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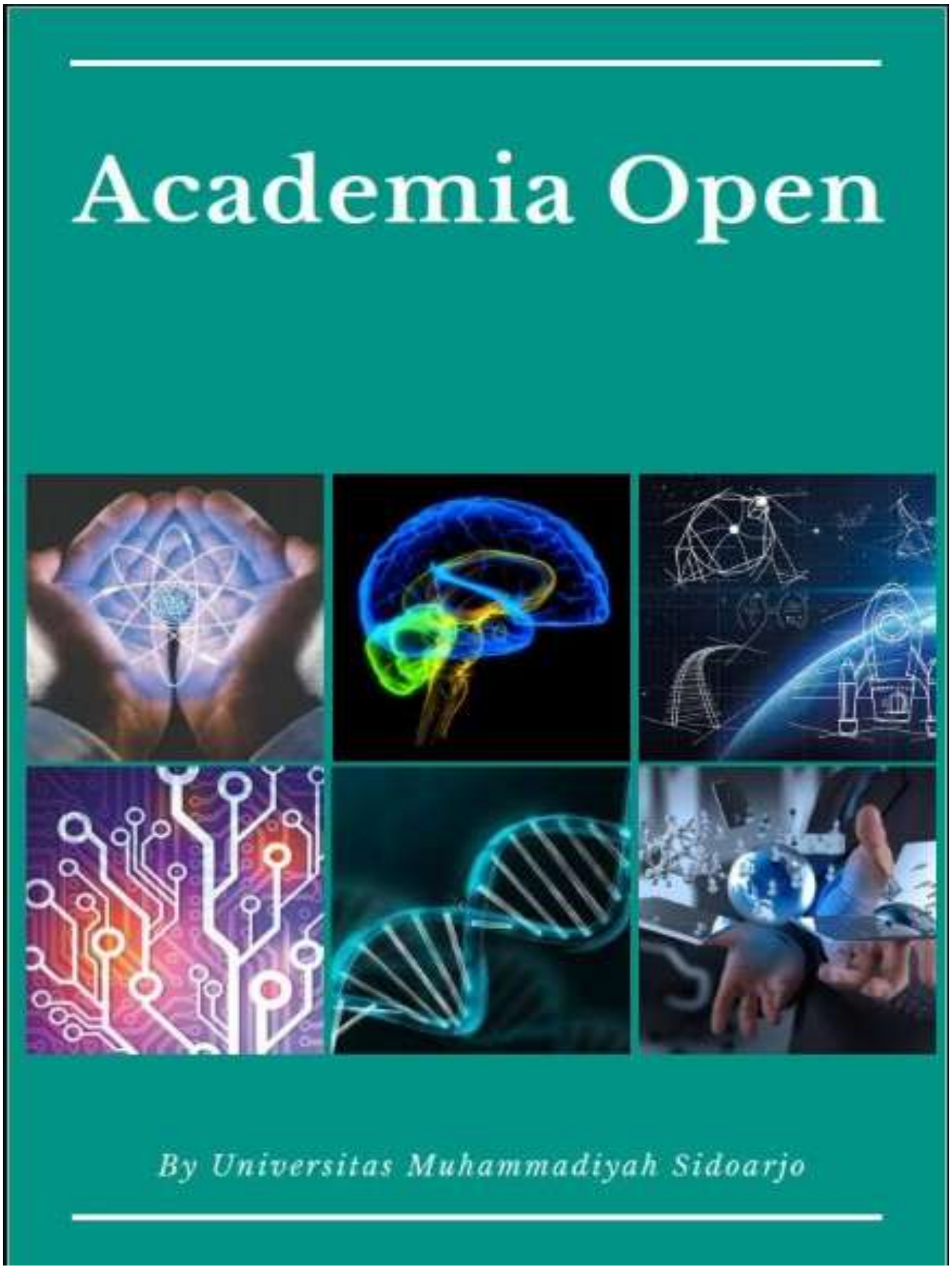


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# Table Of Contents

**Journal Cover** ..... 1
**Author[s] Statement** ..... 3
**Editorial Team** ..... 4
**Article information** ..... 5
Check this article update (crossmark) ..... 5
Check this article impact ..... 5
Cite this article ..... 5
**Title page** ..... 6
Article Title ..... 6
Author information ..... 6
Abstract ..... 6
**Article content** ..... 8


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**Academia Open**

Vol. 12 No. 1 (2027): June
DOI: 10.21070/acopen.12.2027.16303

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**Academia Open**

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# Mapping Multiple Representations and Critical Thinking Patterns in Physics Education

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## Abstract

**General Background:** Developing critical thinking skills is essential in physics education because abstract phenomena require students to interpret, analyze, evaluate, and draw evidence-based conclusions. **Specific Background:** Multiple representations combining verbal, visual, graphical, tabular, and mathematical formats are widely integrated with instructional strategies and digital media to support conceptual reasoning. **Knowledge Gap:** However, existing findings remain scattered across diverse contexts, leaving the overall research direction, implementation patterns, and assessment alignment unclear. **Aims:** This systematic literature review and bibliometric study examined publication trends, instructional applications, thematic relationships, and keyword developments regarding multiple representations and critical thinking in physics learning from 2021 to 2026. Following PRISMA 2020 guidelines, 17 eligible articles were selected from 1,000 Google Scholar records via Publish or Perish and analyzed using content analysis and VOSviewer. **Results:** Publications fluctuated between 2021 and 2026, while classroom applications frequently combined multiple representations with inquiry, collaboration, Android comics, e-books, and augmented reality. Bibliometric mapping positioned physics as the central node connected to critical thinking, 3D simulations, authentic assessment, and 21st-century skills, with recent thematic shifts toward collaboration and 21st-century education. Notably, reviewed studies exhibited inconsistent reporting of critical thinking indicators and limited quantitative gain data. **Novelty:** This study integrates content synthesis with bibliometric mapping to expose the gap between representational media use and explicit cognitive assessment. **Implications:** Future physics instruction and multi-database reviews should explicitly align inter-representational translation activities with clearly defined indicators and valid assessment instruments.

