

Trends of Multiple Representations in Physics Learning (2020-2025): A Systematic Literature Review

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Systematic Review

Keywords: multiple representations, physics education, systematic literature review, bibliometric analysis, higher-order thinking skills

Posted Date: September 10th, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-10980344/v1>

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Additional Declarations: The authors declare no competing interests.

Abstract

This study investigates research trends and reported effects of multiple representations in physics learning through a systematic literature review combined with bibliometric analysis. Data were collected from the Scopus database covering the period 2020–2025, yielding 527 documents, of which 28 empirical studies were selected following the PRISMA protocol. Bibliometric analysis using Biblioshiny identified publication trends, influential works, productive countries, and thematic developments. The results indicate a significant increase in research output after 2022, reflecting growing global attention to multiple representations in physics education. Network visualization shows that multiple representations function as a central conceptual framework connecting conceptual understanding, critical thinking, problem solving, assessment, and technology integration. Content analysis reveals that verbal, graphical, and diagrammatic representations are the most frequently used, followed by mathematical representations. Most studies report positive effects on students' conceptual understanding, higher-order thinking skills, and engagement. However, these effects vary depending on instructional design, scaffolding strategies, sequencing of representations, and alignment with specific physics topics. Limited integration of cultural contexts and insufficient exploration of representational coordination remain key gaps. Future research is recommended to develop integrative frameworks, improve assessment of representational competence, and explore context-based and culturally responsive approaches in physics learning.

1. Introduction

Physics as a science that studies natural phenomena requires the ability to present various things to understand concepts. The capacity to describe physical processes in various representations can help students solve challenging physics problems. Therefore, the ability of students to present concepts in various ways is an interesting topic in physics and mathematics education (Kohl & Finkelstein, 2008). Different forms of representation illustrate a concept of a problem that can be addressed through multiple approaches, including written descriptions, drawings, illustrations, charts, and mathematical formulas (Campos et al., 2020; Fatmaryanti et al., 2018; Leisen et al., 2023; Testa & Catena, 2022; Warsono et al., 2020). Utilizing various forms of representation can assist learners in enhancing their innovative thinking when tackling challenges (Bicer, 2021).

Multiple representations allow to help teachers improve students' learning achievement, which can provide several different ideas and techniques in improving physics learning (Hartini & Sinensis, 2019). The majority of studies in physics focusing on various representations have taken place in the fields of kinematics, mechanics, and general physics classes (Volkwyn et al., 2020) instead of relying on archimedes' concept, earlier research has utilized three or four representations (Kriek & Legesse, 2023). Multiple representations refer to the combination of formats used to generate, process, or present information (Gilbert, 2008). In the realm of natural sciences, typical illustrations comprise graphs, textual descriptions, equations, and diagrammatic representations, along with representations that are specific to particular fields, such as Lewis structures in chemistry and free body diagrams in physics. Collectively,

these form part of the disciplinary community of discourse, defined by a common language expressed through shared understandings of representations (Driver et al., 1994). Multiple representation also means re-representing the same concept in different formats, including verbal, pictorial, graphic, and mathematical (Prain & Waldrup, 2008). In physics, representations are commonly presented in several complementary forms. These include diagrams, such as motion diagrams, free-body diagrams, field-line diagrams, and electrical circuit diagrams, which help students visualize physical phenomena. Graphical representations, including energy bar charts and momentum bar charts, illustrate relationships among physical variables and require students to develop the ability to interpret and construct graphs. Mathematical representations are essential for solving quantitative problems and expressing physical relationships precisely. However, mathematical representations are most effective when supported by qualitative representations, enabling students to understand the underlying concepts rather than merely memorizing formulas and equations.

This paper is different from several review papers that have been conducted by previous researchers, such as the review paper conducted by Munfaridah et al., (2021) who conducted a review of multiple representations of physics books at the university level. The research conducted focused on the undergraduate level and therefore failed to provide a more comprehensive synthesis of the knowledge base that encompasses all ages and educational levels. Rasyid et al., (2025) conducted a review related to improving multiple representation skills in physics learning. The research focuses on learning models, learning media and indicators used to measure multiple representation abilities. From the published papers, none have used analysis using VOSviewer and Biblioshiny to see the distribution of research related to multiple representations in the world. So, this is a new step to comprehensively find out the development of multiple representation research in physics learning. With these two methods, it is intended that research related to multiple representations can be found accurately and produce scientific reports.

