Indonesian Society for Science Educators
Journal of Science Learning
journal homepage: ejournal.upi.edu/index.php/jslearning

How to Improve Multiple Representation Skills in Physics Learning: A Systematic Literature Review

Fauziah Rasyid[1]*, Jumadi Jumadi[1], Proki Karandja Hawur[1]

[1]Magister of Physics Education, Faculty of Mathematics and Natural Science, Universitas Negeri Yogyakarta, Indonesia

*Corresponding author: fauziahrasyid.2023@student.uny.ac.id

ABSTRACT This study aims to explore the literature on learning interventions that can enhance students' multiple representation skills and identify indicators for assessing multiple representation abilities in physics education. Following the PRISMA procedure, the research is a systematic literature review using qualitative content analysis techniques. The applied procedure includes identification, screening, eligibility assessment, and article inclusion. Article searches were conducted through Scopus, ERIC, and SINTA using relevant keywords. Out of 669 articles selected based on inclusion and exclusion criteria, 26 articles were ultimately included and analyzed in this study. The findings indicate that interventions applied to improve multiple representation skills include teaching models, media, instructional materials, learning approaches, and instructional design tools. Teaching models such as Discovery Learning, Problem-Based Learning (PBL), STEM, and Blended Learning, when combined with technology-assisted media like ethnoscience, Augmented Reality (AR), and mobile applications, have been shown to significantly enhance students' multiple representation skills in physics education. Indicators for measuring multiple representation abilities are diverse, with key indicators involving the use of combinations of various representations, such as mathematical equations, graphic diagrams, and verbal explanations. This study emphasizes the importance of integrating teaching models with technology-assisted media and ethnoscience in physics education, which can significantly support the development of students' multiple representation skills.

Keywords Multiple representation, Physics learning, Representation skill, Systematic review, Systematic literature review.

1. INTRODUCTION

Physics is a crucial subject but often poses challenges for both students and teachers. These challenges arise due to its difficult subject with complex material and abstract concepts (Niyomufasha, Ntivuguruzwa & Mugabo, 2024; Pals, Tolboom & Suhre, 2023). One effective strategy to address these challenges is the use of multiple representations, which integrates various forms of representation to convey abstract concepts more concretely and enhance broader comprehension (Munfaridah, Avraamidou & Goedhart, 2021). Physics concepts can be represented in various ways, such as situational descriptions, symbolic expressions, graphs, images, and diagrams (Bollen, Van Kampen, Baily, Kelly & De Cock, 2017). These representations encompass graphical, mathematical, and verbal forms in physics (Treagust, Duit & Fischer, 2017). The use of multiple representations has proven to be an effective teaching strategy for deepening students' conceptual understanding in physics (Treagust, Won, & McLure, 2018). By combining different representations, students are enabled to experience physical phenomena or concepts more holistically (Geyer & Pospiech, 2019). Thus, the implementation of multiple representations assists students in understanding abstract concepts, facilitates knowledge transfer, and supports problem-solving (Niyomufasha, Ntivuguruzwa & Mugabo, 2024; Susac, Planinic, Bubic, Jelicic & Palmovic, 2023). Thus, employing multiple representations in physics is effective in concretizing abstract concepts, enhancing understanding, and supporting students' problem-solving abilities.

The use of multiple representations should ideally improve students' academic success in learning physics. However, its effective implementation requires students to have the ability to interpret and assimilate various forms of these representations (Treagust, Duit & Fischer, 2017). Students' understanding of physics is influenced by their ability to translate knowledge effectively across different

Received: 27 November 2024
Revised: 09 January 2025
Published: 29 March 2025

types of representations (Takaoğlu, 2024). The ability to understand, interpret, and communicate complex physics concepts effectively through various forms of representation refers to multiple representation skills (Fatmaryanti et al., 2024). This skill is essential for learning, problem-solving, and communication in science, particularly in physics, where multiple representations often serve as the foundation for understanding phenomena (McPadden & Brewe, 2017). To develop multiple representation skills, students require structured practice and guidance, enabling them to achieve a deeper understanding of the concepts being studied (Riechmann, Koenig & Rexilius, 2022). Utilizing multiple representations skills significantly supports students in comprehending and reinforcing their understanding of physics concepts.

Although multiple representation skills are essential, students often face difficulties in representing physics concepts across various types of representations (Susac, Planinic, Bubic, Jelicic & Palmovic, 2023). Research indicates that students encounter challenges in physics representation tasks presented in textbooks (Aregehagn, Lykknes, Getahun & Febri, 2023). Additionally, students often struggle to apply multiple representation approaches, such as understanding abstract concepts, using unfamiliar types of representations, and working with free-body diagrams, including constructing and interpreting them effectively (Niyomufasha, Ntivuguruzwa & Mugabo, 2024). Prior research also highlights differences in students' performance across various representation types, though no single type consistently proves to be the easiest for all students (Susac, Planinic, Bubic, Jelicic & Palmovic, 2023). When given the option to choose a type of representation, students tend to prefer pictorial forms over verbal, graphical, or mathematical representations; however, this preference does not necessarily lead to better problem-solving success (Susac, Planinic, Bubic, Jelicic & Palmovic, 2023). Students struggle not only with creating representations but also with using them effectively to solve problems.

Considering the importance of multiple representation skills and the difficulties associated with their use, as highlighted in the literature, researchers initiated a systematic review study to explore ways to enhance multiple representation skills in physics learning. Previous systematic review studies, such as Permatasari, Rahayu & Dasna (2022) have explored the use of multiple representations and their impact on improving learning outcomes in chemistry. Another study broadly investigated the application of multiple representations in physics at the higher education level (Munfaridah, Avraamidou & Goedhart, 2021). The literature review study by Munfaridah, Avraamidou & Goedhart (2021) indicates that using multiple representations can support physics instruction at the university level. In contrast, this study emphasizes multiple representation as a crucial skill in physics learning, with a particular focus on high school students, while also considering its importance across different educational levels.

A systematic literature review is essential for identifying research priorities and understanding initial conceptual frameworks for future studies (Higgins et al., 2019). It also helps to clarify and deepen the information obtained (Ilma, Wilujeng, Widowati, Nurtanto & Kholifah, 2023). Systematic literature reviews are beneficial in aiding researchers, practitioners, and policymakers to design more effective studies and policies (Kurniawan, Suhandi, Samsudin, Thi & Xuan, 2024).The aim of this study is to conduct a systematic review exploring strategies to enhance students' multiple representation skills in physics learning. To better understand and evaluate strategies for improving students' multiple representation abilities in physics learning, this study systematically reviews published research on multiple representations in physics education using the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) procedure (Moher, Liberati, Tetzlaff & Altmanet, 2009; Page et al., 2021) .

The research questions formulated for this study are as follows: (RQ1) What interventions, including teaching models and learning media, are effective in supporting the enhancement of multiple representation abilities in physics learning? (RQ2) What indicators are used to measure multiple representation skills in physics learning?

This systematic review research contributes by providing valuable insights to researchers, educators, and education practitioners regarding effective interventions in physics learning to enhance students' multiple representation abilities. The findings of this review offer a robust foundation for planning and developing more effective physics learning approaches that foster deeper mastery of multiple representation skills.

2. METHOD

The aim of this study is to conduct a systematic review exploring ways to enhance students' multiple representation abilities in physics learning. To achieve this objective, the study employs a qualitative approach known as descriptive content analysis (Page et al., 2021). The systematic review procedure follows the PRISMA guidelines, which include identification, screening, eligibility, and inclusion stages (Page et al., 2021).

The article selection procedure begins with the identification stage, which involves conducting a literature search. This systematic review employs a search across multiple databases, in accordance with the systematic review approach (Sutton, Clowes, Preston & Booth, 2019). Article searches were carried out in the Scopus, ERIC, and SINTA databases using keyword techniques adapted to the specific characteristics of each database. The article search method is detailed in Table 1. The initial database search

Table 1 The article search method utilized databases such as Scopus, ERIC, and SINTA

Database	Search Term	Adjustments
Scopus	Article title: “Representation” AND Article title, abstract, keywords: "multiple representation" AND "physics" AND "learning" Article title: “Representation” AND Article title, abstract, keywords: “graphical” OR "mathematical" OR "verbal" OR "visual" AND "physics" AND "learning"	-
ERIC	“multiple representation” AND "physics" AND "learning" title:"representation" “graphical” OR "mathematical" OR "verbal" OR "visual" AND "physics" AND "learning" title:"representation"	Peer reviewed only
SINTA	Representation physics	Search Google Scholar document

yielded 669 articles, from which 69 duplicate articles were removed.

The second step of the selection process involved applying specific selection criteria to narrow the search. The studies included were open-access journal articles or conference papers published in English or Indonesian from January 2014 to November 2024. A more detailed list of the article selection criteria is provided in Table 2.

