexities of students' understanding. By utilizing this method, researchers can produce findings that are not only informative but also relevant and applicable in the development of theories and practices in the field of physics education (Ergİn, 2013).

Participants

The participants involved in this study were 36 eleventh-grade students from the Science major, consisting of 12 males and 24 females. The average age of the students was between 16 and 17 years. The research was conducted at a high school in the East Seram Regency. This study aligns with significant findings in quantitative descriptive research with a small sample size. First, the study conducted by Rasi et al. (2017) xamined children in Finland, who spend a considerable amount of time outdoors during the winter. Outdoor recreation in winter has various impacts on children's well-being. The participants consisted of 30 children aged 7–8 years living in the Lapland and North Ostrobothnia provinces of Finland. The results indicated that cold weather does not hinder outdoor activities for children in Finland. However, the duration of outdoor recreation becomes shorter as outdoor temperatures decrease. Second, the research by Pellicano et al. (2007) analyzed the sensory characteristics of buffalo meat from animals fed diets with varying amounts of vitamin E. The samples used in this study were taken from 12 buffaloes divided into three groups: a control group (N=4) receiving a normal diet, a low vitamin E diet (LVE) group (N=4) receiving 600 IU/day, and a high vitamin E diet (HVE) group (N=4) receiving 1500 IU/day. The analysis was conducted using the quantitative descriptive analysis (QDA) method. The meat samples taken were from the hindquarter (rump) and stored at -20°C for two months. This study concluded that vitamin E supplementation in buffalo diets affects the sensory characteristics of the meat differently. The low vitamin E diet increased tenderness and juiciness but decreased color uniformity. These results indicate potential for further research on the impact of nutrition on meat quality and consumer preferences. Third, another study conducted by Meyers et al. (1991) involved 73 undergraduate students (sophomores, juniors, and seniors) enrolled in communication classes at a large university in the Midwest. The participants were divided into 15 discussion groups, each consisting of 5 members (some groups had 4 members due to absences). Each group discussed three items from the choice dilemma questionnaire (CDQ), which presents problematic tasks involving serious life dilemmas. The discussions were recorded, and no time limit was set. The main objective of this study was to improve the coding scheme for arguments in the context of group decision-making discussions and to conduct preliminary quantitative analysis of the arguments in those discussions. The three cases presented serve as comparisons to demonstrate that descriptive quantitative research with a small sample size is still feasible.

Research Instruments

The instrument used to identify students' MR abilities in physics is a multi-representation test on circular motion presented in an essay format. The MR in physics follows Kohl & Finkelstein (2006) and consists of verbal (spoken words, written text, phrases or sentences), graphical (graphs, diagrams with labeled axes), pictorial (pictures, images, sketches, diagrams), and mathematical (numerical calculations, equations, formulae, or any quantitative reasoning). This test consists of 8 questions (2 questions on verbal representation, 2 questions on graphical representation, 2 questions on pictorial representation, and 2 questions on mathematical equation representation). The content validity testing was conducted with two experts, one qualified in physics and the other in physics education, to determine the validity level of the instrument used. In the assessment process, the Physics Education Research (PER) rubric was used, which relates to evaluating the ability to represent information in various ways, developed by Etkina et al., (2006). This rubric employs a scoring system ranging from 0 to 3, where 0 indicates no representation or a missing answer, 1 indicates inadequate representation, 2 indicates incomplete or inaccurate representation that requires improvement, and 3 indicates adequate and correct representation. The analysis of students' MR abilities in physics was conducted using descriptive statistics.

Data Analysis Techniques

The data obtained from the research includes students' MR abilities and their difficulties in solving representation-related problems, which were then analyzed and presented in the form of brief descriptions, tables, and charts. To assess students' MR abilities in physics, the test results were analyzed using descriptive statistics in the form of percentages, following the competency guidelines set by Fitrianna et al. (2018), as shown in Table 1. Additionally, this analysis also examines differences in students' multirepresentational abilities in physics based on gender, given that the sample size is considered small. Representation is a crucial element in effective physics learning. When at least two representations are used, either simultaneously or at some point during the learning process, it is referred to as a multirepresentational system (Ainsworth, 2006).