A Bibliometric analysis is used in this study. A Bibliometric analysis is a powerful technique that can manage large amounts of data and produce systematic, visible, and reproducible findings (Aria et al., 2021). Through the analysis of conceptual, intellectual, and social structures, scientific mapping can show the knowledge structure and dynamics of a topic by evaluating bibliographic data (Sharm et al., 2021). According to the researcher's knowledge, there has been no previous study that uses bibliometric analysis using Rstudio to analyze multiple representations from related Scopus. Therefore, the purpose of this study is to provide a complete picture of multiple representations using bibliometric analysis tools. The main objectives of this study are as follows:

1. What are the most cited trends in publications and documents globally for the period 2020 to April 2025 with the theme of dual representation?
2. Where have the countries been most productive in dual representation over the past ten years? including the most cited countries!
3. How to visually represent the conceptual structure of the Scopus network visualization related to dual representation, the impact of dual representation and its indicators

4. How does multirepresentation integration improve the quality of physics learning?
5. When do multiple representations potentially hinder learning?
6. How can further research on multiple representation be conducted?

2. Methods

This research was conducted systematically with bibliometric analysis using a set of Biblioshiny in R language as an analysis tool. Biblioshiny is an application in visualization provided by the web with the R programming language to perform bibliometric analysis (Aria & Cuccurullo, 2017). Bibliometric analysis in this study is used to collect data, conduct in-depth analysis, and select research according to the topic. In-depth analysis in bibliometrics includes document analysis which includes document analysis with a quantitative approach and statistical visualization to help record bibliographic characteristics and current literature trends relevant to current research. Standard protocols for bibliometric analysis of individual journals were followed in this study, similar to other research studies (Bhat et al., 2023; Wakid et al., 2024). The first step taken in this research process is to determine keywords in the article search on the scopus database as follows.

1. There are 107 documents with keywords: (TITLE-ABS-KEY (representation) AND TITLE-ABS-KEY (physics education)) AND PUBYEAR > 2019 AND PUBYEAR < 2026 AND (LIMIT-TO (SUBJAREA, "PHYS") OR LIMIT-TO (SUBJAREA, "SOCI")) AND (LIMIT-TO (DOCTYPE, "ar")) AND (LIMIT-TO (LANGUAGE, "English")) AND (LIMIT-TO (SRCTYPE, "j")) AND (LIMIT-TO (OA, "all")).
2. There are 369 documents with keywords: (TITLE-ABS-KEY (physics learning) AND TITLE-ABS-KEY (representation learning)) AND PUBYEAR > 2019 AND PUBYEAR < 2026 AND (LIMIT-TO (SUBJAREA, "PHYS") OR LIMIT-TO (SUBJAREA, "SOCI")) AND (LIMIT-TO (DOCTYPE, "ar")) AND (LIMIT-TO (LANGUAGE, "English")) AND (LIMIT-TO (SRCTYPE, "j")) AND (LIMIT-TO (OA, "all"))
3. There are 14 documents with keywords: (TITLE-ABS-KEY (graphic) AND TITLE-ABS-KEY (physics) AND TITLE-ABS-KEY (representation)) AND PUBYEAR > 2019 AND PUBYEAR < 2026 AND (LIMIT-TO (SUBJAREA, "SOCI")) AND (LIMIT-TO (DOCTYPE, "ar")) AND (LIMIT-TO (LANGUAGE, "English"))
4. There are 23 documents with keywords: (TITLE-ABS-KEY (diagrams) AND TITLE-ABS-KEY (physics) AND TITLE-ABS-KEY (representation)) AND PUBYEAR > 2019 AND PUBYEAR < 2026 AND (LIMIT-TO (SUBJAREA, "SOCI")) AND (LIMIT-TO (DOCTYPE, "ar")) AND (LIMIT-TO (LANGUAGE, "English"))
5. There are 10 documents with keywords: (TITLE-ABS-KEY (figures) AND TITLE-ABS-KEY (physics) AND TITLE-ABS-KEY (representation)) AND PUBYEAR > 2019 AND PUBYEAR < 2026 AND (LIMIT-TO (SUBJAREA, "SOCI")) AND (LIMIT-TO (DOCTYPE, "ar")) AND (LIMIT-TO (LANGUAGE, "English"))
6. There are 55 documents with keywords: (TITLE-ABS-KEY (mathematics) AND TITLE-ABS-KEY (physics) AND TITLE-ABS-KEY (representation)) AND PUBYEAR > 2019 AND PUBYEAR < 2026 AND (LIMIT-TO (SUBJAREA, "SOCI")) AND (LIMIT-TO (DOCTYPE, "ar")) AND (LIMIT-TO (LANGUAGE, "English"))

A total of 578 documents were then collected in one database to filter out duplicate articles. The results of the duplicate article filter were obtained from 527 articles that were still filtered using abstract selection which aimed to remove articles that were not the results of the research, for example in the form of reviews, content analysis, which is in the form of analysis of methods, instruments, and results, as well as removing articles whose subjects were not school students at the senior high school level. This study adheres to the PRISMA guidelines to ensure a transparent and rigorous methodology as shown in Figure 1. All references were managed using Mendeley, while the remaining 28 articles were then read, analyzed, categorized, and coded using a spreadsheet program. In addition, what we want to reveal are the trends of the most cited publications and documents globally, where the most productive countries, topic trends and theme mapping use R studio software. R is an object-oriented and functional programming language, making it highly extensible and facilitating the automation of analysis and creation of new functions (Bhat et al., 2023).

