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Research Trends in Physics Learning Strategies: A Systematic Literature Review Addressing Students' Conceptual Understanding Difficulties in Kinematics

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Abstract: Conceptual understanding is a basic skill that students need to have in learning. This has encouraged many researchers to implement strategies in learning to improve students' understanding of kinematics material. This article conducts a comprehensive review of 22 Scopus indexed journals to answer research questions related to What strategies are used in learning kinematics material and what difficulties do students experience during learning? The method is carried out using the PRISMA stages which consist of four journal mapping processes, namely identification, screening, eligibility, and included in this review. The review results indicate that from 2016 to 2024, various strategies and comparative studies have been implemented in kinematics learning. Most of these strategies effectively enhance students' conceptual understanding. However, there are still some difficulties for students in understanding the concept of kinematics which are still underlined, especially in understanding the interpretation of x-t, v-t, and a-t graphs.

Keywords: Kinematics; Learning Strategies; Students' Conceptual; Student's Understanding; Understanding Difficulties

Introduction

Conceptual understanding is an important aspect in learning, because without this ability, students will have difficulty in solving problems (Safari *et al*, 2020). Conceptual understanding can be interpreted as students' ability to connect various knowledge they have to find the most effective solution in solving a problem (Banda & Nzabahimana, 2021; Mi et al., 2020). Good conceptual understanding also plays a role in increasing students' effectiveness in solving problems (Al-Mutawah et al., 2019).

In physics learning, conceptual understanding needs to be improved so that students can connect the knowledge they have acquired with physics concepts. Thus, they can realize their intuitive understanding and adjust it to the new concepts given (Vosniadou, 2019). In addition, good conceptual understanding contributes to the development of metacognition, namely the ability to manage and reflect on one's own thinking processes. Strong metacognition makes it easier for students to transfer physics knowledge to everyday life and integrate various information to build more complex understandings, thus encouraging creative and innovative thinking (Mills, 2016).

The trend of educational research in improving conceptual understanding in physics learning has been widely carried out. Starting from the application of learning models (Maskur et al., 2019; Abaniel, 2021); (Martawijaya et al., 2023), developing teaching materials (Asrizal et al., 2023; Asrizal et al., 2024), instructional media (Moro & Billote, 2023), learning environment design (Krumphals & Haagen-Schutzenhofer, 2021), etc. In research using learning models, most results show

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that the effectiveness of increasing conceptual understanding is better when students are placed as the center of learning (Dong et al., 2019; Alharbi, 2024). This is because, by placing students as the center of learning, students can become more actively involved in learning, thus helping students to build their understanding concepts better, especially in learning that is closely related to everyday life, such as in kinematics material.

Kinematics is a physics subject that often integrates various representations in describing the movement of an object. The basic topics of discussion are related to position and displacement, speed and velocity, acceleration, and their respective relationships to time (D'arco & Guerritore, 2022). This material is also a basic material in learning physics. Therefore, many studies choose kinematics as their research topic. Various strategies have also been carried out to maximize the instructional impact of students on this concept. However, the facts in the field show that there are still many students who have difficulty in understanding the concept of kinematics. This is due to various things, starting from different thinking styles (Saminan et al., 2019), low mathematical ability (Lichtenberger et al., 2017), students' inability to integrate various representations (Klein et al., 2017), and others. The many interrelated studies need to be summarized in a systematic literature review so that the common thread can be drawn.

Previous research related to systematic literature reviews in the field of physics learning has been conducted by (Banda & Nzabahimana, 2021) by reviewing good learning models in the application of PhET simulation during learning. Furthermore, research by (Wandi et al., 2023) has conducted a literature review on the theory and practice of students' conceptual understanding in physics learning through several articles in the last 10 years. Research on the effectiveness of several models in physics learning has also been studied, including Inquiry (Strat et al., 2024), Problem-Based Learning (Suwasono et al., 2024; Nurmahasih & Jumadi, 2023), Project Based Learning (Suwasono et al., 2024), etc. However, there has been no systematic literature review that focuses on the discussion of various strategies that have been implemented to improve students' understanding of kinematics material, accompanied by a general description of conceptual understanding, as well as obstacles and recommendations in learning.