The screening phase was conducted to assess the relevance of the articles to the research objectives, specifically focusing on efforts to enhance students' multiple representation abilities in physics education. Empirical studies containing physics teaching interventions were selected. Abstracts, titles, and keywords of 381 articles were reviewed, resulting in the exclusion of 349 articles that did not fulfill the inclusion criteria. The remaining 32 articles were examined based on their full text, leading to the exclusion of 6 articles. As a result, 26 articles were included in this systematic review. The flowchart of the article selection procedure is illustrated in Figure 1.

Figure 1 illustrates the flowchart of the article selection procedure, resulting in 26 articles that meet the established criteria. The data that met the criteria were further analyzed. The analysis considered the types of interventions applied to enhance multiple representation skills, focusing on teaching models, learning media, and the indicators used to measure these skills. To complement the analysis results, categorization was also carried out based on the educational level and physics topics examined in the research.

Table 2 Inclusion and exlusion criteria

Type of criterion	Criteria	Inclusion	Exlusion
Type of publication	Journal articles	X	
	Conference paper	X	
	Reports		X
	Dissertations		X
	Books and book chapters		X
Open access	Open access	X	
Publication period	January 2014-November 2024	X	
Language	English	X	
	Indonesian	X	
	Other		X
Place of study	Worldwide	X	
Type of study	Empirical investigations	X	
	Literature reviews		X
	Theoretical reviews		X
Research methods	Qualitative	X	
	Quantitative	X	
	Mixed methods	X	
Focus on the school subject	Physics	X	
	Other		X
Independent variable	Multiple representation or representation skill	X	
	Other		X

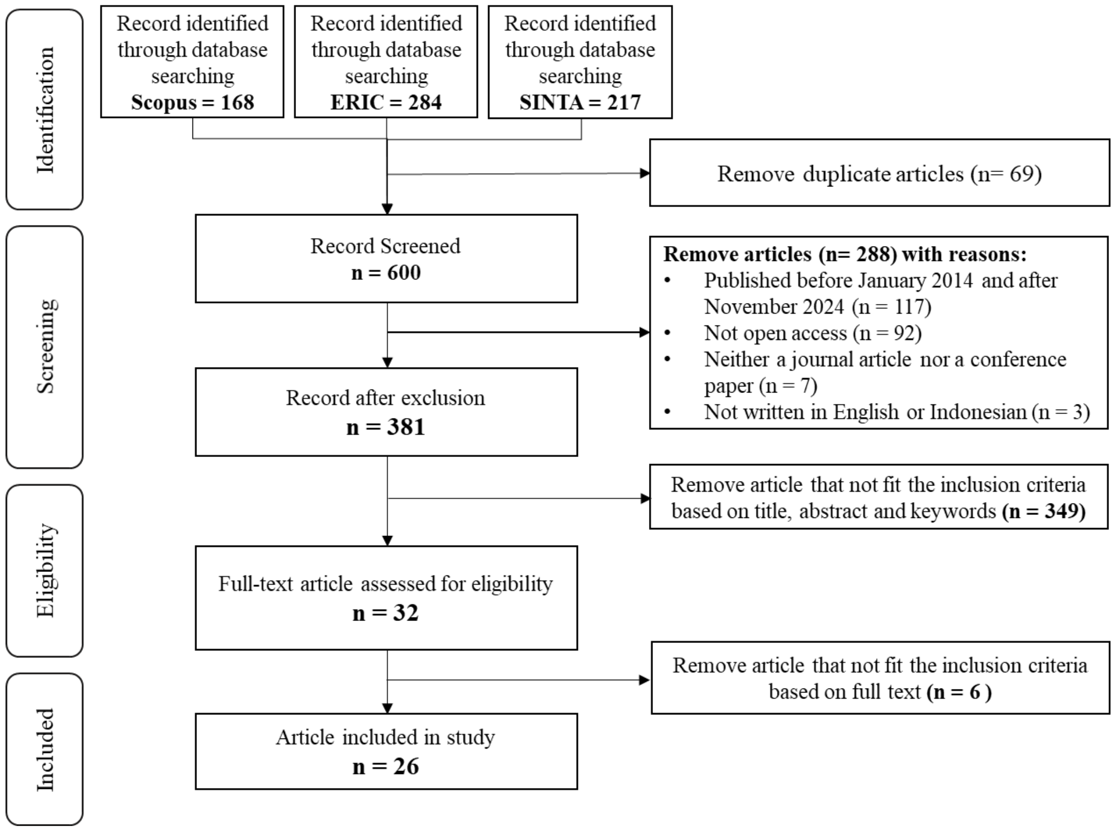

Figure 1 Article selection procedure

3. RESULT

This study aims to systematically review experimental research to explore the interventions implemented to enhance students' multiple representation skills in physics education. The studies are categorized based on the instructional models and media applied. Additionally, this study explores the indicators of multiple representation skills in physics and maps the selected articles based on physics topics and educational levels.

3.1 Learning Interventions to Enhance Students' Physics Multiple Representation Skills

Representation skills or multiple representations can be enhanced through the implementation of instructional interventions. Based on the reviewed studies, various interventions have been identified to improve students' single and multiple representation abilities in physics learning. The range of implemented interventions is summarized in Table 3.

Table 3 presents 26 articles detailing various types of instructional interventions that effectively enhance multiple representation skills in physics learning. Each study listed in Table 3 reports research findings demonstrating that the applied interventions effectively improve students' physics representation skills. The enhanced representation skills vary widely, including multiple representations, verbal representations, mathematical representations, graphical representations, vector representations, and others. The interventions implemented are also diverse, encompassing the use of instructional media, teaching tools, learning approaches, teaching materials, media integrated with teaching models, as well as media and teaching materials. The categorization of teaching models used in studies aimed at improving multiple representation skills in physics is detailed in Table 4.

Table 4 presents the teaching models utilized in studies aimed at enhancing students' multiple representation skills in physics learning. The table reveals that the majority of studies, totaling 21, did not report the specific teaching models used. Conversely, five studies explicitly mentioned the teaching models employed, including discovery learning, blended learning, problem-based learning, and STEM. Table 4 also highlights that the application of instructional media dominates the literature as an intervention for improving students' multiple representation skills. The instructional media reported to enhance students' multiple representation abilities in physics are summarized in Table 5.

Table 5 presents the interventions in the form of instructional media aimed at enhancing students' multiple representation skills in physics. The table indicates that the most frequently used media is technology-assisted ethnoscience media, while the least utilized is media and teching material based on ethnoscience assisted by technology.

Table 3 Interventions used to enhance physics multiple representation skill

No	Author	Intervention	Intervention Type	Outcome (Representation Type)
1	(Adlina & Supahar, 2019)	Android-based Worked Example Application for Kinematics (WEAK)	Learning tool	Mathematical representation
2	(Alfianti et al., 2023)	Media Augmented Reality integrated local wisdom in direct curent electricity topic	Learning media	Multiple representation
3	(A. E. Damayanti & Kuswanto, 2021)	Android-based marble games featuring physics comics grounded in indigenous knowledge	Learning media	Verbal representation
4	(Fatmaryanti et al., 2024)	Remote laboratories	Learning design	Multiple representation
5	(Fithrathy & Ariswan, 2019)	Learning multimedia	Learning media	Graphic and verbal representation
6	(Husna & Kuswanto, 2018)	Mobile learning based on local wisdom	Learning media	Vector and diagram representation
7	(Hutamasari & Kuswanto, 2018)	Mobile learning based on local culture	Learning media	Verbal and diagram representation
8	(H. D. Kurniawan & Kuswanto, 2021)	Learning media integrating local wisdom of the becak (pedicab), supported by the Android-based CAKA media	Learning media	Mathematical representation
9	(Kuswanto et al., 2019)	Physics comic based on local wisdom assisted by android	Learning media	Mathematical representation
10	(Liliarti & Kuswanto, 2018)	Android-based mobile learning application integrated local culture	Learning media	Diagramatic and argumentative representation
11	(Maghfiroh & Kuswanto, 2022)	Benthik Android Physics Comic	Learning media	Vector representation
12	(Muzdalifah et al., 2018)	Multirepresentation based physics learning	Learning approach	Multiple representation
13	(Nuha et al., 2021)	Worksheets assisted by Augmented Reality	Teaching material	Verbal representation
14	(Priyadi et al., 2020)	Android physics comics	Learning media	Mathematical representation
15	(Putri et al., 2023)	Adaptive e-modules using Moodle-based blended learning	Teaching material	Multiple representation
16	(Rahayu & Kuswanto, 2021)	Android-based comic carom game integrated with discovery learning	Media and model	Mathematical representation
17	(Rahmasari & Kuswanto, 2023)	Physics pocketbook using PBL model with AR and local wisdom	Media and model	Mathematical and graphical representation
18	(Rahmat et al., 2023)	Mobile learning integrated with traditional game	Learning media	Multiple representation
19	(Rahmayani et al., 2024)	Physics E-book with Augmented Reality integrated STEM	Teaching material and model	Multiple representation
20	(Raras & Kuswanto, 2019)	Android-assisted learning media based on the Jemparingan tradition (JEMASIK)	Learning media	Graphic and vector representation
21	(M. R. D. Saputra & Kuswanto, 2019)	Android-assisted physics mobile learning with the HomboBatu theme on smartphones	Learning media	Diagram representation
22	(H. Saputra et al., 2021)	Conceptual Problem Solving (CPS) Approach	Learning approach	Multiple representation
23	(Permata Sari et al., 2020)	Android-assisted comic based on local wisdom: Engklek (Hopscotch) game	Learning media	Mathematical representation
24	(Setiyadi et al., 2019)	Multimedia learning modules assisted by an android smartphone	Media and teaching material	Mathematical representation
25	(Warsono, Setiyadi, et al., 2020)	Local wisdom-based physics learning module	Teaching material	Verbal and vector representation
26	(Warsono, Nursuhud, et al., 2020)	Multimedia Learning Modules (MLMs) integrated local wisdom	Media and teaching material	Diagram Representation