3. Result and Discussion

Of the 527 articles obtained, 28 articles were then analyzed in depth. Many articles are omitted because most of them are review articles and do not focus on students. In addition, many articles discuss representation in general, not specifically in physics subjects at the high school level. To get concrete answers to the research questions asked, the researchers chose articles that really focused on the use of augmented in physics learning in schools.

Table 1 above provides an overview of the main information about the documents analyzed, offering a comprehensive data overview. Data obtained from the Scopus database related to multiple representations of 28 documents have been analyzed using Biblioshiny. From Table 1, an overview of the number of authors is 1361 and author's keywords are 1478.

Table 1
Essential Information about the data

Description	Result
Sources	Scopus
Period	2020:2025
Document	28
Authors	89
Single-authored doc	0
'Co-Authors per Doc'	3.46
'Author's Keywords'	91
'Average citations per doc'	8.464
Document Average Age	3.18
International co authorships Percentage	32.14

3.1. Publication Trend and Most Global Cited Documents

Based on the trend of research publications in Fig. 2 related to representation in physics learning at the high school level, it shows a significant increase in the last five years. After experiencing a decline in 2021 that was likely influenced by the limitations of field research during the pandemic, the number of publications increased sharply starting in 2022 and peaking in 2024. This increase indicates that representation, especially visual and technology-based multi-representation, is getting more attention in physics education.

To provide a more detailed understanding of the citation dynamics across publication years, Table 2 presents the distribution of publications along with their citation performance indicators, including mean total citations per article (Mean TC per Art), mean citations per year (Mean TC per Year), and citable years. The data reveal that earlier publications, particularly those from 2020, tend to have higher average citation counts compared to more recent publications. This pattern is expected, as older articles have had a longer time to accumulate citations. Furthermore, although recent publications (e.g., 2023–2025) show lower citation averages, this does not necessarily indicate lower impact, but rather reflects their shorter exposure time within the academic community.

Table 2
Distribution of Publications

Year	Mean TCperArt	N	MeanTCperYear	CitableYears
2020	27.80	5	3.97	7
2021	11.00	1	1.83	6
2022	6.67	6	1.33	5
2023	3.67	3	0.92	4
2024	3.12	8	1.04	3
2025	2.20	5	1.10	2

Building upon these citation patterns, the most globally cited documents are further identified and summarized in Table 3. Based on trends, it can be seen in Table 3. that the most frequently cited papers are (de Aldama & Pozo, 2020; Hochberg et al., 2020; Kokkonen et al., 2022; Matejak Cvenic et al., 2021; Permata Sari et al., 2020; Polverini et al., 2025; Rahmayani et al., 2024; Sari et al., 2022; Volkwyn et al., 2020; Xing et al., 2022). The most frequently cited references and authors, totaling 10, have been compiled and presented in Table 3. Many respected and high-quality journals have consulted and cited Scopus indexed papers in their research. Interestingly, the list of the most cited includes two publications from the *"Physical Review Physics Education Research"*. This shows that this journal has a significant impact on the field of multiple representation research, as evidenced by the large number of citations received for its publications. From Table 3, it can also be seen that the largest total citations of Hochberg et al. (2020), 9.43% come from the *Journal of Science Education and Technology*

Table 3
Most Global Cited Documents

Paper	TC	TC per Years	Normalized TC
Hochberg K, 2020, J Sci Educ Technol	66	9.43	2.37
Volkwyn Ts, 2020, Learn	31	4.43	1.12
Permata Sari F, 2020, Rev Mex Fis E	19	2.71	0.68
De Aldama C, 2020, J Educ Comput Res	18	2.57	0.65
Kokkonen T, 2022, Learn Instr	15	3.00	2.25
Matejak CveniĆ K, 2021, Phys Rev Phys Educ Res	11	1.83	1.00
Polverini G, 2025, Phys Rev Phys Educ Res	10	5.00	4.55
Xing H, 2022, J Baltic Sci Edu	6	1.20	0.90
Rahmayani F, 2024, Int J Inf Educ Technol	6	2.00	1.92
Abdurrahman A, 2022, Online Learn Edu Res	6	1.20	0.90