Therefore, this article will discuss, summarize, and provide readers with an overview of strategies in the field of education in improving students' understanding of kinematics concepts. Furthermore, this article will also provide an overview of how students' understanding develops before and after the strategy is applied in learning. In other words, this article is a literature review that investigates the role of learning strategies in improving students' conceptual understanding by answering the questions: What strategies are used in learning kinematics material and what difficulties do students experience during learning? So that through this Systematic literature review article, it can be a consideration for future research.

Method

The research was conducted by collecting Scopus indexed journals using mathematical review selection reporting with the PRISMA approach adapted from (Banda & Nzabahimana, 2021). Through the PRISMA stages, articles were successfully collected from several databases, namely Google Scholar, ERIC, Scimago, ResearchGate, Taylor and Fracis, Academia, and directly on the Google search page. The search was limited to the period 2016-2024 (the last 8 years) using the keywords "(Kinematics and (Conceptual Understanding or model learning or strategies in physics education)". The researcher also used the keyword "teaching material" because the use of teaching materials is also a strategy in learning.

To answer the research questions, an article inclusion and exclusion process was carried out to select relevant articles. The stages of the article inclusion and exclusion process were carried out as in Table 1. The total number of papers obtained by entering each keyword in the database web is 1396 with details of Google Scholar 261, ERIC 136, Scimago 936, and Taylor and Francis 17. The flow diagram of the paper inclusion and exclusion process is as shown in Figure 1.

Some papers that cannot be downloaded from this database will be searched extensively through journal outlets such as Google Search, ResearchGate, and Academia. The extensive search obtained a total of 46 papers. The articles were then accumulated in Microsoft Excel to then delete several identical journals using the "remove duplicate" menu. From this process, it was found that there were 495 papers that were duplicates from several database sources used, leaving 901 papers. These 901 articles were then screened by title to select articles that were relevant to the research question, leaving 185 journals with appropriate titles. The researcher then read the abstracts of the 185 journals to determine which journals contained research results that were in accordance with the context being discussed. In this process, there were 116 journals that were deliberately excluded because the brief presentation of the research seen from the abstract did not match the research question. After that, the researcher will start to analyze the data, and it was obtained that 47 journals were excluded for certain reasons. The final result then left 22 journals that were considered suitable for in-depth study.

Tabel 1. Inclusion and Exclusion Criteria

PRISMA Stage	Number of Articles (n)	Validation Method
Total articles found	1396	Search across multiple databases with specified keywords.
Articles removed due to duplication	495	Removing duplicates using the "Remove Duplicates" feature in Microsoft Excel.
Article after duplication removed	901	-
Articles removed after title filtering	716	Title filtering based on inclusion and exclusion criteria.
Articles after title filtering	185	-
Articles removed after abstract screening	116	Abstract screening to ensure content is relevant to the research.
Articles with appropriate abstracts	69	-
Articles deleted for some reason	47	In-depth analysis of article content by researchers and peers.
Final articles included in the study	22	Articles that have passed all validation stages are included in the systematic review.