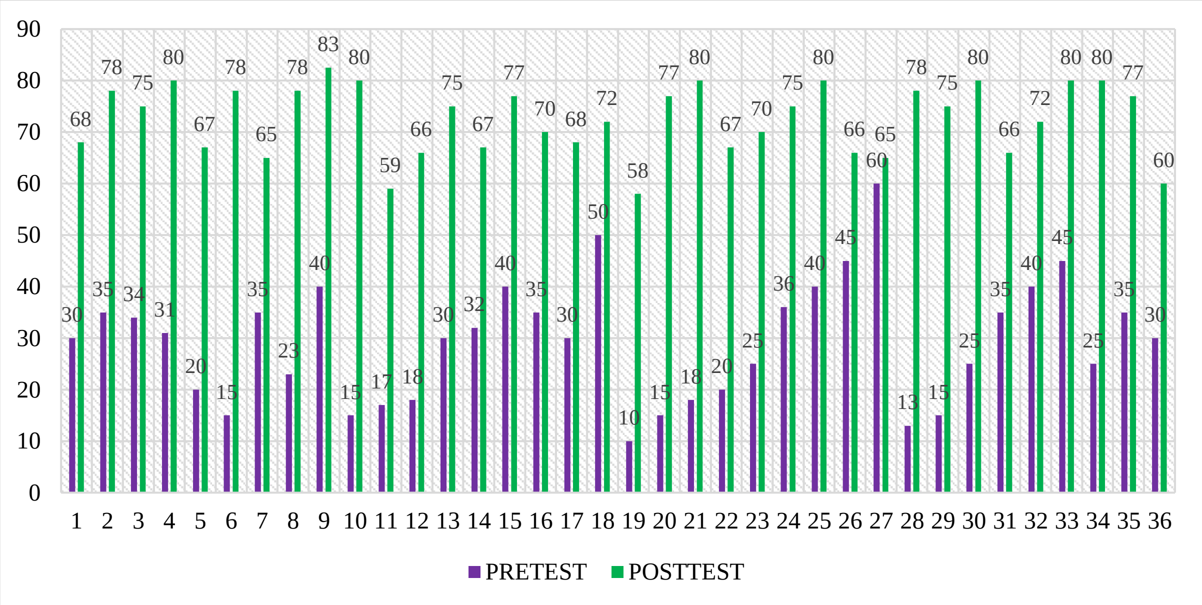
Table 1. Criteria for Students' MR Disposition in Physics

Score	Category
Score < 58.5	Low (L)
58.5 ≤ score ≤ 65.5	Moderate (M)
score > 65.5	High (H)

RESULTS AND DISCUSSION

Physics MR Abilities in the Concept of Circular Motion

The data on the dual representation abilities of high school physics teachers regarding the concept of circular motion can be seen in Figure 1.



Gambar 1. Students' MR skills in physics on the concept of circular motion

Based on Figure 1, the average percentage of MR abilities in the pretest and posttest of students on the concept of circular motion is 28.70 and 70.59, respectively. The initial data indicate that students' MR abilities are very low. We decided to take this data as a starting point and proceeded to provide students with material on the concept of circular motion. This is evidenced by the large number of students who scored 0 or 1 in each type of representation. These results are quite ironic given the importance of MR abilities for students. This study's findings align with earlier findings by Kassiavera et al. (2019), which indicated that students' multi-representation abilities were very low at 35.9%. This is because almost all students find it easier to interpret verbal aspects and write mathematical representations. Therefore, based on this analysis, it can be concluded that students' representations are low because some students have not yet fully understood the concept of circular motion. Additionally, another finding that aligns with this is from Aravind & Heard (2010), where after conducting simulations, students attended a lecture that explained the theory behind circular motion. The results indicate that this combination significantly enhances students' understanding of physics concepts. For example, 73.5% of students were able to solve the given conceptual problems after attending the lecture. We decided to use this data as a baseline and continued by teaching students about the forces acting on a car as it moves along a racetrack with and without friction. The content of this lecture is presented in the following section. Subsequently, by teaching physics using multi-representation, 73.5% of students were able to solve problems correctly based on their knowledge from the simulations and subsequent lectures. 12.2% of students were able to model the problems correctly based on the knowledge they had just acquired but could not arrive at the correct final answer due to errors in their algebra/calculations. 14.3% of students were unable to model the problems correctly. This may indicate that some parts of the lecture were unclear to the students or need reinforcement.