3.2. Most Productive and Cited Countries

Based on data from the Scopus database, as shown in Fig. 3, Indonesia is among the most productive countries in multiple representation research. This finding indicates that Indonesian researchers have made significant contributions to the development of multiple representation research. Indonesia's position among these leading countries demonstrates a strong commitment to advancing knowledge and promoting the implementation of multiple representations in physics education. This also highlights Indonesia's important role in contributing to the international development of multiple representation research and practice. The most important aspect of the classroom learning process is the transformation of information into knowledge through effective instructional practices. According van der Meij & de Jong (2006), students rarely interact directly with real-world phenomena in classroom settings. Instead, they learn through representations that provide information about real events, processes, or systems. Such representations are particularly valuable when real systems are too complex to be brought into the classroom (e.g., a physics experiment), too dangerous (e.g., surgical intervention), or inaccessible to direct observation (e.g., historical events). Therefore, representations should not be considered exact equivalents of real systems; rather, they serve as simplified descriptions that support students in constructing conceptual understanding.

Table 4 shows that the United States has the highest average number of citations per article (14.60), indicating the strong academic impact of its publications in multiple representation research. In terms of total citations, the United States also ranks first with 1,359 citations, followed by Germany (432), China (399), Australia (310), the United Kingdom (299), Switzerland (138), Italy (120), France (103), and India (92).

Table 4
Most Cited Countries

Country	TC	Average TC
USA	1359	14.60
Germany	432	16.00
China	399	15.30
Australia	310	18.20
UK	299	21.40
Switzerland	138	17.20
Italy	120	10.90
France	103	20.60
India	92	13.10

3.3. Network visualization

Figure 4 presents the VOSviewer visualization of the bibliometric map based on publications from 2020 to 2025. The analysis indicates that multiple representations have evolved from being primarily visualization support strategies to becoming a central pedagogical framework in physics education research. The central position of the keyword *multiple representations* in the co-occurrence network suggests that it functions as a conceptual bridge connecting conceptual understanding, problem-solving, and higher-order thinking skills. These findings confirm that representations are not merely tools for presenting information but also cognitive mechanisms that facilitate students' construction of scientific understanding. Furthermore, the prominent position of this keyword within the network highlights its increasing influence in guiding research directions and instructional innovations in physics education, emphasizing its role in promoting meaningful learning and conceptual development.

Historically, early research has focused more on strengthening conceptual understanding through a variety of representation formats (graphic, mathematical, verbal, and diagram). This approach is in line with the view that understanding the concept of physics requires the ability to translate between representations. In a theoretical perspective, this is consistent with the DeFT framework developed by Shaaron Ainsworth, which emphasizes that the use of multiple representations has three main functions: a complementary function, a constraining function, and a constructive function. Bibliometric maps show that complementary and constructive functions seem to be the dominant focus in early-stage research. However, the latest trend shows a significant shift. The overlay visualization reveals a distinct cluster centered on augmented reality, which is closely connected with critical thinking, problem-solving, graphical representation, and benthic (a traditional Indonesian game used as a local learning context). This cluster indicates that recent studies increasingly integrate multiple representations with immersive technologies to support higher-order cognitive skills. The emergence of keywords such as augmented

reality, animation, and adaptive learning in the most recent time span further suggests that this field is entering a phase of immersive technology integration. This integration not only enriches the forms of representation but also transforms the way representations interact with students' cognitive processes. As a result, representations are no longer static; instead, they have become more dynamic, interactive, and contextual.

Within the framework of multimedia learning theory put forward by Richard E. Mayer, learning effectiveness increases when information is presented through visual and verbal channels in an integrated manner, taking into account the principle of cognitive load. The integration of immersive technology can be understood as an extension of multimedia principles into a more complex and interactive learning environment. However, this increased complexity also demands careful representation design so as not to cause cognitive overload. Furthermore, the emergence of critical thinking as the dominant outcome in recent publications shows a paradigm shift from conceptual orientation to high-level cognitive orientation. This reflects a shift in focus from simply understanding the laws of physics to the ability to analyze, evaluate, and synthesize information based on various representations. In other words, multiple representations are now positioned as a means to develop Higher Order Thinking Skills (HOTS), not just to improve conceptual accuracy.