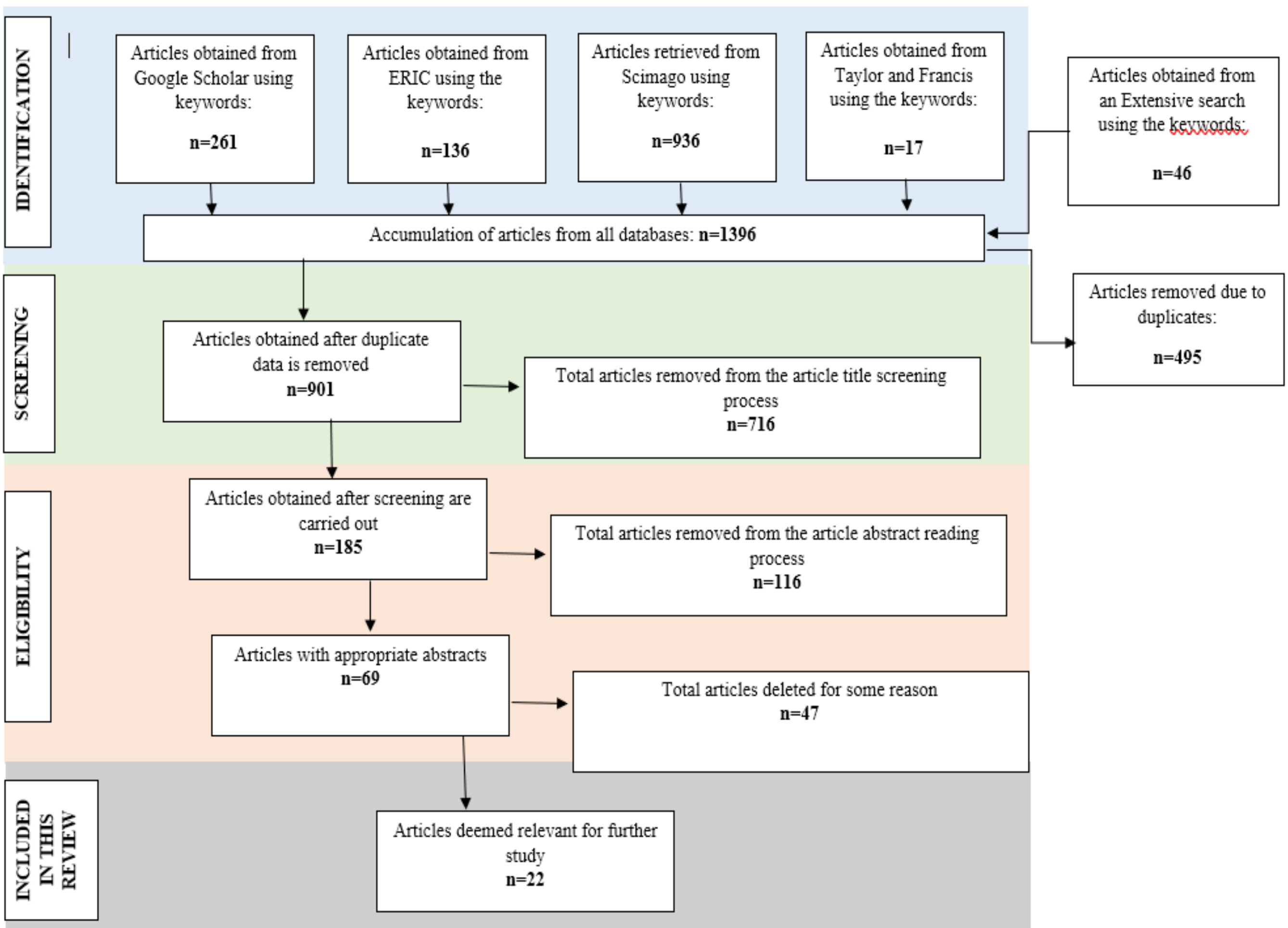

Figure 1. Flowchart of reporting inclusion and exclusion of Systematic Literature review

Result and Discussion

In the period from 2016 to 2024, 22 journals relevant to the research question have been selected. In the early year, namely 2016, only one journal was found suitable for review. This result increased in 2017, where 4 relevant journals were found, then decreased again in 2018. The most journals were found in 2019 and then stabilized in the last three years. The visualization is depicted in Figure 2.