## Highlights

- Seventeen reviewed articles from 2021 to 2026 showed fluctuating annual output alongside growing integration of augmented reality, e-books, and Android media.
- Bibliometric clusters revealed a temporal shift from mobile-based analysis toward collaborative learning and twenty-first-century competencies.
- Reviewed literature lacked consistent indicator reporting and explicit explanations of how learners translate information across verbal, visual, graphical, and mathematical formats.

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**Keywords**

Multiple Representations; Critical Thinking; Physics Education; Systematic Literature Review; Bibliometric Analysis

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## INTRODUCTION

In science education, particularly physics, students are expected to understand a variety of phenomena that are often abstract in nature and therefore difficult to observe directly. Students rely not only on their ability to understand concepts and memorize facts, but also on their ability to interpret, analyze, evaluate, and draw conclusions based on the information they acquire during the learning process. These activities are related to critical thinking skills; therefore, the development of critical thinking skills is essential in physics education. Critical thinking is a higher-order cognitive skill that involves the ability to manage, analyze, evaluate, and reflectively use available information to draw conclusions [1]. This skill is important because learning physics requires reasoning, not just understanding concepts and memorizing formulas. In physics education, critical thinking skills are essential because students will be confronted with a variety of information, phenomena, and problems that will require them to analyze, evaluate, and draw conclusions [2]. Physics phenomena cannot be fully understood through a single representation alone, because the same phenomenon can convey different complementary yet information. In physics education, various forms of representation are used to illustrate concepts and phenomena, such as verbal descriptions, diagrams, graphs, symbols, and mathematical equations [3]. Students may have difficulty interpreting or making connections between different representations. These difficulties can hinder students' ability to identify relationships between physical quantities, interpret phenomena, and use the information they have obtained to solve problems. The study's findings indicate that students' critical thinking skills still fall into the low category, particularly their ability to analyze information, provide reasons based on information, and interpret. This challenge highlights the need for a teaching approach that provides students with opportunities to learn physics through various forms of representation. Multirepresentation involves presenting instructional material in a variety of different yet complementary forms of representation, so that using multiple representations can help students understand complex concepts [4]. A multirepresentational approach can provide students with opportunities to practice their abilities to interpret, analyze, evaluate, compare, and connect the information they have learned. Multirepresentation enables students to maximize their learning experience by helping them view physics concepts from different perspectives, explaining the relationships between concepts, and assisting them in the problem-solving process. The development of critical thinking skills With multiple representations, students will be required to interpret information, identify relationships among representations, compare information, analyze it, and draw conclusions based on the information obtained.Multiple representations and critical thinking skills are equally important in physics education; therefore, it is necessary to understand how the use of multiple representations contributes to the development of critical thinking skills.

Several studies indicate that the use of multiple representations in physics has been widely adopted to help students understand concepts and solve problems. The use of representations such as verbal, pictorial, graphical, tabular, and mathematical representations can help students gain information from various perspectives and make connections between them. In addition to studies focusing on conceptual understanding, some studies have linked multiple representations to critical thinking skills. A specific study presented multirepresentation as a means of enhancing students' critical thinking skills and attitudes during physics instruction [5]. This confirms that multirepresentation can engage thinking processes such as interpreting information, analyzing, and drawing conclusions. The study combined multirepresentation with a creative problem-solving model to develop critical and creative thinking skills [6]. The findings of these studies demonstrate the interrelated contributions of multiple representation and critical thinking skills. The development of multirepresentation has also been integrated with technology and learning media. A study by Rahmayani et al. (2024) [7] developed an e-book integrated with STEM-based augmented reality to support critical thinking skills and multirepresentation skills in physics learning. Overall, previous research has extensively examined multiple representations in physics learning, including representational forms, learning approaches, and student learning outcomes. Some studies have also focused on conceptual understanding or problem-solving skills, or examined the development of critical thinking skills. Several studies have also demonstrated the relationship between multiple representations and critical thinking skills, whether integrated with learning models, approaches, or technology.

Research on multiple representations in physics learning has been growing and showing positive results for diverse student abilities. This research has begun to integrate diverse learning approaches and models, the use of media and teaching materials, and a focus on different student abilities and characteristics. This diversity results in scattered findings across various research contexts, thus not providing a comprehensive picture of how multiple representations play a role in developing critical thinking skills in physics learning.Diani et.al[8] looking for trends, challenges and opportunities for using multiple representations in science learning. Rasyid et al.,[9] have also conducted a systematic literature review focused on efforts to improve multi-representation skills in physics learning. Systematic studies that have been conducted on multi-representation have mostly discussed the development of multi-representation in science learning [8]. However, the findings reported in various studies are still scattered, making it difficult to gain a complete understanding of how multi-representation is involved in the development of students' critical thinking skills in physics learning. Therefore, a systematic literature review is needed to identify and analyze existing evidence related to the forms of multi-representation used, how to implement multi-representation, and how it contributes to students' critical thinking skills as reported in previous studies.

Therefore, this study will be conducted to gain a deeper understanding of the role of multiple representations in developing students' critical thinking skills in physics learning. The novelty of this study lies in the systematic synthesis to map the development of publications, research themes, and the use of multiple representations that can support the development of critical thinking skills. This study aims to provide an overview of the direction of research development, the relationship between multiple representations and critical thinking skills, the implementation of the use of multiple representations to support critical thinking skills, and opportunities that can still be developed. In achieving these objectives, this study will be directed to answer the following research questions: (RQ1) How is the development of research publications on multiple representations and critical thinking skills in physics learning based on the year of publication? (RQ2) How will multiple


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Vol. 12 No. 1 (2027): June
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representations be implemented in learning to support the development of critical thinking skills? (RQ3) How are the developments and relationships between research themes on multiple representations and critical thinking skills over time? (RQ4) What are the main themes and keywords that are developing in research on multiple representations and critical thinking skills?

# METHOD

This research will utilize the Systematic Literature Review (SLR) method, which will then be combined with bibliometric analysis. SLR is used to identify, select, and review research findings related to critical thinking and multi-representation skills, particularly in physics learning. Bibliometric analysis, on the other hand, is used to assess research developments and to identify relationships between themes and keywords that will emerge within the field of study. The literature review process will adhere to the PRISMA 2020 guidelines, which include identification, screening, assessment, eligibility, and selection of articles for analysis.