Epistemologically, this shift can also be attributed to the constructivist view of science learning, which emphasizes that understanding is built through active interaction with different forms of representation. In this context, the integration of immersive technologies expands opportunities for meaning construction by providing more authentic visual-spatial and interactive learning experiences. However, the bibliometric analysis also reveals several research opportunities that remain insufficiently explored. While recent studies have increasingly integrated multiple representations with immersive technologies to enhance conceptual understanding and higher-order thinking skills, their application in assessment remains relatively limited. The co-occurrence network shows that *assessment* forms an independent research cluster with only a weak connection to the central keyword *multiple representations*. This finding suggests that previous studies have focused primarily on the instructional role of multiple representations rather than on their integration into assessment practices. Consequently, assessment based on multiple representations remains an underexplored area, despite its potential to evaluate students' conceptual understanding, representational competence, and higher-order thinking skills more comprehensively. Furthermore, the relationship between multiple representations and cultural or local contexts is also relatively limited, indicating the need for more contextualized research. Future studies should therefore explore the integration of multiple representations into both assessment practices and culturally responsive learning environments to broaden their educational impact in physics education.

This opens up opportunities to develop a more contextual approach, for example by integrating representations based on local phenomena or ethnophysics in a technology-based learning environment. Overall, these results suggest that research on multiple representations is entering an integrative phase that combines cognitive approaches, digital technologies, and an orientation on the development of higher-level thinking skills. The challenge ahead is no longer to prove the effectiveness of representation

in general, but to design a learning ecosystem that systematically optimizes the interaction between various forms of representation, technology, and students' cognitive processes.

3.4. Word Cloud

After the overlay visualization analysis showed that the retrieved studies evolved toward the integration of immersive technology and an orientation to critical thinking, the word cloud visualization further strengthened these findings by illustrating the frequency of keyword occurrences, as shown in Fig. 5.

In the word cloud, physics education emerges as the most dominant contextual term, indicating that the retrieved studies are primarily situated within the field of physics education. This finding is consistent with the previous overlay visualization, which demonstrated that the major research clusters are strongly connected within the context of physics teaching and learning. As multiple representations was used as one of the primary search terms and inclusion criteria during the literature retrieval process, its prominent appearance in the word cloud is expected. Therefore, the interpretation focuses on the accompanying research themes that characterize the current development of multiple representations research.

Among these themes, augmented reality appears as one of the most prominent keywords, highlighting the increasing integration of immersive technologies into physics learning. This finding is consistent with the overlay visualization, which identified augmented reality as one of the most recent and rapidly developing research topics. Likewise, the frequent occurrence of critical thinking indicates that recent studies increasingly emphasize the development of higher-order thinking skills alongside conceptual understanding through multiple representation-based instruction.

Other prominent keywords, including local wisdom, assessment, science education, physics comic, mathematical representation, and secondary education, demonstrate the diversity of current research directions. These themes suggest that multiple representations have been widely integrated with contextual learning, digital technologies, innovative instructional media, and assessment practices to enhance students' learning experiences in physics education.

Overall, the word cloud complements the overlay visualization by emphasizing the frequency of major research themes, whereas the overlay illustrates their temporal development and structural relationships. The combination of these visualizations indicates that recent studies increasingly integrate multiple representations with emerging technologies, contextual learning approaches, and higher-order thinking skills within physics education.

The combined findings from the overlay visualization and word cloud reveal that:

1. Physics education remains the primary context for research on multiple representations.
2. Augmented reality has emerged as one of the most prominent technology-related research themes.\

3. Critical thinking is increasingly emphasized as an important learning outcome.
4. Current research demonstrates greater integration of multiple representations with contextual learning, digital technology, and innovative assessment practices.

Thus, both visualizations complement each other and reinforce the interpretation that the research landscape is moving toward an integrative, technology-enhanced, and representation-based approach to physics learning that supports the development of more complex cognitive competencies.

The thematic map presented in Fig. 6 illustrates the conceptual structure of the retrieved literature based on two dimensions: centrality, which reflects the relevance of a theme to the overall research field, and density, which indicates the degree of internal development of that theme. Because *multiple representations* was used as the primary search term and inclusion criterion, its prominent position in the thematic map is expected. Therefore, the interpretation focuses on the relative positions of the accompanying themes within the literature on multiple representations rather than treating the prominence of *multiple representations* itself as an independent finding.

The upper-right quadrant (motor themes) contains multiple representations, augmented reality, and local wisdom. Within the retrieved literature, the close association of augmented reality and local wisdom with multiple representations indicates that these topics constitute well-developed and highly connected research directions. This finding suggests that recent studies increasingly integrate multiple representations with immersive technologies and contextual learning approaches based on local wisdom.

In contrast, the upper-left quadrant (niche themes) includes science education, current, and physics. These themes exhibit relatively high internal development but weaker connections with the dominant themes in the multiple representations literature. Their position suggests that, although these topics have been investigated in specific contexts, they remain relatively isolated from the main thematic structure identified in this dataset.