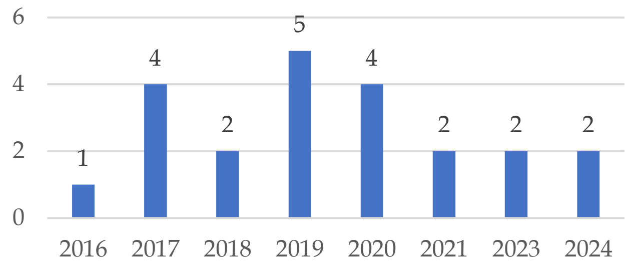

Figure 2. Distribution of study journals

Kinematics material is included in the initial material and becomes the basic material in learning physics, so a good understanding of the concept of kinematics can make it easier for students to learn the next material. However, according to some students, this material is still considered difficult to understand because it requires problem reasoning skills and the ability to integrate various representations well (Putra et al., 2018). Moreover, low mathematical ability also complicates the causes of students' difficulties in understanding kinematics concepts (Lichtenberger et al., 2017; Hung & Wu, 2018). So far, many strategies have been implemented in learning to improve students' understanding of kinematics material. Starting from the development of teaching materials (Hartini et al., 2020; Mufit et al., 2022; Taqwa et al., 2022), use of learning aids media (Firdaus et al., 2017; Fartina et al., 2020), student worksheet (Lichtenberger et al., 2017; Klein et al., 2017; Lusiana & Yohandri, 2019; Makiyah et al., 2022), application of various learning models (Hartini et al., 2020; Lusiana & Yohandri, 2019; Kusumawati et al., 2019), or the application of other strategies such as modifying the representation of kinematics problems (Zavala et al., 2017). Figure 3 provides a visualization of the description of students' difficulties in understanding kinematics material.

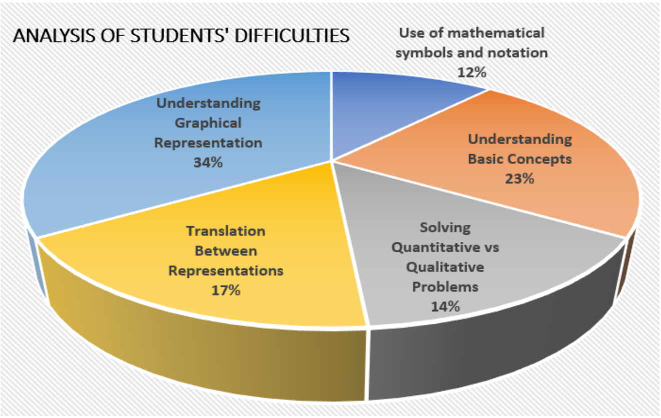

Figure 3. Analysis of Students' Difficulties

Research by (Hartini et al., 2020) has tried to develop teaching materials by integrating the 7E learning model (Elicit, Engage, Explore, Elaborate, Evaluate, and Extend) on the kinematics of straight motion material. The results of his research showed that by using the 7E learning cycle teaching materials, it succeeded in increasing students' post-test scores with an N-Gain of 0.31 (intermediate category). Furthermore, the use of these teaching materials in learning can also make it easier for teachers to choose effective learning strategies after knowing students' initial knowledge through the first stage, namely Elicit. The existence of the Elicit stage will also help students understand new concepts because they have recalled the material they have studied previously (Broadfoot et al., 2020). Meanwhile, the other six stages will encourage students to be active during learning, so that students can explore and understand the material better (Fartina et al., 2020).

Something similar was also done by (Mufit et al., 2022) by implementing the process of activating students' preconceptions before learning through the development of complex cognitive-based E-books combined with experimental videos. Videos will help students visualize a phenomenon that occurs, so that students can more easily understand a concept (Firdaus et al., 2017). In his research, the researcher tried to bring up physical phenomena that trigger cognitive conflicts between concepts and students' intuitions, so that in the final stage students will be able to evaluate their mistakes better and realize that some intuitions are not always correct when associated with various concepts. The results of the study showed that the teaching materials developed were considered effective in improving students' conceptual understanding of kinematics material. Not only that, during the learning process, several misconceptions that occurred in students were also analyzed, including: students assume that acceleration is always zero if an object moves at a constant speed (Tatira, 2024; Zavala et al., 2017), difficulty distinguishing distance from displacement, difficulty distinguishing instantaneous and average speed (Firdaus et al., 2017), and students tend to assume that heavy objects will fall faster than light objects in the concept of Free Fall Motion (Syuhendri, 2021).