Effective physics teaching will help students better understand the use of representations in explaining a physics concept and enable them to translate the representations of that concept from one form to another. Additionally, teachers need to reflect on effective ways to organize their knowledge and, consequently, choose adequate forms of representation (Majidi & Emden, 2021). The benefits of using MR are as follows: First, each representation brings unique advantages and benefits for conceptual understanding. Second, MR conveys complementary information about scientific concepts. Thus, multi-representation can enhance students' understanding and support them in recognizing what is important across various representations. This means that some representations complement each other but also limit each other. Third, the use of multi-representation can support abstraction across representations, helping learners build relational knowledge and thus develop schemes that can be generalized and transferred (Lichtenberger et al., 2024). Furthermore, for teachers, using various representations in their teaching practices, such as images, diagrams, written explanations, and mathematical expressions, can enhance students' problem-solving abilities (Lucas & Lewis, 2019). The findings of Kriek & Legesse (2023) indicate that the use of eight representations is more effective in helping students understand physics principles. This is due to the use of more relevant representations and appropriate technology to enhance conceptual understanding in physics, as well as emphasizing the importance of careful planning in the selection of suitable representations. However, previous research has found that when students read visual representations, some reading difficulties may arise, especially when the representations are complex or dynamic (López & Pintó, 2017).

MR in teaching can provide teachers with the opportunity to utilize various representations to explain abstract physics phenomena by transforming them into visual representations. The use of MR can even help students enhance their creative thinking during problem-solving. MR allows teachers to improve students' learning outcomes in the classroom, which is consolidated through the provision of diverse ideas and technical tools to enhance their physics learning (Kriek & Legesse, 2023). This is supported by Kohl et al. (2007), who state that MR learning can be considered a key to physics education. The MR approach in teaching and learning has the potential to produce effective learning processes. Through diverse representations, a learning environment is created that actively engages all students' potential, activating their learning abilities both cognitively and hands-on, making learning more meaningful than before (Masrifah et al., 2020). This is further supported by Ainsworth (2006) research, which indicates that when learners can interact with appropriate representations, their performance improves. Moreover, according to the research findings Payandeh et al. (2023), the in-depth MR learning method allows for the hierarchical arrangement of descriptive factors, where higher layers capture more abstract concepts. Ideal high-level representations consist of simple factors that are linearly correlated. This is due to the feature extraction nature in representation learning, where representations can be shared and used across various tasks. Other research findings indicate that physics, when using evolving MR, can maintain scientific consistency in the fields of material and molecular sciences (Kong et al., 2021; Fang et al., 2022).

Abilities of Each Type of Representation

The students' MR abilities in physics regarding the concept of circular motion analyzed in this study are divided into four types of representations: verbal, graphic, pictorial, and mathematical, based on gender. The results of the study, based on Figure 2, indicate that the highest achievement in students' representation abilities regarding the concept of circular motion occurs in verbal representation. This achievement is observed in both female and male students, with scores of 85 and 80, respectively. This is because verbal or textual representation is crucial in explaining scientific phenomena in a simpler and more understandable language. Good physics questions should be presented in verbal form or in language that is easy to understand and not complicated. Additionally, presenting physics questions in the form of everyday cases or phenomena stimulates students' critical and analytical thinking skills. Verbal explanations or statements can be presented in writing or expressed verbally. Physics learning heavily relies on verbal skills, as the thinking process cannot occur without them. If we want to assess students' representation abilities in solving problems related to representation, it is necessary to develop instruments to measure these abilities. However, school teachers more often develop assessment instruments to measure and train students' higher-order thinking skills, while instruments to measure and train representation skills are rarely developed. Therefore, it is essential to develop instruments and understand their characteristics to measure and assess students' abilities, particularly the most basic representation, which is verbal representation as a form of qualitative problem-solving (Adawiyah & Istiyono, 2021). However, in this study, physics questions were provided in essay form. The analysis data for each type of representation is presented in Figure 2.