The data for this study were obtained using the Publish or Perish software from the Google Scholar database. Publish or Perish (PoP) is used to assist in the process of searching, collecting, and managing data from articles found. The search will be conducted four times with different keyword combinations to obtain relevant articles. The first search uses a combination of the keywords "multiple representations," "critical thinking," and "physics" for the years 2021-2026. Subsequent searches will be conducted with variations of keywords that still represent the three main concepts of the study, namely ("multiple representations" OR "multiple representation approach" OR "multirepresentational" OR "multirepresentations") AND ("critical thinking skills" OR "critical thinking ability" OR "critical thinking") AND ("physics learning" OR "physics education"). Articles found based on keywords will be explored in RIS/CSV format, which will then undergo a selection and analysis process.

Use software VOSviewer developed by van Eck and Waltman (2010) was used to obtain data on the relationships between keywords, citation relationships and the development of the selected research topic.To determine which articles to use in the research, the search results will be determined based on inclusion and exclusion criteria, ensuring that the articles analyzed are relevant to the research objectives and focus. Details of the selection criteria can be seen in Table 1.

**Table1.***Inclusion and Exclusion Criteria*

| Criteria | Inclusion | Exclusion |
|---|---|---|
| Publication Year | 2021-2026 | < 2021 |
| Publication Type | Research journal articles | Thesis, proceedings, books |
| Research Topics | Discussing multiple representations and critical thinking skills | Not relevant |
| Field of study | Physics Learning | Besides Physics |
| Article Access | Full text available | Not available |

The article selection process will be carried out in stages according to the PRISMA 2020 process. The first stage, the identification stage, will collect articles from the PoP search results based on keywords and year range. The PoP search results will then be checked for duplicate articles based on the article titles. Articles that have undergone the deduplication process will then be selected based on the title and abstract. At this stage, articles that do not meet the established criteria will be removed, and then a full-text check will be conducted to ensure the articles' suitability to the criteria and research focus. Articles that have met all established criteria will then be selected for analysis.

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Vol. 12 No. 1 (2027): June
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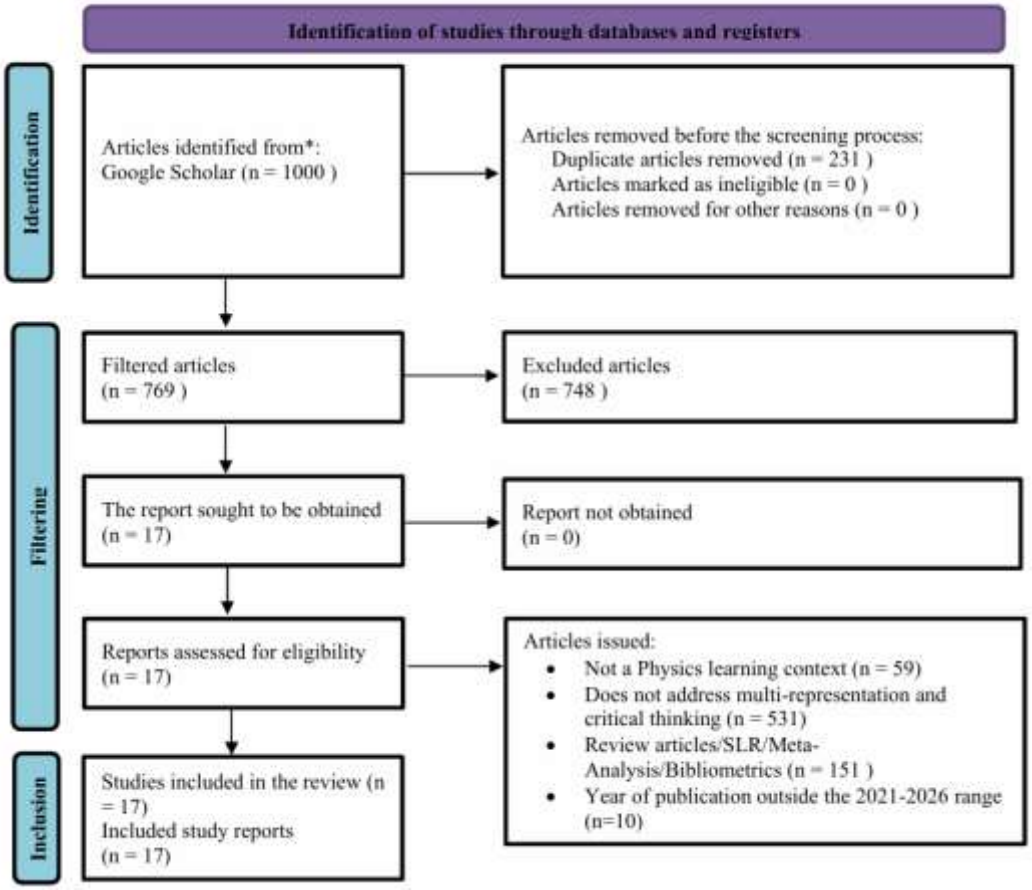
**Picture1.** *Flowchart of the article selection process based on PRISMA 2020*




Articles submitted after the selection stage will then be extracted to obtain information that will answer the research questions. Analysis will be conducted through descriptive analysis, content analysis, and finally bibliometric analysis. Descriptive analysis is conducted to obtain an overview of research developments based on the year of publication and other bibliographic information. Content analysis will be conducted to identify how multiple representations are used in physics learning and also related to students' critical thinking skills. Bibliometric analysis will be conducted using VOSviewer software. This analysis aims to visualize the relationships between keywords and research themes that have developed so far. The analysis will be tailored to each research question. RQ1 will be analyzed through the development of the number of publications and bibliographic information. RQ2 will be analyzed through content analysis of the application of multiple representations in physics learning. RQ3 will be analyzed through mapping and interpreting the relationships between article themes. RQ4 will be analyzed using keyword mapping through VOSviewer to identify the main themes and keywords that have developed.