Further research on the development of teaching materials was conducted by (Taqwa et al., 2022) who integrated motion diagrams with a teaching module. This study refers to the constructivist theory which emphasizes student independence in developing their own understanding. During learning, the module provided presents various problems that students must solve and discuss solutions to. The results of the study showed that the majority of students had difficulty understanding two objects with opposite speeds (Ceuppens et al., 2019), determine the speed of an object

(Tatira, 2024), and confusion in reading the acceleration graph against time a(t). After using the module, there was an increase in students' conceptual understanding as seen from the pretest-posttest scores with an N-Gain value of 0.543 and a d-effect size of 2.189, which means that the module has a strong influence in improving students' conceptual understanding.

Table 1: Results of the literature review regarding strategies and descriptions of students' difficulties in understanding concepts

Category of Strategy used	Student Understanding Overview
Integration of models with learning media or teaching materials (Syuhendri, 2021); (Makiyah et al., 2022); (Fartina et al., 2020); (Firdaus et al., 2017); (Kusairi et al., 2019); (Mufit et al., 2022); (Taqwa et al., 2022); (Hartini et al., 2020); (Lusiana & Yohandri, 2019)	- Students often think that heavy objects will fall faster - Students tend to use their own frame of reference, rather than an inertial frame of reference - Many students understand the concept but not deeply - Students have difficulty connecting theoretical concepts with real-life applications - Students' understanding of graphs is still lacking - Students assume that acceleration is always zero when an object is moving at a constant speed - The majority of students cannot distinguish between distance traveled and displacement - Students have difficulty connecting the meaning of graphs with real phenomena - Students often misinterpret the slope of a graph - Students have difficulty distinguishing between average velocity and instantaneous velocity - Students think that a graph is a picture of the trajectory of a moving object - Students have difficulty understanding the motion of two opposing objects (lack of understanding the meaning of the + and - signs in velocity) - Students have difficulty determining instantaneous velocity from the x(t) table - Students have difficulty understanding and interpreting the a(t) and v(t) and v(t) graphs - Students have difficulty interpreting the x(t), v(t), and a(t) graphs - Students' understanding is weak in understanding the relationship between variables between graphs
Treatment through the format and representation of the questions used (Ceuppens et al., 2019); (Klein et al., 2021); (Kusumawati et al., 2019); (Lichtenberger et al., 2017); (Zavala et al., 2017); (Broadfoot et al., 2020); (Tatira, 2024)	- Students tend to understand the relationship between position and velocity rather than velocity and acceleration - Understanding of the concept of area under a v(t) graph is better understood than a(t) graph - Students show different understandings depending on the variables used (such as velocity vs. acceleration) - Many students assume that constant acceleration results in zero velocity - Students tend to be less precise in determining the gradient of the graph - Many students have difficulty connecting various kinematic representations - Students are confused about interpreting the slope and height of the graph - Students are unable to translate information between graphical and mathematical representations - Students have difficulty understanding the principles of the coordinate system and the relationship between position, velocity, and acceleration - Students tend to view graphs as direct representations of reality - Students have difficulty understanding the meaning of negative velocity in x(t) graphs - Students have difficulty switching between representations - Students take a long time to understand the relationship between the representations used
Komparative Study (Barniol et al., 2024); (Bollen et al., 2016); (Hung & Wu, 2018); (Susac et al., 2018); (Taqwa et al., 2023).	- Physics students find it easier to solve problems about the slope of a graph compared to the area under the graph - Psychology students find it easier to solve qualitative problems than quantitative problems - Physics students are confused about interpreting the slope and height of a graph - Psychology students have difficulty understanding the relationship between graph variables - All students tend to use an intuitive approach rather than a formal approach - All students tend to only read the initial and final values without considering the slope of the graph - Students in the numerical group show better performance than students in the symbolic group - The greatest performance is seen in the steps of executing the plan and evaluating the solution