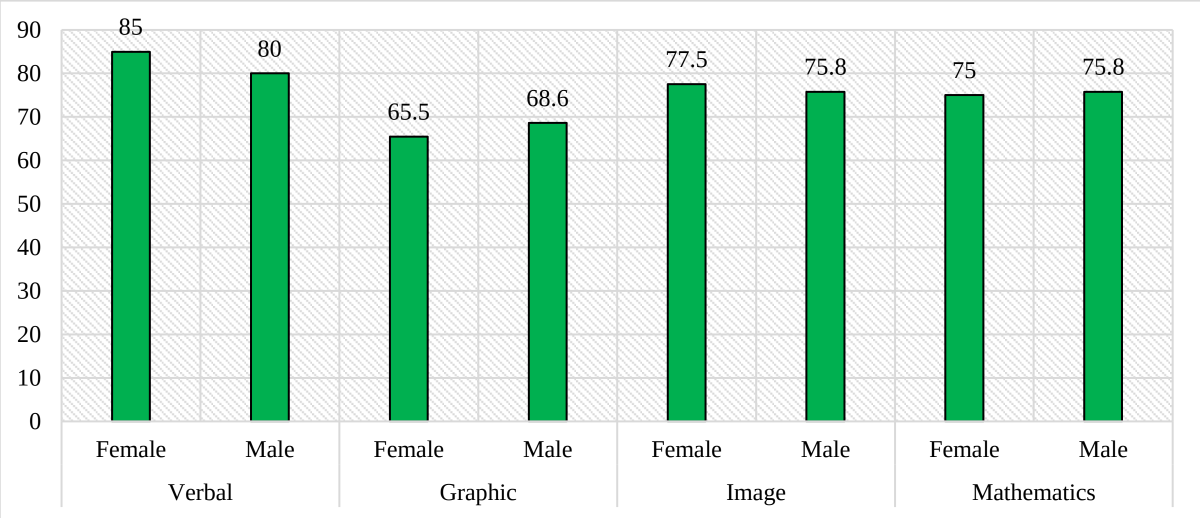


Figure 2. Students' MR abilities in physics for each type of representation by gender

Furthermore, the lowest achievement occurs in graphic representation for both female students and male teachers. One factor contributing to the low ability of teachers to represent concepts in graphic form is their lack of knowledge and understanding of pictorial diagrams, as many physics teachers are not familiar with what pictorial diagrams entail, making it difficult for them to solve the given problems. This is evidenced by the scores of 65.5 for female students and 68.6 for male students. A correct understanding of graphs will enhance meaningful physics learning, especially in finding solutions to physics problems accurately; however, this finding is quite the opposite. Research by Poluakan (2019) explains that the role of vector diagrams is very important in mechanics as well as in other physics concepts. Physical laws will be accurately explained when appropriate image representations are used. To help students better understand graphs, teachers should ask students to consider two types of diagrams: pictorial diagrams arranged according to natural structure and organizational diagrams arranged semantically. Mastery of complete representation diagrams will be the first step toward reconstructing comprehensive understanding to systematically and comprehensively solve physics problems. Furthermore, this research aligns with the study by Aprilia & Dwandaru (2024) , which found that the largest percentage of students' abilities regarding graphic representation was in the low category. Graphic representation is one of the fundamental skills that students must possess. However, in reality, students still struggle to connect and integrate MR and to draw conclusions from the information. Additionally, the use of graphic representations can also assist students in solving physics problems (Bollen et al., 2017). Furthermore,Wong et al. (2011) have outlined how learning through various representations can be applied both inside and outside the classroom. We believe that providing students with the opportunity to create different representations of physical phenomena and reflect on the relationships among those representations can help them develop a deeper and more coherent understanding of physics concepts, as well as enhance their problem-solving skills in physics. Findings by Dillon Thomas (2025) indicate that students often struggle to connect and utilize various representations (verbal, diagrammatic, and symbolic) of physical phenomena. The coloring strategy aims to help students overcome these difficulties. The majority of students provided positive feedback regarding the use of color in teaching materials. Approximately 40% of students felt that coloring helped them make connections between different representations, as shown in Figure 3.