## RESULTS AND DISCUSSION

A. Development of Research Publications

The analysis of 17 articles provides an overview of the development of research publications discussing multi-representation and critical thinking skills in physics learning over a five-year period, from 2021 to 2026. The analysis will be conducted on selected articles that meet all inclusion criteria in the screening process. The distribution of publications has shown that research related to multi-representation and critical thinking skills in physics learning exhibits a fluctuating pattern. The highest number of articles was seen in 2026, while the lowest number was in 2022. This difference indicates that the contribution of publications in the literature review to be analyzed was not evenly distributed throughout the research period. However, this pattern only provides an overview of the distribution of articles that have met the inclusion criteria in the study and cannot be used directly to conclude the overall development of research in this field. The distribution of articles by year can be seen in Figure 2.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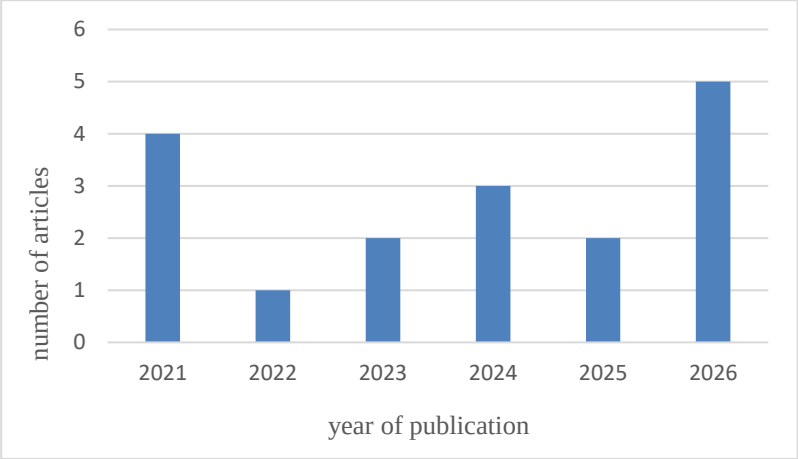
**Picture2.** *Distribution of Publications by Year*




Based on Figure 2, the distribution of publications provides an overview of the distribution of research relevant to the study's focus within the predetermined period. However, the number of articles in a given publication year cannot directly reflect the quality of the research or the effectiveness of multiple representations in supporting the development of critical thinking skills in physics learning. Therefore, this development analysis still needs to be supplemented by examining the forms of representation used, the learning strategies implemented, and how the research measures critical thinking skills.

B. Application of Multirepresentation to Support Critical Thinking Skills

The implementation of multiple representations in physics learning is a crucial aspect to analyze in this study. The analysis was conducted with the aim of identifying the forms of representation used in each article, how these representations are applied in learning activities, and how they relate to critical thinking skills. Based on the final 17 articles analyzed after meeting the inclusion criteria, the discussion in this section will focus more on the patterns of multirepresentation implementation and how this process impacts students' critical thinking skills in physics learning.

Multiple representations in physics learning can apply various forms of representation to present information, for example, verbal, visual, graphic, simulation, tabular, and mathematical representations. The application of these various representations is not only seen from the number of representations used, but also from how the relationships between representations help students understand a physics concept. Therefore, the analysis of the selected articles will pay attention to how students use, compare, interpret, and connect representations to build a conceptual understanding of physics. A synthesis of the application of multiple representations in supporting critical thinking skills can be seen in Table 2.

**Table2.** *Application of Multirepresentation in Supporting Critical Thinking Skills*

| No. | Author (Year) | Form of Representation | Strategy & Media | Critical Thinking Aspects |
|---|---|---|---|---|
| 1 | Fadillah Rahmayani, Heru Kuswanto, Anggi Datiatur Rahmat (2024) | Verbal, visual, and mathematical. | STEM-based AR-integrated e-book | Identifying problems, Formulate problems, Give logical arguments and Analyze and make decisions |
| 2 | Temitope Gabriel Ogunyemi, Hakeem Olanrewaju Akintoye, Tunde Owolabi (2025) | Mathematical, verbal or linguistic, visual, pictures and diagrams, tables, graphs, symbols, and audio and visual media | Multiple Representations (MR), which is compared with the conventional lecture method. | Not written in detail, only explained using the Physics Critical Thinking Test (PCTT) |
| 3 | Muhammad Minan Chusni, Suherman (2021) | Graphs, tables, images, and other forms of verbal or written communication as a means of presenting scientific information | Multi-representation based authentic assessment | Clarity, interpretation, analysis, evaluation, reason, and self-regulation; the article states seven indicators |
| 4 | Elminasari Panjaitan; Rita Juliani; Nurliana Marpaung (2021) | Verbal, mathematical, pictorial, and graphical | Group Investigation (GI) cooperative learning model combined with multi-representation. | Operational indicators are not explicitly detailed; analytical, reflective, argumentative, and evaluative thinking |
| 5 | Siska Desy Fatmaryanti, Eko Setyadi Kurniawan, Yusro Al Hakim, | Verbal, graphic, diagram, picture, and mathematical form | Arduino experiment-based multi-representation learning | Measuring the 4Cs, critical thinking aspects: analyze leading questions, gather information, evaluate |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| No. | Author (Year) | Form of Representation | Strategy & Media | Critical Thinking Aspects |
|---|---|---|---|---|
| | Sarwanto, Desy Luthfianti Ulfah (2024) | | | information, and consider alternative answers to leading questions. |
| 6 | AA Anggraeni, IW District, and U. Rosidin (2021) | Multiple representations at each stage of STEM; specific forms not systematically detailed in research descriptions | A STEM approach integrated with multiple representations and 21st century learning | Critical thinking is discussed as a potential benefit of multiple representations, but specific indicators and direct measurements are not reported. |
| 7 | Bayu Aji Wicaksono and Heru Kuswanto (2026) | AR-assisted graphical, verbal/textual, mathematical, and 3D visuals; the representation variable measured specifically is the graphical representation ability | Guided Inquiry Learning assisted by e-books integrated with Augmented Reality (AR). | Understand the problem, analyze the problem, plan the solution, evaluate the solution, draw conclusions, and reinterpret. |
| 8 | Muhammad Matori Rahman, Aris Doyan, and Sutrio (2021) | Verbal, pictorial, graphic, and mathematical | A video-assisted multirepresentation learning approach | Providing arguments and drawing conclusions identified explicitly |
| 9 | Anissa Maghfiroh and Heru Kuswanto (2022) | Vector representation capabilities and visual comics | Android-assisted physics comic that integrates traditional benthic games | Analyze information about parabolic motion and conclude results based on the given data or conditions. |
| 10 | Sinta Marsila, Irwan Koto, and Dedy Hamdani (2026) | Visual representation in the form of 3D objects and visualization of static fluid phenomena based on Augmented Reality (AR) | Problem-Based Learning (PBL) combined with AR Assemblr Edu media. | Elementary clarification, basic support, inference, advanced clarification, strategies and tactics |
| 11 | Fajar Kurnianto; Anggi Datiatur Rahmat; Heru Kuswanto (2024) | Graphics, verbal/text, 3D visuals. Specifically graphics | Physics learning using traditional games integrated with Augmented Reality (AR) | Interpretation of problems, analysis of facts, evaluation, creating a conclusion |
| 12 | Ahmad Priyadi and Heru Kuswanto (2023) | Visual/images, verbal/text and mathematical media are also equipped with learning videos. | Android-based physics comic with the context of Gajah Mungkur Dam | Analyze facts, formulate problems, put forward logical arguments, clarify and draw conclusions |
| 13 | Milisa Milisa, Saiyidah Mahtari, and Suyidno Suyidno (2026) | Verbal, graphic, mathematical, and visual | Multi-representation based Guided Inquiry | Interpretation, prediction, analysis, conclusion |
| 14 | Bambang Supriadi, Dyah Arum Arimurti, Dimas Halim Perdana, Kiki Dinda Octari, and Tamara Pingki (2026) | Focuses on mathematical, verbal representation frameworks | Mathematical representation-oriented rotational dynamics learning using the Gauss–Jordan method. | One that is measured but not clearly detailed |
| 15 | Ujang Fahmi Abdillah (2026) | Verbal, mathematical, graphic, pictorial | Integration of TPACK (Technological Pedagogical Content Knowledge) and multi-representation in virtual practicum | One that is measured but not clearly detailed |
| 16 | Fauzi Bakri, Tiara Nurmalita Sani, Handjoko Permana (2023) | AR-based verbal, visual, tabular, graphical, mathematical and animation | Textbook development using the Dick and Carey model with contextual learning with multiple representations | Critical thinking as one of the 4C components |
| 17 | Jamaludin; Altje Latununuwe; Gazali Rachman; Ashari Bayu P. Dulhasyim (2025) | Visual, mathematical, and verbal | Multi-representation learning based on marine-archipelagic context | Measured together with communication, collaboration and creative skills |