Category of Strategy used	Student Understanding Overview
	- Students in the symbolic group have difficulty understanding and manipulating symbols, because symbols are less familiar, reducing students' motivation to solve problems - Students in the numerical group have difficulty if the numbers used cannot be or are too large - Students with visual representation problems are better at solving problems than students with mathematical representations. Students have difficulty understanding abstract mathematical representations (tend to memorize formulas without understanding their meaning) - The majority of students have difficulty calculating the distance traveled from the v(t) graph because it is related to the area under the curve - Students have difficulty connecting the equation x(t) with the equation v(t) or a(t) - Students tend to directly use mathematical formulas without evaluating their physical logic - Calculus students have a better understanding than algebra students - Both groups of students have difficulty understanding the difference between average speed and instantaneous speed. Some students have difficulty understanding the slope of the graph with the y value at a certain point - Some students use the height of the graph as the velocity - Graphs are often misinterpreted as a physical concept of the phenomenon of the movement of an object - Students tend to make mistakes in interpreting the steepness of the graph as the most negative velocity value - Students often think that graphs are "photographs" of the path - The calculus group finds it easier to understand the concept of derivatives (slope of the graph) than the concept of antiderivatives (area under the curve) - The kinematics group is better at solving problems, because the calculus group is less able to relate mathematical equations to real situations - Students tend to immediately look at the value on the y-axis without paying attention to the relationship between the graph (x-axis and y-axis)

Different strategies have been applied through the test formats used. Research by (Lichtenberger et al., 2017) highlights the application of various questions in analyzing students' understanding of kinematics material. However, although students' understanding increased after learning, there were still several obstacles experienced by students, namely in understanding the area under the graph. On the other hand, modifications to the kinematics graph understanding test have been carried out by (Zavala et al., 2017) by adding 9 new items to the Test of Understanding in Kinematics (TUG-K) to ensure parallelism in measuring certain concepts, and removing 4 items that were considered less relevant. Although the results of the study can provide a more structured understanding of kinematics concepts, the general picture of students' understanding still shows that students have difficulty understanding the area under the graph. In addition, in the parallelism of concepts, it shows that there are differences in students' understanding when the variables used are different even though the mathematical concepts used are the same (such as acceleration vs. velocity). This shows that many students still memorize mathematical formulas without understanding their meaning (Taqwa et al., 2022). Therefore, it is necessary to pay more attention to teaching qualitative and quantitative aspects together to students in teaching kinematics. (Bollen et al., 2016).

Syuhendri at 2021 c (Zavala et al., 2017). However, by involving logical analysis to compare old concepts with new concepts, this study successfully highlighted that the test used can significantly reduce conceptual errors and is able to improve students' conceptual understanding of kinematics material. So in line with research by (Broadfoot et al., 2020, Hartini et al., 2020; Mufit et al., 2022) this study recommends the need to activate students' old understanding before providing new understanding.

The majority of strategies used in learning kinematics are by using multiple representations. (Klein et al., 2017; Lichtenberger et al., 2017; Kusumawati et al., 2019; Taqwa et al., 2023). Researched by (Klein et al., 2017) by using multiple choice questions and true-false questions have integrated three representation formats, namely graphs, images, and mathematical expressions. In its application, students will be given graphs to recognize and understand various kinematic representations, such as position and time graphs, velocity and time, or acceleration and time. Then students are asked to determine the relationship between variables, translate them into mathematical and verbal equations, identify and match the appropriate answers. During learning, the obstacles experienced by students are during the process of translating graphs into mathematical and verbal forms (Lichtenberger et al., 2017; Kusumawati et al., 2019). This happens because of the lack of understanding of students in interpreting the mathematical form of a phenomenon that occurs. (Klein et al., 2021; Taqwa et al., 2023).

On the other hand, the application of multiple representations of tables, images, and graphs has been carried out by (Lichtenberger et al., 2017) who in his research found that students had difficulties in understanding the concept of kinematics, namely: students often misinterpreted the concept of the area under the curve (Klein et al., 2021; Lichtenberger et al., 2017; Zavala et al., 2017; Susac et al., 2018), students have difficulty in transferring conceptual understanding between representation formats, and students' limitations in understanding basic mathematical concepts such as slope. Therefore, this study recommends a form of teaching that emphasizes mathematical foundations first before kinematics learning is carried out. In addition, after teaching, students also need to be trained with various representation concepts.