Table 4 Teaching models and interventions to enhance physics multiple representation skills

No	Models of Teaching	Intervention Strategies	Frequency
1.	Discovery learning	Ethnoscience media assisted by technology	2
2.	Problem based learning	Ethnoscience media assisted by technology	1
3.	STEM	Ethnoscience media assisted by technology	1
4.	Blended learning	Media and teaching material assisted by technology	1
5.	No information	Ethnoscience media assisted by technology	12
		Media and teaching material assisted by technology	2
		Teaching material assisted by technology	1
		Media and teaching material beased on ethnoscience assisted by technology	1
		Remote learning	1
		Learning approach multiple representation	1
		Teaching material based on ethnoscience assisted by technology	1
		Conceptual Problem Solving (CPS) Approach	1
		Media assisted by technology	1
		Learning tool with worked example	1

Table 5 Learning media implemented to enhance physics multiple representation skills

No	Learning media type	Description	Frequency
1	Ethnoscience media assisted by technology	• Media Augmented Reality integrated local wisdom in direct curent topic • Indigenous knowledge-based physics comic of Android-based marbles games • Mobile learning based on local wisdom • Mobile learning based on local culture • Learning media based on the local wisdom of *becak* (pedicab) assisted by the Android CAKA media • Physics comic based on local wisdom assisted by android • Android-based mobile learning application integrated local culture • Benthik android physics comic • Android-based carom games comic integrated to discovery learning (MIKIMOM) • Problem-Based Learning (PBL) physics pocketbook integrating Augmented Reality (AR) with the local wisdom • Mobile learning integrated with traditional game • STEM-based physics E-book with Augmented Reality • Jemparingan tradition (JEMASIK)-based and android-assisted learning media • Physics Mobile Learning (PML) with Hombo Batu theme smartphone Android assisted • Comic based on local wisdom: Hopscotch (engklek) game android-assisted	15
2	Learning media and teaching material assisted by technology	• Adaptive e-modules through Moodle-based blended learning • Multimedia learning modules assisted by an android smartphone	2
3	Learning media assisted by technology	• Android physics comics • Learning multimedia application using Adobe Flash	2
4	Learning media and teaching material beased on ethnoscience assisted by technology	• Multimedia Learning Modules (MLMs) integrated local wisdom	1

3.2 Indicators for Measuring Students' Multiple Representation Skills

The review findings reveal that the representation skills enhanced in the studies are highly diverse, as are the indicators used to measure these representation or multiple representation skills. The results of the article review regarding the indicators used to assess representation or multiple representation skills are presented in Table 6.

Table 6 presents the indicators of multiple representation skills in physics. From Table 6, it is evident that mathematical representation skills are the most frequently featured in the studies. Although diverse, the indicators of mathematical representation skills can be synthesized into two main indicators: using appropriate equations or mathematical modeling and performing accurate mathematical operations. On the other hand, representation skills such as graphical and argumentative representations are rarely accompanied by specific indicators. Additionally, the use of indicators that combine two types of representations is relatively uncommon, such as diagram and vector representations, verbal and diagram representations, pictorial and verbal representations, mathematical and graphical representations, as well as mathematical and verbal representations.

3.3 Article Distribution Based on Physics Learning Topics

The classification of physics learning topics used in studies aimed at enhancing multiple representation skills in physics is highly diverse. Additionally, some studies involve more than one physics topic. The most frequently studied topic in research on improving students' multiple representation skills is momentum and impulse. Conversely, the least commonly used topics include direct current, Ohm's law and Kirchhoff's law, kinetic and potential energy, volume flow rate, continuity equation, frictional force, Archimedes' principle, heat transfer, thermodynamics, elasticity, renewable energy, vectors, linear motion, and optics. The detailed mapping of physics learning topics is presented in Table 7.

Table 6 Indicatos of multiple representation skills

No	Type of representation	Indicators	Autors
1.	Mutiple representation	Utilizing mathematical and graphical representations. Utilizing mathematical and pictorial representations.	(Alfianti et al., 2023)
		Identify and manipulate mathematical equations to solve problems. Understand, explain, and articulate concepts and principles, and solve problems through written verbal descriptions. Represent data or information using charts, graphs, or tables.	(Rahmayani et al., 2024)
2.	Mathematical representation	Determine the right mathematical symbols. Understand the right mathematical symbols. Determine the right mathematical equation. Determine the use of numbering and symbols in the correct equation.	(Adlina & Supahar, 2019)
		Derive conclusions by applying mathematical equations Performing operations to obtain results	(Fatmaryanti et al., 2024)
		Identifying the appropriate equation relevant to the given problem Applying mathematical operations to resolve the problem	(H. D. Kurniawan & Kuswanto, 2021)
		Write problems into mathematical equations Operate mathematical equations	(Priyadi et al., 2020)
		Develop mathematical equations or models. Solve problems using mathematical equations.	(Putri et al., 2023)
		Identifying mathematical equations based on the problem. Interpreting mathematical symbols in the context of the problem. Performing operations on numbers or symbols in mathematical equations accurately.	(Rahmasari & Kuswanto, 2023)
		Identifying the correct equation based on the given problem. Performing mathematical operations on the equation. Collect the relevant data. Apply mathematical operations. Record the final calculation results along with the appropriate units. Mathematical equation Written text	(Rahayu & Kuswanto, 2021) (Setiyadi et al., 2019) (Sari et al., 2020)

Table 6 Indicatos of multiple representation skills

No	Type of representation	Indicators	Autors
3	Verbal representation	Understanding concepts, principles, and solve problems by expressing them in written form Providing verbal explanations using various forms of data, including symbols, images, and mathematical representations	(A. E. Damayanti & Kuswanto, 2021)
		Discovering concepts verbally through the presentation of data, physical phenomena, and conveyed information. Expressing the meaning of a concept in written (verbal) form.	(Fatmaryanti et al., 2024)
		Provide a detailed and clear explanation of the problem. Clarify the definitions and terminology associated with the concept. Interpret mathematical representations, diagrams, and graphs into verbal descriptions.	(Nuha et al., 2021)
		Provide an interpretation of a given representation in written form. Document the solution to the problem through written sentences. Address statistical problems using descriptive text or written explanations.	(Putri et al., 2023)
4.	Diagrammatic representation	Making diagrams Structuring diagrams Building perceptions from diagram	(Liliarti & Kuswanto, 2018)
		Create sketches that illustrate the physics problem. Construct object diagrams or external diagrams (motions/forces) for the observed object, ensuring they are complete, clear, and relevant to the physical situation. Provide clear and accurate descriptions or labels on the diagram. Utilize diagrams to solve the physics problem.	(M. R. D. Saputra & Kuswanto, 2019)
		Construct a diagram with all its components. Perform mathematical calculations in accordance with the diagram's explanation	(Warsono, Nursuhud, et al., 2020)
5.	Visual representation	Organizing thermodynamic process data into tabular representations. Interpreting and explaining thermodynamic graphs or processes	(Putri et al., 2023)
6.	Graphical Representation	Relating graphs to mathematical formulas. Representing real-world objects or situations through graphical models. Extracting information from graphs and calculating the relevant physical quantities.	(Rahmasari & Kuswanto, 2023)
7.	Argumentative representation	Delivering a statement Building arugmentations from physical fenomenon Predicting, observing and explaining a problem	(Liliarti & Kuswanto, 2018)
8.	Vector and diagram representation	Describe and recognize scalar and vector quantities. Describe and compute the vector quantity accurately to solve the problem. Describe and compute the vector quantity accurately to solve the problem. Utilize a diagram to analyze the interactions within the system.	(Husna & Kuswanto, 2018)
9.	Verbal and diagram representation	Explain the concept through verbal explanation. Provide labels and physical symbols on diagrams through verbal description. Identify the correct concept based on data or physical phenomena. Address problems using verbal explanations or sentences. Utilize the diagram as an aid to solve the problem.	(Hutamasari & Kuswanto, 2018)
10.	Pictorial and verbal representation	Proposes a new pattern in comparison to other representations.	(Rahmat et al., 2023)
11.	Graphic and verbal representation	Interpreting the meaning of a graph	(Rahmat et al., 2023)
12.	Graphic and mathematical representation	Validating the information gathered from a graph. Interpreting graphs to solve problems through mathematical representation.	(Rahmat et al., 2023)
13.	Mathematical and verbal representations	Conveying mathematical equations through various representations.	(Rahmat et al., 2023)