Based on the synthesis results, 17 articles will be analyzed as a basis for discussing the implementation of multiple representations in supporting the development of critical thinking skills and the relationship and development of the


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research theme. The table above contains variations in the forms of representation used, the learning strategies applied, the media used, and how aspects of critical thinking were studied. The application of multiple representations shows variations in the forms of representation and learning strategies used. Some studies have combined several forms of representation such as verbal, visual, and mathematical, while others have used a combination of graphs, tables, images, diagrams, media, and symbols. This wide variety indicates that multiple representations are not only applied as a means of conveying information but can also be part of learning designs and research on critical thinking skills.

Multiple representations can be used as an approach to presenting concepts or information, where information is presented in various forms of representation, such as verbal, visual, graphic, tabular, and mathematical, so that students can gain a deeper understanding. This finding is also in line with Lichtenberger et al.,[10]This study examines how multiple external representations are presented in physics learning, thus providing a foundation for understanding that the design and organization of representations are essential to learning. The application of multiple representations in physics learning has shown variations in connecting representations to learning activities. Based on the articles analyzed, multiple representations are utilized not only to present physics concepts in various forms of representation but also to integrate them with strategies and media that support student engagement in learning.[11], [12]This integration can also be seen through the use of digital technology and the use of various learning approaches such as augmented reality, STEM approaches, cooperative learning, and guided inquiry.[5], [7], [13], [14], [15], [16], [17].Some studies have also integrated contextual learning such as regional culture or games.[18], [19], [20], [21]This diversity demonstrates that multiple representations can be integrated with various learning approaches, digital media, experimental activities, and contextual activities. Therefore, the implementation of multiple representations is not limited to a single learning model or specific media type. However, the use of various forms of representation does not guarantee the development of critical thinking skills. Their contribution needs to be understood through learning activities that guide students in interpreting information, connecting evidence, analyzing physics problems, and how students construct accountable conclusions.

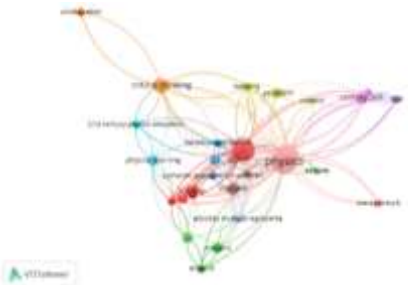
Based on the research synthesis, it was also found that the relationship between multiple representations and critical thinking skills has varying emphases. Some studies have explicitly included critical thinking indicators, while others have emphasized representational skills or positioned critical thinking skills as a useful skill in learning. This distinction is significant because the presence of multiple representations in learning activities is not necessarily accompanied by direct measurement of critical thinking skills. Therefore, research results need to be interpreted by considering the research objectives, the indicators to be used, and how these skills will be measured.

From a learning perspective, multiple representations have the potential to support critical thinking skills when students not only receive information in different forms but also are asked to connect and evaluate that information. For example, students are asked to observe a physical phenomenon, analyze the observations in tabular form, interpret graphs, and then explain the relationships found through verbal and mathematical argumentation. This series of activities can provide opportunities to practice analysis, interpretation, evaluation, and drawing conclusions. This implication suggests that developing multirepresentation-based learning needs to consider not only the completeness of the representations but also the integration between the representations and how questions guide students' thinking processes. However, the effectiveness of multirepresentation implementation still needs to be confirmed through empirical research results that explicitly measure critical thinking skills, rather than simply linking discussion to critical thinking skills.