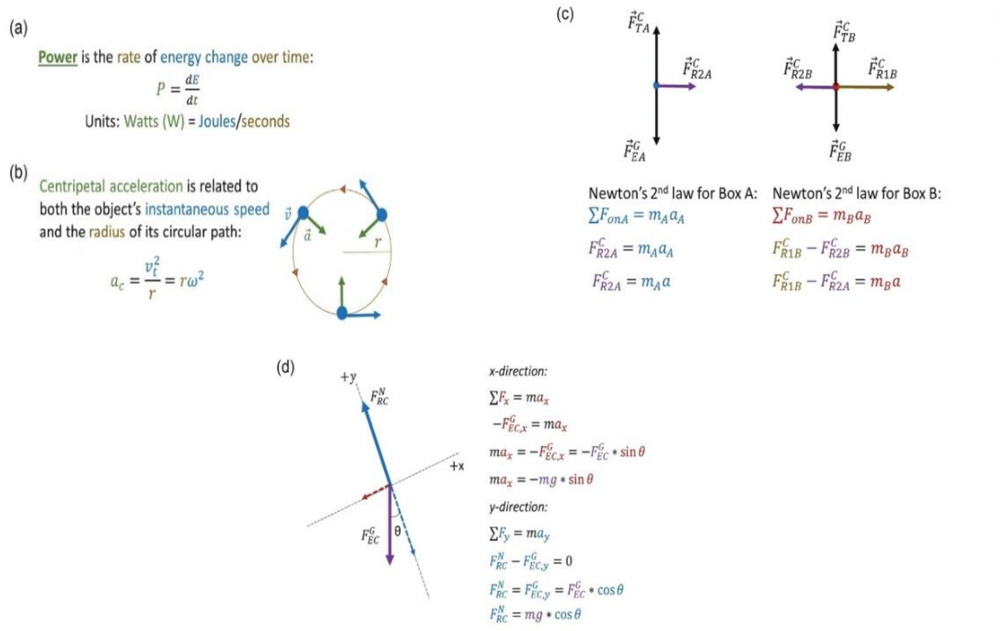


Figure 3. An example of a color-coding strategy for (a) and (b) definitions, including units and diagrams; (c) problem-solving, specifically analyzing the forces on two objects connected by a rope and pulled by another object; and (d) problem-solving with the decomposition of two-dimensional vectors. In (a)–(c), a unique color is used for each quantity; in (d), colors are used to categorize spatial dimensions.

Based on the analysis results, it is also evident that image representations and mathematical equations are categorized as high. Students should possess the ability to create and use all types of representations in learning, as these various forms of representation are interconnected and reinforce explanations of physics concepts. According to Angell et al. (2008) many physics phenomena in everyday life are abstract, necessitating visual explanations such as text or images. The use of MR, by establishing connections among different types of representations, can aid in understanding and solving physics problems. Furthermore, a type of representation deemed most appropriate by the teacher may not necessarily be understood by all students. In the classroom learning process, a teacher must be able to utilize various types of representations if some students find it difficult to comprehend the representation being used. According to Mainali (2021), if a concept is emphasized only in one or two forms of representation, it will only benefit a subset of students. Students have different explanations for specific situations, possess varying prior knowledge patterns, and have different integration patterns within particular concepts. This can be interpreted to mean that students' integration of prior learning and new learning is not a dichotomy of right or wrong, but rather a continuum of levels. Therefore, assessing students' understanding of concepts should not be viewed as simply right or wrong, but must consider the level of understanding achieved. The level of individual student integration within a particular concept may not align with their understanding of other concepts. As a result, assessments of students' understanding within specific concepts must also vary to provide an effective and authentic assessment process, starting with designing high-quality tasks and assessment instruments. This pattern indicates that students' alternative conceptions and the degree of conceptual change are important aspects in evaluating the endpoint of instruction (Villarino, 2018). For instance, presenting a concept solely through verbal representation may pose challenges for students who excel in spatial abilities in understanding the presented concept. Therefore, teachers must possess the skills to create various types of concept representations. The ability to represent a concept in multiple ways is a crucial competency for teachers to ensure that learning is meaningful for students. Consequently, teachers need to enhance their representation skills across all types of representations. These MR skills can be practiced with students through other topic materials