Table 7 Classification based on physics learning topic

No.	Physics topic	Frequency
1.	Momentum and impulse	7
2.	Sound wave	3
3.	Newton's law	3
4.	Work and energy	2
5.	Parabolic motion	3
6.	Circular motion	2
7.	Kinematics	2
8.	Potential and kinetic energy	1
9.	Direct current	1
10.	Ohm's and kirchoff law	1
11.	Volume flow rate	1
12.	Continuity equation	1
13.	Frictional force	1
14.	Archimedes law	1
15.	Heat transfer	1
16.	Thermodynamics	1
17.	Elasticity	1
18.	Renewable energy	1
19.	Vector	1
20	Linear motion	1
21.	Optics	1

Table 8 Classification based on education level

No.	Education level	Frequency
1	Senior high school	25
2	Prospective physics teacher	1

The physics topics involved in this study are highly diverse, most of which are commonly taught to senior high school students. Therefore, an analysis was conducted to determine the distribution of studies based on educational levels, as shown in Table 8. The data reveals that the majority of the studies were conducted with senior high school students as subjects, totaling 25 studies. In contrast, only one study included pre-service physics teachers as research participants.

4. DISCUSSION

Success in the field of science heavily relies on the ability to utilize various forms of representation, such as text, graphs, equations, and diagrams (Hill & Sharma, 2015). The ability of multiple representations is crucial for students to better understand and deepen their comprehension of physics concepts (Geyer & Pospiech, 2019), as well as to support problem-solving (Bollen, Van Kampen, Baily, Kelly & De Cock, 2017). However, it has been reported that students face difficulties in using different types of representations (Susac, Planinic, Bubic, Jelicic & Palmovic, 2023). Thus, efforts are needed to enhance students' ability to use representations or multiple representations. This review study explores the literature related to various interventions aimed at improving multiple representation skills in physics learning. The findings suggest that the interventions can include the application of learning media, learning tools, instructional design, and teaching models combined with media and instructional materials.

4.1 Learning Interventions to Enhance Students' Physics Multiple Representation Skills

Teaching Models to Improve Multiple Representation Skills

The teaching models reported in studies focused on enhancing multiple representation skills in physics are relatively few (See Table 4). Moreover, the teaching models are not implemented as stand-alone interventions but are combined with learning media and instructional materials. Table 4 shows that four teaching models have been used in these interventions, including discovery learning, Problem-Based Learning (PBL), STEM, and blended learning.

Discovery learning is the most frequently used model in the reviewed studies, including studies by Rahayu & Kuswanto (2021) and Saputra & Kuswanto (2019). The study by Rahayu and Kuswanto (2021) investigated the effectiveness of ethnoscience-based comic game media with Android, which incorporates discovery learning steps, thus applying discovery learning. The results showed that the use of media with the discovery teaching model can enhance the mathematical representation skills of high school students in physics learning (Rahayu & Kuswanto, 2021). The study by Saputra & Kuswanto (2019) demonstrated that a mobile-based physics learning media integrated with ethnoscience, applied with the discovery learning model, can improve high school students' diagram representation skills in physics learning.

The PBL model was used in a study by Rahmasari & Kuswanto (2023) to examine the effectiveness of a PBL model combined with AR-assisted pocketbooks and local wisdom in enhancing mathematical and graphical representation skills. The results of the study indicated that the PBL model, combined with AR-based pocketbooks and local wisdom, was effective in improving mathematical and graphical representation skills (Rahmasari & Kuswanto, 2023). Both the PBL and discovery teaching models are effective in enhancing students' representation skills. A study by Ertikanto, Rosidin, Distrik, Yuberti & Rahayu (2018) compared the effects of discovery learning and PBL on science learning outcomes and mathematical representation skills. The study revealed no significant differences between the use of PBL and discovery learning in improving mathematical representation skills and science learning outcomes (Ertikanto, Rosidin, Distrik, Yuberti & Rahayu, 2018).

STEM learning, combined with AR-integrated e-books, was applied in a study by Rahmayani, Kuswanto & Rahmat, (2024) to improve students' multiple representation skills in physics. The results showed that STEM-based AR-integrated e-books can enhance high school students' multiple representation skills in physics learning. In line with these findings, a study by Widyawati, Kuswanto, Sanioso & Zhanbyrbaevna (2024) indicated that STEM-integrated PBL models can enhance students' verbal representation skills in science learning (Widyawati, Kuswanto, Sanioso & Zhanbyrbaevna, 2024). Furthermore, when viewed as a subject of learning, STEM also requires the use of various symbolic representations (such as text and formulas) as well as graphical representations (such as images and graphs) to communicate content (Rexigel, Kuhn, Becker & Malone, 2024). STEM and multiple representations are interrelated, where the STEM approach can be used to enhance multiple representation skills, and multiple representations can support STEM subjects.

Blended learning is another teaching model used in studies to improve students' multiple representation skills in physics learning. Blended learning combined with adaptive e-modules accessed via Moodle can improve high school students' multiple representation skills in physics learning (Putri, Khumaedi, & Mindyarto, 2023). Blended learning, which utilizes technology, is considered an effective model as it combines conventional and electronic learning (Susanti, Diani, Satiarti, Munawaroh & Fujiani, 2021). Blended learning has a positive impact on physics learning, including improving physics learning outcomes (Fibisari, Yuberti, Saregar, Syafrimen & Anwar, 2023), and supporting the development of students' creative thinking skills (Serevina & Meyputri, 2021).

Learning media to improve multiple representation skills

Educational Media in this Review Study is the most frequently applied intervention to improve students' multiple representation skills in physics learning (See Figure 2). The most commonly used learning media in these studies is technology-assisted ethnoscience media. Ethnoscience refers to learning activities that link local wisdom with scientific concepts (Jufrida, Kurniawan & Basuki, 2024). The integration of local wisdom into the learning process enhances the quality of physics education (Liliarti & Kuswanto, 2018). Physics learning that integrates culture, local knowledge, and local wisdom is an effort to connect students with the context of science (Risdianto, Dinissjah, Nirwana & Kristiawanal, 2020; Ubaidillah, Hartono, Marwoto, Wiyanto & Subali, 2023). The application of ethnoscience also impacts improved student learning outcomes (Sudarmiani & Trilaksana, 2020), enhanced critical thinking skills (Risdianto, Dinissjah, Nirwana & Kristiawanal, 2020), higher-order thinking (Hikmawati et al., 2024), and better understanding of physics concepts. The integration of local wisdom into the curriculum can enrich students' learning experiences and impart cultural values (Lestari & Suyanto, 2024). Ethnoscience media has been proven to have a positive impact on learning, improving representation skills and other cognitive abilities while introducing students to culture.

The media used are varied, including multimedia (Warsono, Nursuhud, Darma, Supahar & Oktavia, 2020), comics (Damayanti, 2021; Kuswanto, Sari, Wardani & Nikmah, 2019; Maghfiroh & Kuswanto, 2022; Sari, Nikmah, Kuswanto & Wardani, 2020; Priyadi, Kuswanto, & Sumarna, 2020), and applications (Liliarti & Kuswanto, 2018). Technology-assisted media refers to the use of technology to access and enhance these media, such as Augmented Reality (AR) (Alfianti, Kuswanto, Rahmat & Nurdiyanto, 2023), Android-assisted media (Damayanti & Kuswanto, 2021; Kurniawan & Kuswanto, 2021; Raras & Kuswanto, 2019), and mobile learning (Husna & Kuswanto, 2018; Hutamasari & Kuswanto, 2018). The results of this review show that the application of technology-assisted ethnoscience media can improve students' multiple representation skills and various representation abilities in physics learning.