C. Relationships and Theme Development

Based on the results of bibliometric analysis using the VOSviewer application in Figure 3, the keyword co-occurrence network) describes a pattern of relationships and mapping of themes that are interconnected in the literature related to the implementation of multi-representation in supporting students' critical thinking skills, especially in physics learning. This visualization is divided into four main clusters represented by different node colors, the size of the node will describe the frequency of keyword occurrence, while the thickness of the connecting line will describe the strength of the relationship between variables.

**Picture3.** *Keyword Co-Occurrence Network*



Based on Figure 3, the first cluster is marked in red, centered on the keywords "physics," "3D simulation," "student," "validity," and "authentic assessment instrument." The existence of this cluster demonstrates that the primary focus of researchers in implementing multi-representation is the development of interactive media based on 3D simulations, accompanied by testing the validity of authentic assessment instruments. The use of 3D here allows students the opportunity to explore abstract physics phenomena through various forms of representation. Hahn and Klein[22], examines the use of simulations and drawing activities in vector field material. This study provides an example that representation can be combined with certain activities, not just for the presentation of information. The second cluster, represented by orange, shows the dominance of the keywords "critical thinking" and "collaboration." The critical thinking node has a fairly large number of nodes and is related to almost all other clusters. This indicates that critical thinking skills have a position as the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main dependent variable in this research trend. The close relationship between "critical thinking" and "collaboration" shows that the development of critical thinking skills in students through multi-representation tasks will be more optimal when combined with collaborative learning.

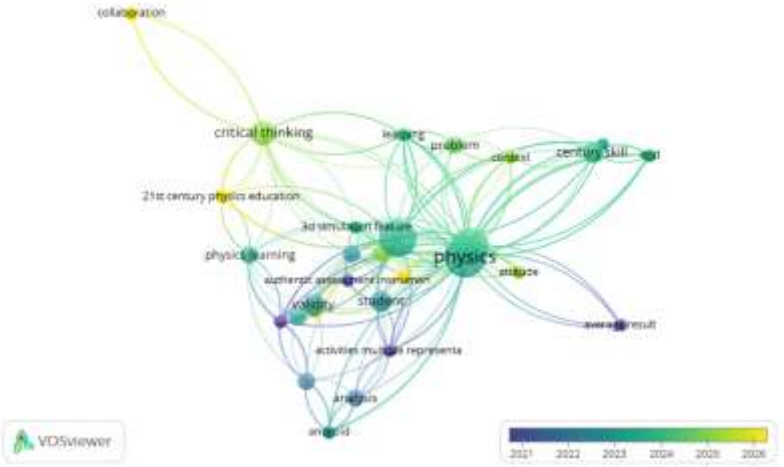
The three clusters are represented by the color blue, and blue contains the keywords "android," "analysis," "physics learning," and "multiple representation activities." This keyword relationship indicates the development of learning media trends that are starting to shift to digital platforms based on mobile devices (mobile/android). Android-based applications enable students to conduct multi-representation analysis activities, such as connecting graphs, diagrams, and mathematical equations, both independently and in groups. Finally, there is a purple cluster represented by the keywords "century skill" and "21st-century physics education." The relationship in this cluster indicates a broader context, where the implementation of multi-representation and the development of critical thinking skills in physics learning is a response to the demands of qualifications in education in the 21st century.

Overall, the pattern of inter-cluster relationships in this study shows that research related to multiple representations in physics learning has evolved from simply using printed teaching materials to utilizing interactive technologies such as 3D simulations and the use of Android applications which are then designed to measure and improve students' critical thinking abilities and 21st-century skills through valid assessments.

D. Keyword Development

The relationship between research themes regarding physics learning shows variations in the time of keyword appearance during the 2021-2026 study period, as seen in Figure 3.

**Picture4.** *Overlay Visualization*




Based on the overlay visualization in Figure 4, it shows the variation in the average publication year for the identified keywords. Keywords such as analysis and android tend to have a blue to blue-green color, while the keywords critical thinking, collaboration, and 21st-century physics education show a color slightly closer to yellow. This color difference indicates a variation in publication time between themes in the collection of articles to be reviewed. This finding has illustrated that research attention in the analyzed period covers a variety of focuses ranging from the analysis and utilization of Android-based media to themes related to critical thinking skills, collaboration, and physics education in the 21st century. The development of themes in this mapping shows the relationship between physics learning, the use of technology-based media, and critical thinking skills.Ate et.al.,[23]also highlighted the opportunities for using digital technology and the need to expand the multi-representational research approach in physics learning. This shared focus demonstrates the relevance of technology and multi-representational themes in physics learning.

E. Research Gap

Based on the analysis of 17 articles, research conducted on multiple representations in physics learning has applied various forms of representation, such as verbal, visual, tabular, graphic, and mathematical, which are then combined with learning strategies and media. However, based on the information identified in the analyzed articles, research attention has not been consistently directed at the process of students connecting one form of representation to another. The use of various forms of representation in physics learning has not shown any in-depth process of translation, integration of information, and reasoning between representations. Research also discusses the relationship between the application of multiple representations and critical thinking skills. Some studies have clearly stated such aspects as interpretation, analysis, evaluation, argumentation, and drawing conclusions. However, in several articles, critical thinking skills are only mentioned as a measured variable, a component of competence, or an expected benefit without clearly stating the indicators of the ability. This difference indicates the need for research that not only states that multiple representations can support critical thinking skills but also provides a clear explanation of the aspects of critical thinking that will be targeted and how those aspects will be measured. The need for clear measurement is also a concern in Chusni and Suherman's research.[24]who developed an authentic, multi-representation-based assessment instrument to measure students' critical thinking skills. The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research suggests that multi-representation is not only used to present information but can also be used in constructing assessment instruments. These findings reinforce the importance of distinguishing between the use of multi-representation as a learning approach and as a basis for presenting questions to measure students' critical thinking skills.

Based on these findings, research opportunities lie in the development of multi-representation-based physics learning explicitly designed to train and measure critical thinking indicators. Future research should clarify not only the representational forms and media used, but also how students move from one representation to another when analyzing physical phenomena. Furthermore, assessment instruments need to be aligned with the targeted critical thinking indicators to more clearly examine their contribution to learning. This direction could strengthen the relationship between multi-representation learning design, student cognitive activity, and the measurement of critical thinking skills in physics learning.