regularly, allowing students to become familiar and proficient. Verbal, pictorial, graphic, and mathematical presentations can be used to instill skills in drawing conclusions, recognizing assumptions, summarizing information or ideas, interpreting data, and evaluating arguments

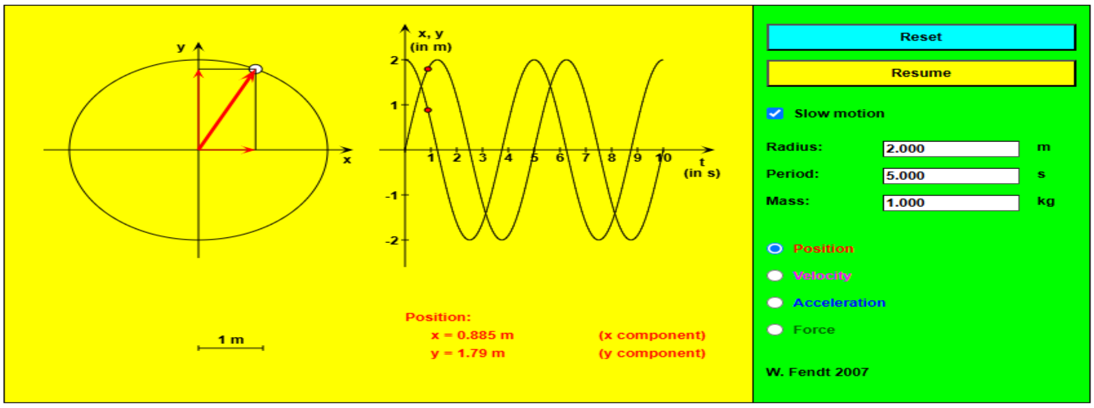


Figure 4. An HTML5 application simulating circular motion for MR studies

Figure 4 is an HTML5 application that simulates circular motion and shows how position, velocity, acceleration, and net force change over time (https://www.walter-fendt.de/html5/phen/circularmotion_en.htm). The radius vector (red) connects the center of rotation (the origin of the coordinate system) to the rotating object. The velocity vector (purple) is tangent to the circle and perpendicular to the radius vector. The acceleration vector (blue), surprisingly, is directed inward (toward the center). Here, acceleration does not imply an increase or decrease in speed (magnitude of velocity) but rather a change in the direction of motion. The same applies to the force (green) acting on the moving object. Circular motion plays a crucial role in nature and technology. For instance, planets move in (approximately) circular orbits around the sun. The terms centripetal acceleration and centripetal force indicate that these vectors are directed toward the center of circular motion. Circular motion alters perceptions of up and down. For a skateboarder, the need to lean the body toward the center of the arc is an embodiment of centripetal acceleration (Malmqvist & Pendrill, 2022).