Physics learning media that can also be used to enhance students' representation skills include media and teaching materials assisted by technology. Technology-assisted

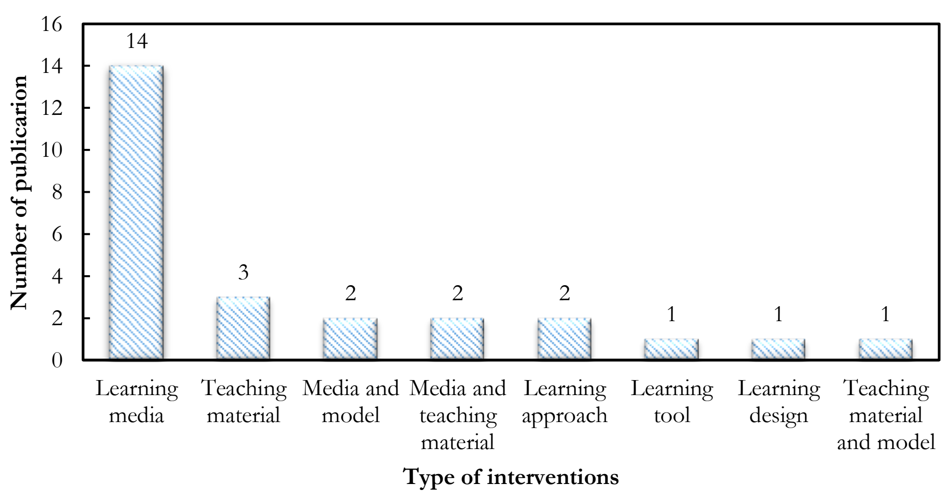

Figure 2 Types of interventions used to enhance physics multiple representation skill

media and teaching materials include adaptive e-modules through Moodle (Putri, Khumaedi, & Mindyarto, 2023) and multimedia learning modules assisted by an Android smartphone (Setiyadi, Darma, Wilujeng, Jumadi & Kuswanto, 2019). E-modules are viewed as teaching materials (Putri, Khumaedi, & Mindyarto, 2023); however, since they contain learning media, e-modules can also be seen as learning media (Setiyadi, Darma, Wilujeng, Jumadi & Kuswanto, 2019). The use of technology-assisted modules can improve multiple representation skills (Putri, Khumaedi, & Mindyarto, 2023) and students' mathematical representation skills (Setiyadi, Darma, Wilujeng, Jumadi & Kuswanto, 2019) in physics learning.

Table 5 shows that all the media applied in physics learning to improve students' multiple representation skills are technology-assisted media. Educational technology plays a significant role in enhancing the effectiveness of learning (Ubaidillah, Hartono, Marwoto, Wiyanto & Subali, 2023). It has been demonstrated that technology of mobile learning enhances student learning outcomes in physics (Abdullah, Afikah, Apino, Supahar & Jumadi, 2024). The use of Augmented Reality technology can enhance student learning (Garzón & Acevedo, 2019). Therefore, the use of educational technology strongly supports the effectiveness of physics learning.

4.2 Indicators of Multiple Representation Skills in Physics Learning

The nature of physics as a subject is often considered difficult due to its abstract content (Pals, Tolboom & Suhre, 2023), which requires the ability to utilize multiple representations to help students understand physics concepts more easily. Multiple representations skill have significant potential in the understanding of physics concepts by students (Guentulle, Muñoz, Nussbaum & Madariaga, 2024). The ability to use multiple representations can be enhanced and measured using specific indicators of multiple representation skills.

Multiple representation skills are a combination of two or more individual representations (Alfianti, Kuswanto, Rahmat & Nurdiyanto, 2023). Therefore, indicators of multiple representation skills include using mathematical, graphical, and pictorial representations (Alfianti, Kuswanto, Rahmat & Nurdiyanto, 2023) as well as representing data through diagrams, graphs, or tables (Rahmayani, Kuswanto & Rahmat, 2024). In addition, multiple representation skills (see Table 6) also include combinations of verbal and diagram representations (Hutamasari & Kuswanto, 2018), pictorial and verbal representations, graphic and verbal representations, graphic and mathematical representations, mathematical and verbal representations, and graphic and verbal representations (Rahmat, Wilujeng & Kuswanto, 2023). Each combination of two types of representations has its own set of indicators, as provided in Table 6.

The most frequently studied representation skill in the reviewed studies is mathematical representation. Although the indicators for mathematical representation are diverse, they can be synthesized into two main indicators: using appropriate mathematical equations or modeling, and performing correct mathematical operations. All studies reviewed included these two indicators of mathematical representation. Mathematical representation in physics differs from mathematical representation in mathematics. In the subject of mathematics, mathematical representation refers to the representation used within the mathematical discipline. Studies on mathematical representation in mathematics use indicators including verbal representation, visual representation (diagrams, images, graphs, or tables), and symbolic representation (mathematical statements, numeric symbols, mathematical notation) (Utami, Sa'dijah, & Chandra, 2024). As with physics representations, which include graphical, mathematical, and verbal representations (Treagust, Duit & Fischer, 2017), mathematical representation also includes graphical, table, and diagram representations that help students visualize mathematical concepts (Ahmad, Akhsani & Mohamed, 2023).

Verbal representation involves the ability of students to understand and explain concepts, principles, and problems in written form. Studies using verbal representation and listing its indicators include works by Damayanti & Kuswanto (2021), Fatmaryanti et al. (2024), Nuha, Kuswanto, Apriani & Hapsari, (2021), and Putri, Khumaedi, & Mindyarto (2023). Indicators of verbal representation can be synthesized into three main indicators: delivering clear and detailed verbal explanations, interpreting various forms of representations (such as graphs, images and symbols) into verbal descriptions, and documenting solutions or data through written text.

Diagram representation involves the understanding of diagrams, which enhances meaningful physics learning for students, particularly in determining accurate solutions to physics problems (Poluakan, 2019). Diagram representation and its indicators are discussed in studies by Liliarti & Kuswanto (2018), Saputra & Kuswanto (2019), and Warsono, Nursuhud, Darma, Supahar & Oktavia, (2020). The indicators of diagram representation can be synthesized into three key indicators: constructing diagrams correctly, gaining relevant understanding from diagrams, and using diagrams for problem-solving. The representation skills involved in this study are quite diverse, and so are their indicators. The detailed indicators of these representation skills are presented in Table 6.

4.3 Article Distribution Based on Physics Learning Topics

It is important to recognize the types of physics content when teaching multiple representation skills. Studies show that teaching representational competence in context-specific content is a beneficial approach (Kohl & Finkelstein, 2017). Therefore, it is crucial to explore the types of representations that are relevant to the physics topics taught in the classroom. The physics topics involved in studies aimed at developing multiple representation skills vary widely. Each topic used has different material characteristics. Some studies include more than one topic. For example, the study by Husna and Kuswanto (2018) covers circular motion, potential energy, kinetic energy, volume flow rate, and the continuity equation; Liliarti & Kuswanto (2018) study includes Newton's Law, Archimedes' principle, and heat transfer; Study by Kuswanto, Sari, Wardani & Nikmah (2019) explore sound waves, momentum, and impulse topics; Study Kurniawan & Kuswanto (2021) explore work and energy, Newton's Law, and circular motion topics; and Raras & Kuswanto (2019) includes kinematics motion, kinetic energy, potential energy, momentum, and impulse.

Momentum and impulse are the most commonly used topics (n = 7). These concepts are important in physics, but previous studies have reported difficulties students face in understanding momentum and impulse concepts (Rosa, Cari, Aminah & Handhika, 2018; Wirjawan et al., 2020; Xu et al., 2020). There are three difficult concepts related to momentum and impulse: the principle of angular impulse and momentum for rigid bodies, the law of conservation of angular momentum for rigid bodies, and angular impulse of rigid bodies (Fang & Guo, 2022). Students' difficulties in solving momentum problems can be addressed through multiple representations (Unyapoti, Arayathanitkul & Emarat, 2020). Studies using momentum and impulse topics incorporate verbal representation (Damayanti & Kuswanto, 2021), mathematical representation ((Kuswanto, Sari, Wardani & Nikmah, 2019; Priyadi, Kuswanto & Sumarna, 2020; Rahayu & Kuswanto, 2021), graphic and vector representation (Raras & Kuswanto, 2019), and diagram representation (Setiyadi, Oktavia, Darma & Nursuhud, 2020). Consistent with these findings, a study by (Unyapoti, Arayathanitkul & Emarat (2020) introduced teaching methods through vector diagram representation such as momentum vector diagrams, which helped students understand the principles of momentum conservation, vector properties of momentum, and their application in solving two-dimensional collision problems.

Another commonly used topic in studies of improving students' multiple representation skills is sound waves (n = 3). The wave topic is challenging in physics (Sharma, Gupta & Agarwal, 2023), but topics like sound waves are fundamental in physics (Dagdeviren, 2018). Studies involving sound waves teach various types of physics representations, including multiple representations (Saputra, Mansyur & Supriyatman. 2021), verbal and vector representations (Setiyadi, Oktavia, Darma & Nursuhud, 2020), and mathematical representations (Kuswanto, Sari, Wardani & Nikmah, 2019). Other studies explore the use of pictorial representations for the abstract concept of sound waves. Pictorial representations, such as sinusoidal wave patterns and arrows, are used to give physical form and quantitative properties to abstract concepts like sound waves and forces (Yeo & Gilbert, 2017).