## CONCLUSION

The findings of this study have been summarized to answer the following four research questions. First, regarding publication development, an analysis of 17 articles published during the 2021-2026 period reveals a fluctuating publication pattern. The highest number of articles was published in 2021 and 2026, while the lowest number of published articles occurred in 2022-2023. This pattern demonstrates that research related to multi-representation and critical thinking skills in physics learning has emerged throughout the study period, although the number of articles has not shown a consistent increase from year to year. Second, the application of multiple representations supports critical thinking skills in physics learning. The synthesis results have shown that multiple representations are used through a variety of representation forms such as verbal, visual, graphic, tabular, and mathematical. Its use has been integrated with various learning strategies and media such as inquiry, collaboration, digital comics, e-books, and augmented reality. Critical thinking skills measured include interpretation, analysis, argumentation, evaluation, prediction, and drawing conclusions. However, the clarity of the critical thinking indicators measured varies from article to article. Some articles explicitly explain the indicators being measured, while others do not. Third, the relationship between research themes. The keyword network mapping shows that physics is a central node connected to several themes, including critical thinking, learning problems, context, students, and 3D simulation features. This relationship indicates that research in this study relates physics learning to the development of critical thinking skills, problem solving, learning contexts, and the use of technology-based media. The results of this mapping complement the article analysis by demonstrating the interrelationships between themes, although the relationships in the map cannot directly prove the effectiveness of multiple representations in supporting critical thinking skills. Fourth, regarding emerging themes and key keywords. The overlay visualization shows variations in the average year of keyword publication between 2021 and 2026. Keywords such as android and analysis appear to have a relatively earlier color, while critical thinking, collaboration, and 21st-century physics education tend to show a more recent color. This finding indicates temporal variation in the focus of themes emerging in the dataset, ranging from digital media use and analysis to their relevance to critical thinking and 21st-century competencies. However, this pattern should be understood as a trend based on the average year of keyword appearance, not evidence that newer themes have replaced older ones.

Conceptually, the synthesis findings also indicate that measuring critical thinking skills requires alignment between the type of assessment instrument and the indicators being measured. The authentic assessment based on multiple representations, as identified in the study by Chusni and Suherman, illustrates the use of an instrument to assess aspects of clarity, interpretation, analysis, evaluation, reasoning, and self-regulation. Meanwhile, Ogunyemi et al. employed the Physics Critical Thinking Test (PCTT), but did not describe its indicators or question formats in detail. Based on these findings, multiple-representation-based essay questions may be considered for assessing students' interpretation and analysis skills, as they allow students to explain relationships among representations and provide reasoning based on the available information. However, the reviewed studies do not provide sufficient empirical comparisons to establish that essay questions are more effective than multiple-choice questions in measuring these skills. Overall, this study indicates that multiple representations play an important role in physics education research related to critical thinking skills, both through the use of various forms of representation and their integration with learning strategies and instructional media. The identified research gaps primarily concern the inconsistent descriptions of critical thinking indicators and the insufficiently detailed explanations of the relationship between multiple-representation activities and the critical thinking processes being developed. Furthermore, the reviewed studies provide limited explanations and comparisons of the assessment instruments used to measure each critical thinking indicator.

This study also has methodological limitations because the literature search relied on only one database, Google Scholar, accessed through Publish or Perish. The use of a single database may have resulted in relevant articles being overlooked, while the selection process based on predetermined criteria may have introduced publication and selection biases. In addition, the analysis was limited to 17 articles; therefore, the bibliometric mapping and synthesis may not fully represent the overall development of research on multiple representations and critical thinking skills in physics education. Accordingly, the findings should be interpreted within the scope of the sources and selection criteria employed in this study. Future research should design learning activities that explicitly explain the relationships among forms of representation, students' cognitive activities, and the critical thinking indicators being assessed, so that the contribution of multiple representations to the development of critical thinking skills in physics education can be examined more systematically. Further reviews are also recommended to use multiple scholarly databases, expand the coverage of relevant articles, and apply transparent selection and reporting procedures to minimize potential publication and selection biases.