The lower-left quadrant (emerging or declining themes) contains physics education, assessment instrument, and secondary education. Their location indicates relatively low centrality and density, suggesting that these themes are either emerging areas of investigation or topics that currently have weaker connections within the multiple representations literature. Based on the thematic map alone, it is not possible to determine whether these themes are genuinely emerging or declining.

The lower-right quadrant (basic themes) includes assessment. Its position indicates that assessment represents a fundamental topic connected to multiple representations research, although it exhibits lower internal development than the motor themes. This suggests that assessment continues to provide an important foundation for studies on multiple representations but is not currently among the most intensively developed thematic clusters.

Overall, the thematic map demonstrates that research on multiple representations is increasingly associated with themes such as augmented reality and local wisdom, indicating growing interest in integrating representational approaches with immersive technologies and contextual learning. Rather than describing the overall development of physics education research, the thematic map specifically illustrates how themes are organized and interconnected within the body of literature on multiple representations.

3.5. How representations can support conceptual change and improve physics learning.

To verify the findings obtained from the bibliometric analysis, a content analysis was conducted on the 28 articles that met the inclusion criteria. Each article was coded according to indicators describing the implementation of multiple representations in physics learning, including graphical, diagrammatic or image, mathematical, and verbal representations. Additional indicators comprised the integration of learning technologies, the incorporation of local wisdom or cultural contexts, and the emphasis on assessment. The coding results are summarized in Table 5.

Table 5
Encoding Results for 28 Articles

No	Content Analysis Indicators	Number of Articles
1	Use of graphical representations	27
2	Use of diagram or image representations	27
3	Use of mathematical representations	23
4	Use of verbal representations	28
5	Integration of learning technologies (augmented reality, simulation, AI, digital media)	20
6	Relevance to local wisdom or cultural context	8
7	The main focus is on the assessment aspect	28

The coding results presented in Table 5 indicate that verbal representations were incorporated in all selected studies (28 articles), followed by graphical representations (27 articles), diagram or image representations (27 articles), and mathematical representations (23 articles). These findings suggest that contemporary studies rarely rely on a single representational format. Instead, physics learning commonly combines verbal explanations, visual representations, and mathematical expressions to facilitate students' understanding of scientific concepts from complementary perspectives. Such findings indicate that coordinating multiple representational forms has become a common instructional approach in physics education.

The analysis also shows that learning technologies, including augmented reality, simulations, artificial intelligence, and other digital media, were integrated into 20 studies, reflecting the growing adoption of technology-enhanced learning environments. In contrast, only eight studies explicitly incorporated local wisdom or cultural contexts, indicating that sociocultural perspectives remain relatively underrepresented in multiple representations research. Furthermore, all reviewed studies emphasized assessment, suggesting that representational competence is increasingly regarded not only as a learning strategy but also as an educational outcome that can be systematically evaluated. Previous studies have demonstrated that diagrammatic representation-based assessment instruments validated using Item Response Theory can reliably measure students' representational competence and higher-order thinking skills (Warsono et al., 2020).

Although Table 5 shows that assessment, graphical representations, and diagrammatic representations appear in almost all selected studies, this finding should not be interpreted as implying that these themes occupy equally central positions in the bibliometric network presented in Fig. 4. The apparent difference arises because the two analyses address different dimensions of the literature. The content analysis summarizes instructional characteristics identified from the full text of each article, whereas the network visualization is constructed from keyword co-occurrence extracted from bibliographic metadata. Consequently, a representational approach may be widely implemented in instructional practice without necessarily appearing as a highly connected keyword if authors use different terminology or emphasize different research focuses. Therefore, the differences between Table 5 and Fig. 4 do not indicate contradictory findings but rather demonstrate the complementary nature of content analysis and bibliometric mapping.

The prevalence of multiple representational formats raises an important question regarding how these representations contribute to conceptual change in physics learning. Across the reviewed studies, representations function as cognitive bridges linking observable phenomena, visual models, verbal explanations, and mathematical formulations. Rather than functioning independently, each representation contributes different epistemic information that enables learners to translate concepts across multiple forms of representation. Inquiry-based learning studies have shown that students' engagement in experimentation combined with graphical interpretation significantly enhances conceptual understanding by connecting empirical observations with formal scientific models (Siahaan et al., 2025). Similarly, Volkwyn et al. (2020) demonstrated that coordinating visual representations with formal models promotes more stable conceptual structures and facilitates meaningful conceptual change.