Other physics topics used in studies include force and motion, covering mechanics and dynamics. These topics are quite popular in involving multiple representations, including Newton's laws (n = 3), projectile motion (n = 3), circular motion (n = 2), kinematics (n = 2), frictional force (n = 1), vectors (n = 1), and linear motion (n = 1). These topics involve relatively complex material, requiring good mathematical skills due to vector analysis. When teaching these topics, multiple representations (Muzdalifah, Irianti & Maimurni, 2019; Rahmat, Wilujeng & Kuswanto, 2023), graphical and vector representations (Raras & Kuswanto, 2019), diagrams representation (Saputra & Kuswanto, 2019), verbal and diagram representations (Hutamasari & Kuswanto, 2018), diagrammatic and argumentative representations (Liliarti & Kuswanto, 2018), and mathematical representations (Kurniawan & Kuswanto, 2021) play a crucial role in understanding the material on force and motion. Additionally, a study by Abdillah, Mahardika, Handayani & Gunawan (2021) examined the use of multiple representations in teaching projectile motion and found that multiple representations can enhance physics learning outcomes in this topic. A study by Nieminen, Savinainen & Viiri, (2017) tested multiple representation skills such as graphs, vectors, bar diagrams, motion maps, and interaction diagrams in the topic of force. Their findings indicate that students' representation skills are closely linked to their conceptual understanding of force, and optimal learning outcomes can be achieved through the use of appropriate representations, such as interactive diagrams (Nieminen, Savinainen & Viiri, 2017).

Other physics topics include work and energy (n = 2), renewable energy (n = 1), potential and kinetic energy (n = 1), electricity topics such as direct current (n = 1) and Ohm's and Kirchhoff's laws (n = 1), fluid topics including volume flow rate (n = 1), continuity equation (n = 1), and Archimedes' principle (n = 1). Additional topics discussed include heat transfer (n = 1), thermodynamics (n = 1), optics (n = 1), and elasticity (n = 1). The diverse range of topics studied highlights the potential application and development of multiple representation skills across various physics content. However, it is important to consider the types of representations that are relevant to the specific physics topics involved.

4.4 Implication and Limitation

This study demonstrates that the use of technology-assisted media, such as ethnoscience and AR-based applications, can significantly enhance students' multiple representation skills in physics education. This implies the importance of integrating technology into the physics curriculum to enrich students' learning experiences, aid in their understanding of abstract physics concepts, and strengthen essential representation skills. Moreover, the incorporation of local wisdom in learning can make physics more relevant to students' daily lives, thereby supporting a deeper and more applied understanding.

The limitation of this study lies in the geographic scope of the reviewed studies, which are confined to Indonesia. Despite an extensive search in international databases such as Scopus, similar studies were only found within Indonesia. This indicates a lack of global research on this topic, limiting the ability to generalize the findings to other contexts. This suggests that the topic of enhancing multiple representation skills has not been explored internationally. Future research is recommended to broaden the scope of the topic, such as exploring how multiple representation is applied in education in international contexts..

5. CONCLUSION

This study demonstrates that various interventions, encompassing the use of instructional media, teaching tools, learning approaches, teaching materials, media integrated with teaching models, as well as media and teaching materials. Particularly teaching models such as Discovery Learning, Problem-Based Learning (PBL), STEM, and Blended Learning, when combined with technology-assisted learning media such as ethnoscience, Augmented Reality (AR), and mobile applications, have been shown to significantly improve students' proficiency in utilizing multiple representations in physics education. These models and media help bridge the gap between abstract physics concepts and students' understanding, allowing them to engage with the material in diverse ways. By integrating various forms of representation, such as mathematical equations, graphical models, and verbal descriptions, students are better able to visualize and comprehend complex ideas, making the learning process more engaging and impactful. The study identifies several key indicators for assessing multiple representation skills in physics education. These key indicators for measuring multiple representation skills include students' ability to use a combination of different forms of representation, such as mathematical equations, graphical diagrams, and verbal explanations.

Overall, the integration of appropriate teaching models and technology-assisted media, along with clear indicators for measuring multiple representation skills, provides a robust framework for enhancing students' understanding and problem-solving abilities in physics. These findings emphasize the importance of diverse interventions that helping students develop essential skills required to master physics.

REFERENCES

Abdillah, U. F., Mahardika, I. K., Handayani, R. D., & Gunawan, G. (2021). Multiple representation based physics learning to improve students learning outcomes at SMAN 3 Jember on projectile motion materials. *Journal of Physics: Conference Series, 1832*(1). https://doi.org/10.1088/1742-6596/1832/1/012045

Abdullah, W. D., Afikah, A., Apino, E., Supahar, S., & Jumadi, J. (2024). Moderator effect of mobile learning on students' achievement in physics: A meta-analysis. *Journal of Baltic Science Education, 23*(2), 187–207. https://doi.org/10.33225/jbse/24.23.187

Adlina, A., & Supahar. (2019). Developing Android assisted worked example application on kinematics (weak) to improve mathematical representation ability in high school physics learning. *International Journal of Scientific & Technology Research, 8*(10). www.ijstr.org

Ahmad, Akhsani, L., & Mohamed, Z. (2023). The profile of students' mathematical representation competence, self-confidence, and habits of mind through problem-based learning models. *Infinity Journal, 12*(2), 323–338. https://doi.org/10.22460/infinity.v12i2.p323-338

Alfianti, A., Kuswanto, H., Rahmat, A. D., & Nurdiyanto, R. (2023). Development of DICTY-AR integrated local wisdom to improve multiple representation and problem-solving skills. *International Journal of Information and Education Technology, 13*(9), 1383–1390. https://doi.org/10.18178/ijiet.2023.13.9.1941

Aregehagn, E., Lykknes, A., Getahun, D. A., & Febri, M. I. M. (2023). Representation of image formation—observation in optics in Ethiopian textbooks: Student learning difficulties as an analytical tool. *Education Sciences, 13*(5). https://doi.org/10.3390/educsci13050445

Bollen, L., Van Kampen, P., Baily, C., Kelly, M., & De Cock, M. (2017). Student difficulties regarding symbolic and graphical representations of vector fields. *Physical Review Physics Education Research, 13*(2). https://doi.org/10.1103/PhysRevPhysEducRes.13.020109

Dagdeviren, O. E. (2018). Experiments to investigate the acoustic properties of sound propagation. *Physics Education, 53*(4), 045007. https://doi.org/10.1088/1361-6552/aaaddc

Damayanti, A. (2021). Penerapan model pembelajaran ARIAS berbantuan media Quizizz untuk meningkatkan motivasi belajar aplikasi pengolah angka siswa kelas X akuntansi 2 SMK Negeri 1 Sukoharjo tahun ajaran 2020/2021 [Application of the ARIAS learning model assisted by Quizizz media to improve learning motivation in spreadsheet application of grade X accounting 2 students at SMK Negeri 1 Sukoharjo in the 2020/2021 academic year].

Damayanti, A. E., & Kuswanto, H. (2021). The effect of the use of indigenous knowledge-based physics comics of android-based marbles games on verbal representation and critical thinking abilities in physics teaching. *Journal of Technology and Science Education, 11*(2), 581–593. https://doi.org/10.3926/jotse.1142

Ertikanto, C., Rosidin, U., Distrik, I. W., Yuberti, Y., & Rahayu, T. (2018). Comparison of mathematical representation skill and science learning result in classes with problem-based and discovery learning model. *Jurnal Pendidikan IPA Indonesia, 7*(1), 106–113. https://doi.org/10.15294/jpii.v6i2.9512

Fang, N., & Guo, Y. (2022). Improving student learning of impulse and momentum in particle dynamics through computer simulation and animation. *Journal of Educational Computing Research, 60*(8), 1969–1990. https://doi.org/10.1177/07356331221096979

Fatmaryanti, S. D., Suliswor0, D., Yahaya, N., Ishafit, I., Setiyo, M., Hakim, Y. Al, & Kurniawan, E. S. (2024). Active and authentic learning in remote laboratory: Means of improving prospective physics teachers' multiple representation ability. *TEM Journal, 13*(2), 1018–1027. https://doi.org/10.18421/TEM132-16

Fibisari, R., Yuberti, Saregar, A., Syafrimen, & Anwar, C. (2023). Blended learning model in physics: A meta-analysis study. *AIP Conference Proceedings, 2595*(1), 020009. https://doi.org/10.1063/5.0123820

Fithrathy, A., & Ariswan. (2019). Developing physics learning multimedia to improve graphic and verbal representation of high school students. *Journal of Physics: Conference Series, 1233*(1). https://doi.org/10.1088/1742-6596/1233/1/012071