Furthermore, the use of MR helps both students and teachers enhance their understanding of concepts or phenomena, as each representation focuses on different aspects of the concept or phenomenon. Therefore, MR serves as an excellent resource for students to learn scientific concepts. Educational reform documents in the United States and Europe state that it is important to create learning opportunities in pre-service teacher education to develop teachers' skills related to the use of MR. These skills include knowing the best representations for teaching and how to use them to support the learning of all students (Conceição et al., 2021). Helping students learn physics concepts and developing their problem-solving skills are among the common instructional goals of introductory physics courses (Mason & Singh, 2016). Effective physics problem-solving can be described in terms of the attitudes and approaches used by physics experts. For example, physics instructors generally follow a problem-solving process that involves making connections to underlying principles, creating diagrams and/or other representations of the problem that facilitate further problem-solving processes, and reflecting on their answers to ensure sensitivity and to understand how the problem-solving process helps them organize, expand, and refine their knowledge structures. Conversely, without explicit support and incentives, many introductory physics students often neglect initial conceptual analysis and immediately seek physics formulas to 'plug in and process' with minimal planning for their solutions. Encouraging introductory students to solve problems systematically can help them learn a problem-solving approach that is more akin to that of experts (Good, 2022). Previous research has shown that providing students with explicit instruction on problem-solving strategies, such as creating accurate sketches and including multiple representations, can improve the quality of students' solutions and aid their learning (Heuvelen et al., 2001; Rosengrant et al., 2005).

CONCLUSION

The MR abilities of students in physics learning, particularly related to the concept of circular motion, are generally considered high, with an average percentage reaching 70.59%. This figure indicates that most students have a good understanding of the various representations used to explain this concept. Additionally, when examining gender aspects more closely, the highest achievements in students' MR abilities concerning the concept of circular motion occur across all types of representations. This suggests that students are capable of understanding and communicating physics ideas through various forms of representation. The findings of this study emphasize that students' physics abilities in understanding the concept of circular motion still need improvement, especially in more complex representation aspects such as graphs. These MR skills can be routinely practiced with students through other topic materials, allowing them to become accustomed to and proficient in using different forms of representation. The use of verbal, graphical, pictorial, and mathematical presentations will not only enrich students' understanding but also help instill essential skills in drawing conclusions, recognizing assumptions, summarizing information or ideas, interpreting data, and evaluating arguments more critically. Thus, the development of these skills is expected to enhance students' overall conceptual understanding in physics.

RECOMMENDATION

Several recommendations can be made as follows: 1) The physics curriculum in schools should systematically integrate a MR approach. This can be achieved by developing learning modules that include various types of representations (verbal, graphic, pictorial, and mathematical) for each physics concept, particularly for the concept of circular motion; 2) Implement ongoing training programs for physics teachers to enhance their skills in using various representations in teaching. The focus should be on developing skills in pictorial diagram representation, which showed the lowest results, so that teachers can be more effective in teaching physics concepts; 3) Provide a variety of learning resources that support the MR approach, such as videos, interactive simulations, and physics teaching aids. This will help students understand concepts in a more engaging and relevant way. Additionally, conduct regular evaluations to monitor students' progress in understanding physics concepts and to assess the effectiveness of the applied MR approach.

Recommendations for Future Research are as follows: 1) Conduct longitudinal studies to evaluate the long-term impact of applying a MR approach on students' understanding of physics concepts. This research can provide insights into how MR skills develop over time; 2) Conduct comparative studies between traditional teaching approaches and MR approaches in physics education. This research can help identify the strengths and weaknesses of each method and provide more specific recommendations for teaching practices; 3) Conduct in-depth research on students' MR skills in the context of various other physics concepts. This research can help understand how these skills can be broadly applied and enhance students' overall understanding of physics; 4) Investigate the influence of social and cultural contexts on the application of MR approaches in physics teaching. This research can provide insights into how external factors affect students' understanding and the effectiveness of teaching methods. By implementing these recommendations and continuing research in the suggested areas, it is hoped that students' conceptual understanding of physics, particularly in the concept of circular motion, can significantly improve and reduce existing misconceptions. This study found that teachers are the key to students' success in mastering the concept of circular motion. Therefore, before teachers begin teaching, it is essential that they master the learning concepts with adequate literature to prevent misconceptions that may arise from students coming from diverse backgrounds. Teachers are also advised to present and convey topics through the careful selection of appropriate teaching methods, especially in providing learning evaluations in the form of feedback or reflections to all students.

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Gazali Rachman	✓	✓	✓	✓	✓	✓		✓	✓	✓			✓	
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CONFLICT OF INTEREST STATEMENT
Authors state no conflict of interest.

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