However, the frequent use of multiple representations does not automatically guarantee effective learning. When learners are simultaneously exposed to diagrams, graphs, mathematical equations, and verbal explanations without appropriate instructional guidance, the limited capacity of working memory may become overloaded. Under these circumstances, representations that are intended to complement one another may instead compete for learners' cognitive resources, thereby hindering conceptual understanding. This finding is consistent with Matejak Cvenic et al. (2021) who reported that students

often experience misconceptions when interpreting diagrams without sufficient scaffolding. Likewise, Polverini et al. (2025) highlighted the complexity of visual reasoning even in technology-supported learning environments. Niyomufasha et al. (2024) further reported that engineering students tended to rely primarily on mathematical equations while experiencing difficulties translating between mathematical and visual representations. These findings indicate that the effectiveness of multiple representations depends not only on the availability of different representational formats but also on appropriate instructional scaffolding that supports students in coordinating and translating among representations.

The content analysis further demonstrates that different representational formats are suitable for different areas of physics. Graphs and vector diagrams are predominantly employed in mechanics and kinematics, where position-time graphs, velocity-time graphs, and free-body diagrams connect observable motion with formal physical laws. In electricity and magnetism, macro-micro-symbolic coordination through circuit diagrams, field-line visualizations, and mathematical equations is essential for explaining phenomena that cannot be directly observed (Campos et al., 2020). In optics, dynamic diagrams and spatial visualizations are particularly effective for explaining polarization and refraction, whereas symbolic notation and mathematical models remain fundamental in modern physics, although they require conceptual visual support to reduce abstraction (Tuveri et al., 2025). These findings demonstrate that no single representational format is universally effective across all physics topics. Rather, the effectiveness of multiple representations depends on the compatibility between the representational format and the epistemic structure of the concept being learned.

Several instructional innovations have successfully implemented multiple representations in physics learning. These include augmented reality integrated with local wisdom (Alfianti et al., 2023), STEM-based augmented reality e-books (Rahmayani et al., 2024), representational fluency activities (Hill & Sharma, 2015), authentic remote laboratory learning (Fatmaryanti et al., 2024), and Multiple External Representations combining hands-on experiments, magnetic field-line diagrams, and mathematical representations to support students' understanding of electromagnetic induction (Lichtenberger et al., 2024). Likewise, Tomkelski et al. (2023) demonstrated that integrating multiple representational expressions into Ohm's law instruction helps students establish meaningful connections among conceptual, graphical, and mathematical representations. These studies consistently suggest that learning effectiveness increases when students are guided to coordinate and translate information across multiple representational formats rather than relying on a single representation.

Physics learning through multiple representations therefore extends beyond classroom instruction to include assessment practices. Representations should be integrated not only during learning activities but also within assessment tasks to evaluate students' ability to interpret, translate, and coordinate different representational forms (Izsák & Sherin, 2003). Nevertheless, the reviewed studies indicate that individual researchers do not necessarily employ all representational formats simultaneously. Instead, the selection of representations is generally adapted to the instructional objectives, the characteristics of the physics topic, and the intended learning outcomes.

Finally, the relatively limited integration of local wisdom identified in Table 5 highlights an important research gap. Although recent studies increasingly integrate multiple representations with immersive technologies, comparatively few have incorporated sociocultural contexts into representation-based learning. Moreover, despite the strong emphasis on assessment, further research is needed to develop comprehensive assessment instruments capable of evaluating students' ability to coordinate multiple representational formats. Addressing these gaps will contribute to the development of more contextually relevant and pedagogically effective multiple representations-based physics learning.

3.6. Conditions Where Multiple Representations Have the Potential to Hinder Learning

Although most of the studies analyzed reported the positive impact of multiple representations on conceptual understanding and higher-level thinking skills, this synthesis also showed that their effectiveness was not automatic. Multiple representations can potentially hinder learning if they are not designed and implemented systematically. One of the main factors that can hinder learning is excessive cognitive load. When learners are exposed to various formats of representation (diagrams, graphs, equations, and verbal explanations) simultaneously without adequate guidance, working memory capacity can be exceeded. In this condition, representations that are supposed to complement each other actually compete in the cognitive processing process. Some of the studies analyzed showed that learners had difficulty coordinating graphs, diagrams, and equations if they were not given clear scaffolding in the process of translation between representations.

In addition, the potential for misconception also arises due to incorrect visual interpretation. The findings reported by Matejak Cvenic et al. (2021) and his colleagues suggest that high school students can misinterpret light polarization diagrams when they don't yet have an adequate conceptual foundation. This confirms that exposure to various representations does not directly guarantee the formation of a correct understanding; Representation requires structured conceptual mediation. Another obstacle found is an imbalance of representation preferences. Some studies show that students, especially in the context of engineering, tend to rely more on mathematical equations than on visual representations or graphs. Over-reliance on one form of representation can limit cognitive flexibility and reduce translational ability between representations, which is precisely the core of representational competence in physics.