Garzón, J., & Acevedo, J. (2019). Meta-analysis of the impact of augmented reality on students' learning gains. *Educational Research*

Review, 27, 244–260. Elsevier Ltd. https://doi.org/10.1016/j.edurev.2019.04.001

Geyer, M.-A., & Pospiech, G. (2019). An explorative laboratory study: Changing representations of functional dependencies in physics class of lower secondary school. In E. McLoughlin, O. E. Finlayson, S. Erduran, & P. E. Childs (Eds.), *Bridging research and practice in science education: Selected papers from the ESERA 2017 Conference* (pp. 35–50). Springer International Publishing. https://doi.org/10.1007/978-3-030-17219-0_3

Guentulle, V., Muñoz, R., Nussbaum, M., & Madariaga, L. (2024). How multiple representations using cyber–physical system to teach rectilinear motion improves learning and creativity. *Education Sciences, 14*(3). https://doi.org/10.3390/educsci14030293

Higgins, J. P. T., López-López, J. A., Becker, B. J., Davies, S. R., Dawson, S., Grimshaw, J. M., McGuinness, L. A., Moore, T. H. M., Rehfuess, E. A., Thomas, J., & Caldwell, D. M. (2019). Synthesising quantitative evidence in systematic reviews of complex health interventions. *BMJ Global Health, 4*(Suppl 1), e000858. https://doi.org/10.1136/bmjgh-2018-000858

Hill, M., & Sharma, M. D. (2015). Students' representational fluency at university: A cross-sectional measure of how multiple representations are used by physics students using the representational fluency survey. *Eurasia Journal of Mathematics, Science and Technology Education, 11*(6), 1633–1655. https://doi.org/10.12973/eurasia.2015.1427a

Husna, M., & Kuswanto, H. (2018). Development of physics mobile learning based on local wisdom to improve vector and diagram representation abilities. *International Journal of Interactive Mobile Technologies*, *12*(6), 85–100. https://doi.org/10.3991/ijim.v12i6.8746

Hutamasari, C. V., & Kuswanto, H. (2018). Physics mobile learning of local culture (Fiddle) to improve the verbal and diagram representation competence. *International Journal of Current Research*, *10*(3), 67050–67056. http://www.journalcra.com

Ilma, A. Z., Wilujeng, I., Widowati, A., Nurtanto, M., & Kholifah, N. (2023). A systematic literature review of stem education in indonesia (2016-2021): Contribution to improving skills in 21st century learning. *Pegem Egitim ve Ogretim Dergisi*, *13*(2), 134–146. https://doi.org/10.47750/pegegog.13.02.17

Jufrida, Kurniawan, W., & Basuki, F. R. (2024). Ethnoscience learning: how do teacher implementing to increase scientific literacy in junior high school. *International Journal of Evaluation and Research in Education* , *13*(3), 1719–1730. https://doi.org/10.11591/ijere.v13i3.26180

Kohl, P. B., & Finkelstein, N. (2017). Understanding and promoting effective use of representations in physics learning. In D. F. Treagust, R. Duit, & H. E. Fischer (Eds.), *Multiple representations in physics education, models and modeling in science education 10* (pp. 231–254). Springer. https://doi.org/10.1007/978-3-319-58914-5_11

Kurniawan, H. D., & Kuswanto, H. (2021). Improving Students' Mathematical Representation and Critical Thinking Abilities Using the CAKA Media Based on Local Wisdom. *International Journal of Interactive Mobile Technologies*, *15*(2), 72–87. https://doi.org/10.3991/ijim.v15i02.11355

Kurniawan, Y., Suhandi, A., Samsudin, A., Thi, N., & Xuan, T. (2024). A Systematic Literature Review of Physics Education Teaching Regarding Oscillations. *J.Sci.Learn.2024*, *7*(1), 25–32. https://doi.org/10.17509/jsl.v7i1.57765

Kuswanto, H., Sari, F. P., Wardani, R., & Nikmah, S. (2019). Development of physics comics based on local wisdom (Pak Pak Dor and Sulamanda) assisted by Android to improve mathematical representation ability, hots, and creative thinking. *The International Conference on Educational Research and Innovation (ICERI)*, 16–41.

Lestari, N., P., & Suyanto, S. (2024). A systematic literature review about local wisdom and sustainability: Contribution and recommendation to science education. *Eurasia Journal of Mathematics, Science and Technology Education*, *20*(2), 1–19. https://doi.org/10.29333/ejmste/14152

Liliarti, N., & Kuswanto, H. (2018). Improving the competence of diagrammatic and argumentative representation in physics through android-based mobile learning application. *International Journal of Instruction*, *11*(3), 106–122. https://doi.org/10.12973/iji.2018.1138a

Maghfiroh, A., & Kuswanto, H. (2022). Benthik Android Physics Comic Effectiveness for Vector Representation and Crtitical Thinking Students' Improvement. *International Journal of Instruction*, *15*(2), 623–640. https://doi.org/10.29333/iji.2022.15234a

McPadden, D., & Brewe, E. (2017). Impact of the second semester University Modeling Instruction course on students' representation choices. *Physical Review Physics Education Research*, *13*(2), 20129. https://doi.org/10.1103/PhysRevPhysEducRes.13.020129

Moher, D., Liberati, A., Tetzlaff, J., & Altman, D. G. (2009). Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. In *BMJ (Online)* (Vol. 339, Issue 7716, pp. 332–336). https://doi.org/10.1136/bmj.b2535

Munfaridah, N., Avraamidou, L., & Goedhart, M. (2021). The Use of Multiple Representations in Undergraduate Physics Education: What Do we Know and Where Do we Go from Here? *Eurasia Journal of Mathematics, Science and Technology Education*, *17*(1), 1–19. https://doi.org/10.29333/ejmste/9577

Muzdalifah, W., Irianti, M., & Maimurni, M. (2019). Applying multirepresentation based physics learning to improve the ability of representation of students in class x mipa2 sma babussalam pekanbaru. *Jurnal Geliga Sains: Jurnal Pendidikan Fisika*, *6*(2), 67-74.

Nieminen, P., Savinainen, A., & Viiri, J. (2017). Learning about forces using multiple representations. In D. F. Treagust, R. Duit, & H. E. Fischer (Eds.), *Multiple representations in physics education, models and modeling in science education 10* (pp. 163–182). Springer. https://doi.org/10.1007/978-3-319-58914-5_8

Niyomufasha, T., Ntivuguruzwa, C., & Mugabo, L. R. (2024). The engineering students' use of multiple representations in mechanics problems solving at a selected public university in Rwanda. *Cogent Education*, *11*(1). https://doi.org/10.1080/2331186X.2024.2372941

Nuha, A. A., Kuswanto, H., Apriani, E., & Hapsari, W. P. (2021). *Learning Physics with Worksheet Assisted Augmented Reality: The Impacts on Student's Verbal Representation*.

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., … Moher, D. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. In *The BMJ* (Vol. 372). BMJ Publishing Group. https://doi.org/10.1136/bmj.n71

Pals, F. F. B., Tolboom, J. L. J., & Suhre, C. J. M. (2023). Development of a formative assessment instrument to determine students' need for corrective actions in physics: Identifying students' functional level of understanding. *Thinking Skills and Creativity*, *50*. https://doi.org/10.1016/j.tsc.2023.101387

Permatasari, M. B., Rahayu, S., & Dasna, I. W. (2022). Chemistry Learning Using Multiple Representations: A Systematic Literature Review. *Journal of Science Learning*, *5*(2), 334–341. https://doi.org/10.17509/jsl.v5i2.42656

Poluakan, C. (2019). The importance of diagrams representation in physics learning. *Journal of Physics: Conference Series*, *1317*(1). https://doi.org/10.1088/1742-6596/1317/1/012175

Priyadi, A. N. W., Kuswanto, H., & Sumarna. (2020). Android physics comics to train the mathematical representation ability on momentum and impulse of senior high school students. *Journal of Physics: Conference Series*, *1440*(1). https://doi.org/10.1088/1742-6596/1440/1/012041

Putri, S. R. E., Khumaedi, & Mindyarto, B. N. (2023). *The Effectiveness Of Developing An Adaptive Physics E-Module In Moodle-Based Blended Learning On Students' Representation Ability On Thermodynamics Material* (Vol. 7, Issue 2).