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## References

[1] P. Andreucci-Annunziata, A. Riedemann, S. Cortés, A. Mellado, MT del Río, and A. Vega-Muñoz, "Conceptualizations and instructional strategies on critical thinking in higher education: A systematic review of systematic reviews," 2023,Frontiers Media SAdoi: 10.3389/feduc.2023.1141686.
[2] M. Safaraet al., "Journal of Educational, Cultural and Psychological Studies The Role of Social Intelligence and Resilience in Explaining 61 Students' Distress Tolerance: A Study during Covid-19 Pandemic (Il ruolo dell'intelligenza sociale e della resilience nello spiegare la tolleranza al disagio degli studenti: uno studio durante la pandemica di Covid-19) Hate Speech Recognition: The Role of Empathy and Awareness 101 of Social Media Influence," 2023. [Online]. Available: https://www.ledonline.it/ECPS-Journal/
[3] N. Munfaridah, L. Avraamidou, and M. Goedhart, "The Use of Multiple Representations in Undergraduate Physics Education: What Do we Know and Where Do we Go from Here?,"Eurasian Journal of Mathematics, Science and Technology Education, vol. 17, no. 1, pp. 1–19, 2021, doi: 10.29333/ejmste/9577.
[4] S. Ainsworth, "The functions of multiple representations,"Comput. Educ., vol. 33, no. 2–3, pp. 131–152, 1999, doi: 10.1016/s0360-1315(99)00029-9.
[5] TG Ogunyemi, HO Akintoye, and T. Owolabi, "Multiple Representations as Tools for Enhancing Students' Critical Thinking and Attitudes Towards Physics,"Faculty of Natural and Applied Sciences Journal of Mathematics, and Science Education, vol. 6, no. 4, pp. 1–15, May 2025, doi: 10.63561/fnas-jmse.v6i4.906.
[6] S. Fathonah, E. Cahyono, S. Haryani, S. Sarwi, and NH Lestari, "Application of Multirepresentation-Based Creative Problem-Solving Learning Models to Improve Critical and Creative Thinking Skills for Students,"International Journal of Cognitive Research in Science, Engineering and Education, vol. 12, no. 1, pp. 185–200, Apr. 2024, doi: 10.23947/2334-8496-2024-12-1-185-200.
[7] F. Rahmayani, H. Kuswanto, and AD Rahmat, "Development of E-Book Integrated Augmented Reality Based on STEM Approaches to Improve Critical Thinking and Multiple Representation Skills in Learning Physics,"International Journal of Information and Educational Technology, vol. 14, no. 4, pp. 632–641, 2024, doi: 10.18178/ijiet.2024.14.4.2087.
[8] R. Dianiet al., "Trends, challenges, and opportunities of Multiple-Representation in Science learning: a systematic literature review," Review of Science, Mathematics and ICT Education, vol. 18, no. 1, pp. 29–52, 2024, doi: 10.26220/rev.4657.
[9] F. Rasyid, J. Jumadi, and PK Hawur, "How to Improve Multiple Representation Skills in Physics Learning: A Systematic Literature Review,"Journal of Science Learning, vol. 8, no. 1, pp. 25–40, March. 2025, doi: 10.17509/jsl.v8i1.76514.
[10] A. Lichtenberger, T. Kokkonen, and L. Schalk, "Learning with multiple external representations in physics: Concreteness fading versus simultaneous presentation,"J. Res. Sci. Teach., vol. 61, no. 9, pp. 2258–2290, Nov. 2024, doi: 10.1002/tea.21947.
[11] SD Fatmaryanti, ES Kurniawan, Y. Al Hakim, Sarwanto, and DL Ulfah, "Enhancing 21st Century Skills for Prospective Physics Teachers through Arduino-Based Multiple Representations in Learning Heat and Temperature,"Journal of Science Education Research, vol. 10, no. 4, pp. 1779–1786, Apr. 2024, doi: 10.29303/jppipa.v10i4.5315.
[12] A. Maghfiroh and H. Kuswanto, "Benthic Android Physics Comic Effectiveness for Vector Representation and Critical Thinking Students' Improvement,"International Journal of Instruction, vol. 15, no. 2, pp. 623–640, Apr. 2022, doi: 10.29333/iji.2022.15234a.
[13] E. Panjaitan, R. Juliani, and N. Marpaung, "Analysis of critical thinking skills of students on the topic of optical geometry," inJournal of Physics: Conference Series, IOP Publishing Ltd, 2021. doi: 10.1088/1742-6596/1811/1/012036.
[14] AA Anggraeni, IW District, and U. Rosidin, "The validity and practicality of the student worksheet using STEM-based multiple representations in physics learning," inIOP Conference Series: Earth and Environmental Science, IOP Publishing Ltd, Mar. 2021. doi: 10.1088/1742-6596/1796/1/012016.
[15] IK Mahardika and I. Wicaksono, "Implementation of Multirepresentation Based Physics Modules to Improve Students Critical Thinking Skills,"Journal of Education, Society and Behavioral Science, vol. 36, no. 10, pp. 72–79, Sept. 2023, doi: 10.9734/jesbs/2023/v36i101268.
[16] MM Rahman, A. Doyan, and S. Sutrio, "The Effectiveness of Video-Assisted Multi-Representation Learning Approach Devices to Improve Students' Critical Thinking Skills,"Journal of Science Education Research, vol. 7, no. Special Issue, pp. 56–60, Nov. 2021, doi: 10.29303/jppipa.v7ispecialissue.1063.
[17] S. Marsila, I. Koto, and D. Hamdani, "THE EFFECTIVENESS OF AUGMENTED REALITY-BASED PHYSICS LEARNING USING ASSEMBLR EDU ON STUDENTS' CRITICAL THINKING SKILLS", doi: 10.59052/eduphysics.vXiX.XXX.
[18] F. Kurnianto, AD Rahmat, and H. Kuswanto, "The Effect of Augmented Reality Integrated Traditional Game Nglarak Blarak to Improve Critical Thinking and Graphical Representation Skills,"Pegem journal of Education and Instruction, vol. 14, no. 2, Jan. 2024, doi: 10.47750/pegegog.14.02.41.
[19] A. Priyadi and H. Kuswanto, "THE ANDROID-BASED COMIC OF GAJAH MUNGKUR DAM: IMPROVING MATHEMATICAL REPRESENTATION AND CRITICAL THINKING ABILITIES,"J. Technol. Sci. Educ., vol. 13, no. 1, pp. 116–129, 2023, doi: 10.3926/jotse.1174.


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[20] F. Bakri, TN Sani, and H. Permana, "Physics Textbooks Feature Augmented Reality Technology-Based Media For Kinematics Material: Training 21st Century Skills For High School Students,"Current STEAM and Education Research, vol. 1, no. 1, pp. 13–22, Aug. 2023, doi: 10.58797/cser.010103.
[21] J. Jamaludin, A. Latununuwe, G. Rachman, and ABP Dulhasyim, "Optimizing 21st Century Skills Through Island-based Physics Multirepresentation Learning at Madrasah Aliyah Negeri 1 Maluku Tengah School,"Unram Journal of Community Service, vol. 6, no. 1, pp. 102–110, March. 2025, doi: 10.29303/ujcs.v6i1.751.
[22] L. Hahn and P. Klein, "The impact of multiple representations on students' understanding of vector field concepts: Implementation of simulations and sketching activities into lecture-based recitations in undergraduate physics,"Front. Psychol., vol. 16, 2025, doi: 10.3389/fpsyg.2025.1544764.
[23] O. Ate, P. Parno, and N. Munfaridah, "Multirepresentation in Physics Learning Research: A Content Analysis Review of Trends, Opportunities, and Challenges,"Journal of Science Education Research, vol. 9, no. 1, pp. 32–42, Feb. 2025, doi: 10.21831/jser.v9i1.72954.
[24] MM Chusni and S. Suherman, "Developing authentic assessment instrument based on multiple representations to measure students' critical thinking skills,"Momentum: Physics Education Journal, pp. 194–208, Jul. 2021, doi: 10.21067/mpej.v5i2.5790.


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