A comparative study related to the application of representation formats in kinematics tests has been conducted (Hung & Wu, 2018) which analyzes students' understanding and Self-Efficacy through two types of representation questions, namely numerical and symbolic. Based on the results of the study, it was explained that students in the numerical group had better performance than students in the verbal group, so for example the form of the question: "Students with masses of 60 kg and 40 kg" is easier to understand than questions with the form "Students with masses M and m". This is because symbolic is something more abstract for students and less familiar, thus reducing students' motivation to solve problems. So it can be said that student performance will be much better if they are familiar with it. The next result regarding Self-Efficacy shows that there is no difference in self-efficacy between numerical and symbolic formats. This means that various forms of question representation do not affect students' confidence in themselves in solving problems.

A comparative study of other representation formats was conducted by (Taqwa et al., 2023) which shows that questions with visual representations get better results than questions with numerical representations. Through 12 questions (5 visual representation questions and 7 mathematical representation questions) it can be seen that students have difficulty in understanding abstract mathematical concepts. In addition, students still tend to memorize formulas without understanding their meaning, so that questions with numbers or formulas are believed to be more complicated, thus encouraging students to directly use the formula without evaluating its physical logic. Therefore, it is necessary to link mathematical concepts with graphs and their relationship to phenomena in everyday life in kinematics learning (Barniol et al., 2024; Tatira, 2024). On the other hand, research by (Kusumawati et al., 2019) highlights the application of multi-representation using HOTS questions through the integration of four representations, namely graphic, verbal, diagram, and mathematical. Through the application of this model, there is an increase in students' critical thinking skills and conceptual understanding of kinematics material.

The strategy of integrating learning models and the use of worksheets in kinematics material has also been carried out. In the study (Lusiana & Yohandri, 2019) shows the results that by integrating Project Based Learning and worksheets can improve students' understanding of the material of Uniform Straight Motion. Furthermore, the results of the study provide data that students' competencies in terms of attitude (79.4%), knowledge (64.7%), and skills (67.9%) are in the good category. The results of student responses also stated that the worksheets developed were interesting so that students were motivated to be actively involved in project-based learning. On the other hand, the categorization of student responses in understanding straight motion graphs has been studied by (Bollen et al., 2016) by grouping various ways students answer questions about kinematic graphs. Based on the results of grouping student responses, it is known that students still have difficulty in understanding the difference between average speed and instantaneous speed, still have difficulty in distinguishing the slope of the graph with a certain y value, and students tend to misinterpret the graph such as when the graph goes down it shows decreasing speed, or vice versa (Barniol et al., 2024). Therefore, this study highlights the importance of improving students' qualitative understanding to support success in quantitative representation.

Analysis of understanding of material related to graphs has been carried out by (Susac et al., 2018) through a comparative study of understanding graphs in physics and psychology students. The results of the study show that physics students tend to use the "Rise over run" strategy in understanding graphs, while psychology students use a common sense approach, where high speed will cover a greater distance too. Furthermore, this study provides the results of student data analysis that students' difficulty in understanding the area under the graph is because the majority of students forget and or do not know the basic formula for the area of a flat plane, so students tend to use intuition (which is not in accordance with the principle) in answering questions.

Conclusion

Various strategies in kinematics learning have been carried out in the period 2016-2024. A total of 22 journals have been analyzed based on learning strategies and the general picture of students' difficulties in understanding kinematics material. Various comparative studies have also been conducted to determine the extent of differences in students' conceptual understanding of kinematics material. Most studies show that during the learning process there must be difficulties experienced by students, ranging from integration between representations, low mathematical abilities, difficulty reading graphs, and so on. Regardless of the success of research in reducing or improving students' conceptual understanding, each journal must present suggestions for further research. This shows that there are still some concepts that need to be developed and researched further. This article has provided an overview for readers to find out what strategies have been carried out and how they impact learning.

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Conceptualization, S.N.M.R and S.; methodologi, S.N.M.R and P.; formal analysis, S.N.M.R and A.H.; resource, S.N.M.R.; writing-original draft preparation, S.N.M.R and S.; All authors have read and agreed to the published version of the manuscript.

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The authors declare no conflict of interest

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