Rahayu, M. S. I., & Kuswanto, H. (2021). The effectiveness of the use of the android-based carom games comic integrated to discovery learning in improving critical thinking and mathematical representation abilities. *Journal of Technology and Science Education*, *11*(2), 270–283. https://doi.org/10.3926/JOTSE.1151

Rahmasari, A., & Kuswanto, H. (2023). The effectiveness of Problem-Based Learning physics pocketbook integrating Augmented Reality with the local wisdom of catapults in improving mathematical and graphical representation abilities. *Journal of Technology and Science Education*, *13*(3), 886–900. https://doi.org/10.3926/JOTSE.1962

Rahmat, A. D., Wilujeng, I., & Kuswanto, H. (2023). The Effect of Mobile Learning Integrated Traditional Games Egrang to Improve Multiple Representation Skills. *J.Sci.Learn.2023*, *6*(4), 435–441. https://doi.org/10.17509/jsl.v6i4.57961

Rahmayani, F., Kuswanto, H., & Rahmat, A. D. (2024). 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 Education Technology*, *14*(4), 632–641. https://doi.org/10.18178/ijiet.2024.14.4.2087

Raras, M., & Kuswanto, H. (2019). Developing jemparingan tradition-based and android- assisted learning media for improving the graphic and vector representation ability. *International Journal of Interactive Mobile Technologies*, *13*(5), 58–74. https://doi.org/10.3991/ijim.v13i05.9926

Rexigel, E., Kuhn, J., Becker, S., & Malone, S. (2024). The More the Better? A Systematic Review and Meta-Analysis of the Benefits of More than Two External Representations in STEM Education. *Educational Psychology Review*, *36*(4). https://doi.org/10.1007/s10648-024-09958-y

Riechmann, M., Koenig, M., & Rexilius, J. (2022). *3D-Multi-Layer-Multi-Representation-Maps for Short- and Long-term Mapping and Navigation*. https://doi.org/10.1109/ICAC55051.2022.9911141

Risdianto, E., Dinissjah, M. J., Nirwana, & Kristiawan, M. (2020). The effect of Ethno science-based direct instruction learning model in physics learning on students' critical thinking skill. *Universal Journal of Educational Research*, *8*(2), 611–615. https://doi.org/10.13189/ujer.2020.080233

Rosa, G. C., Cari, C., Aminah, N. S., & Handhika, J. (2018). Students' understanding level and scientific literacy competencies related to momentum and impulse. *Journal of Physics: Conference Series*, *1097*(1), 012019.

Saputra, H., Mansyur, J., & Supriyatman. (2021). The Effect of the Conceptual Problem Solving (CPS) Approach on Students' Representation and Problem-Solving Ability in Physics. *Jurnal Pendidikan Fisika Tadulako Online (JPFT)*, *9*(1), 7–14. http://jurnal.fkip.untad.ac.id/index.php/jpft7PENGARUHPENDEKATANCONCEPTUALPROBLEMSOLVING

Saputra, M. R. D., & Kuswanto, H. (2019). The effectiveness of Physics Mobile Learning (PML) with HomboBatu theme to improve the ability of diagram representation and critical thinking of senior high school students. *International Journal of Instruction*, *12*(2), 471–490. https://doi.org/10.29333/iji.2019.12230a

Sari, F. P., Nikmah, S., Kuswanto, H., & Wardani, R. (2020). Development of physics comic based on local wisdom: Hopscotch (engklek) game android-assisted to improve mathematical representation ability and creative thinking of high school students. *Revista Mexicana de Fisica E*, *17*(2 Jul-Dec), 255-262.. https://doi.org/10.31349/REVMEXFISE.17.255

Serevina, V., & Meyputri, C. U. (2021). Development of blended learning based on website on fluid mechanic material to improve students' creative thinking skills. *Journal of Physics: Conference Series*, *1876*(1). https://doi.org/10.1088/1742-6596/1876/1/012070

Setiyadi, A., Darma, R. S., Wilujeng, I., Jumadi, & Kuswanto, H. (2019). Mathematical Representations Mapping of High School Students after using Multimedia Learning Modules Assisted by an Android Smartphone. *Journal of Physics: Conference Series*, *1233*(1). https://doi.org/10.1088/1742-6596/1233/1/012049

Setiyadi, A., Oktavia, D. A., Darma, R. S., & Nursuhud, P. I. (2020, February). The Development of Terbang Papat and Larung Sesaji Local Wisdom-Based Physics Learning Module to Increase the Senior High School Students' Physics Representation Ability in Realizing Nature of Sciences. In *International Conference on Educational Research and Innovation (ICERI 2019)* (pp. 90-94). Atlantis Press.

Sharma, V., Gupta, N. L., & Agarwal, A. K. (2023). Impact of ICT-Enabled Teaching–Learning Processes in Physical Sciences in Indian Higher Education in Light of COVID-19: A Comprehensive Overview. *National Academy Science Letters*, *46*(5), 465–469. https://doi.org/10.1007/s40009-023-01225-y

Sudarmiani, & Trilaksana, A. (2020). Implementation of the scientific approach on social studies learning based on local wisdom through advanced organizer learning models of the students of junior high schools. *Journal of Physics: Conference Series*, *1464*(1). https://doi.org/10.1088/1742-6596/1464/1/012022

Susac, A., Planinic, M., Bubic, A., Jelicic, K., & Palmovic, M. (2023). Effect of representation format on conceptual question performance and eye-tracking measures. *Physical Review Physics Education Research*, *19*(2). https://doi.org/10.1103/PhysRevPhysEducRes.19.020114

Susanti, A., Diani, R., Satiarti, R. B., Munawaroh, R., & Fujiani, D. (2021). Blended learning model: The effect on physics problem-solving skills viewed from self-efficacy. *IOP Conference Series: Earth and Environmental Science*, *1796*(1). https://doi.org/10.1088/1742-6596/1796/1/012014

Sutton, A., Clowes, M., Preston, L., & Booth, A. (2019). Meeting the review family: exploring review types and associated information retrieval requirements. In *Health Information and Libraries Journal* (Vol. 36, Issue 3, pp. 202–222). Blackwell Publishing Ltd. https://doi.org/10.1111/hir.12276

Takaoğlu, Z. B. (2024). High School Students' Multiple Representation Translation Skills on One-Dimensional Motion: A Cross-Grade Study. *J.Sci.Learn.2024*, *7*(1), 47–55. https://doi.org/10.17509/jsl.v7i1.61099

Treagust, D. F., Duit, R., & Fischer, H. E. (2017). *Models and Modeling in Science Education Multiple Representations in Physics Education*. Springer. https://doi.org/10.1007/978-3-319-58914-5

Treagust, D., Won, M., & McLure, F. (2018). Multiple representations and students' conceptual change in science. In T. G. Amin & O. Levrini (Eds.), *Converging Perspectives on Conceptual Change* (pp. 121–128). Routledge. https://doi.org/10.4324/9781315467139-16

Ubaidillah, M., Hartono, Marwoto, P., Wiyanto, & Subali. (2023). How to Improve Critical Thinking in Physics Learning? A Systematic Literature Review. *Journal of Educational, Cultural and Psychological Studies (ECPS Journal)*, *28*, 161–187. https://doi.org/10.7358/ecps-2023-028-ubai

Unyapoti, T., Arayathanitkul, K., & Emarat, N. (2020). Momentum Vector Diagrams. *The Physics Teacher*, *58*(9), 637–641. https://doi.org/10.1119/10.0002730

Utami, N. A., Sa'dijah, C., & Chandra, T. D. (2024). Students' abilities in mathematical representation to solve mathematics problems. *AIP Conference Proceedings*, *3106*(1), 050012. https://doi.org/10.1063/5.0215805

Warsono, Nursuhud, P. I., Darma, R. S., Supahar, & Oktavia, D. A. (2020). Multimedia learning modules (MLMs) based on local wisdom in physics learning to improve student diagram representations in realizing the nature of science. *International Journal of Interactive Mobile Technologies*, *14*(6), 148–158. https://doi.org/10.3991/IJIM.V14I06.11640

Widyawati, A., Kuswanto, H., Sanioso, A. P., & Zhanbyrbaevna, T. M. (2024). The teachings of tamansiswa (niteni, nirokke, nambahi) based epbl-stem: is it feasible to improve critical thinking skills and science verbal representation?. *Revista de Gestão Social e Ambiental*, *18*(7), 1-18. https://doi.org/10.24857/rgsa.v18n7-027

Wirjawan, J. V.D., Pratama, D., Pratidhina, E., Wijaya, A., Untung, B., & Herwinarso. (2020). Development of smartphone app as media to learn impulse-momentum topics for high school students. *International Journal of Instruction*, *13*(3), 17–30. https://doi.org/10.29333/iji.2020.1332a

Xu, W., Liu, Q., Koenig, K., Fritchman, J., Han, J., Pan, S., & Bao, L. (2020). Assessment of knowledge integration in student learning of momentum. *Physical Review Physics Education Research*, *16*(1), 10130. https://doi.org/10.1103/PhysRevPhysEducRes.16.010130

Yeo, J., & Gilbert, J. K. (2017). The role of representations in students' explanations of four phenomena in physics: Dynamics, thermal physics, electromagnetic induction and superposition. In D. F. Treagust, R. Duit, & H. E. Fischer (Eds.), *Multiple representations in physics education, models and modeling in science education 10*. Springer. https://doi.org/10.1007/978-3-319-58914-5_12