Furthermore, the integration of immersive technologies such as augmented reality also presents design challenges. Although the technology enriches the visualization of abstract phenomena, an overly complex learning environment can create a split-attention effect. The findings of Polverini et al. (2025) show that tasks involving visual representation still require systematic cognitive guidance, even in the context of intelligent systems. Thus, multiple representations have the potential to inhibit learning when the complexity of representation exceeds the cognitive readiness of students, No scaffolding is available for translation between representations; The order in which the representation is presented is not designed progressively, and Technology integration emphasizes the visual aspect more than conceptual

coherence. These findings confirm that the effectiveness of multiple representations is conditional and relies heavily on instructional design based on cognitive principles.

3.7. Directions for Advanced Research in Multiple Representations

Based on the findings of the bibliometric and content analyses, several directions for future research can be identified. First, future studies should focus on developing a more integrative theoretical framework for multiple representations. Greater attention should be given to the cognitive mechanisms underlying representational coordination, particularly how students construct conceptual understanding by translating information across different representational formats. Consequently, future research should move beyond evaluating the overall effectiveness of multiple representations toward investigating the internal cognitive processes that facilitate conceptual change. Second, methodological innovation is needed in assessing representational competence. Although all of the reviewed studies emphasized assessment, relatively few developed instruments capable of comprehensively evaluating students' ability to coordinate and translate across multiple representations. Future research should therefore prioritize the development of diagnostic assessment instruments that capture not only learning outcomes but also the cognitive processes involved in constructing and integrating multiple representations.

Third, the integration of immersive technologies should be guided by established cognitive principles. Augmented reality, interactive simulations, and artificial intelligence should be designed in accordance with Cognitive Load Theory and multimedia learning principles. Future research should therefore focus on adaptive learning environments capable of adjusting the complexity of multiple representations according to students' prior knowledge, cognitive readiness, and learning progress. Fourth, expanding the integration of cultural and local contexts remains an important research direction. The analysis revealed that only a limited number of studies (8 of 28) explicitly incorporated local wisdom or culturally relevant contexts into representation-based physics learning. In the context of this review, local wisdom refers to the integration of local cultural practices, indigenous knowledge, and familiar environmental or natural phenomena into physics learning to provide meaningful contexts for explaining abstract scientific concepts. The available evidence suggests that such contextualization can enhance the meaningfulness and relevance of learning by connecting scientific concepts with students' everyday experiences (Alfianti et al., 2023; Rahmayani et al., 2024). However, given the relatively small number of studies identified, further empirical research is required to determine the effectiveness and generalizability of local wisdom-based multiple representations across diverse educational contexts.

Overall, future research should move beyond simply demonstrating the effectiveness of multiple representations toward designing systematic, adaptive, and context-sensitive learning environments. Such environments should integrate multiple representational formats, appropriate instructional scaffolding, educational technologies, and, where appropriate, culturally meaningful contexts to optimize students' conceptual understanding and cognitive development.

4. Conclusion

This study synthesizes the reported effects of multiple representations in physics learning through a combined systematic review and bibliometric analysis. The bibliometric findings indicate a significant growth of research in the last five years, with increasing global contributions and expanding thematic diversity. Network visualization demonstrates that multiple representations occupy a central position in the research landscape, closely connected to conceptual understanding, critical thinking, problem solving, assessment, and technology integration. The content analysis of selected empirical studies reveals that the majority consistently report positive effects of multiple representations on students' conceptual understanding and higher-order thinking skills. Verbal, graphical, and diagrammatic representations dominate instructional practices, while mathematical representations remain essential for formal reasoning processes. Furthermore, the integration of digital technologies such as augmented reality and simulations reflects a transition toward more interactive and immersive representational environments. However, the reported effects are not uniform. Their effectiveness depends strongly on instructional design, scaffolding strategies, representational sequencing, and alignment with the epistemic structure of specific physics topics. The limited incorporation of cultural or local contextual elements also highlights an important research gap that requires further exploration. Overall, the findings suggest that multiple representations are increasingly conceptualized not merely as complementary visual tools, but as structured cognitive environments that facilitate conceptual restructuring and deeper knowledge construction. Future research should focus on developing comprehensive assessment instruments for representational competence, investigating optimal representational coordination strategies, and expanding contextualized and culturally responsive approaches in physics education.

5. Limitations

This systematic literature review has several limitations that should be considered when interpreting the findings.

First, the data collection was limited to a single database, namely Scopus. Although Scopus is one of the most comprehensive and reputable indexing databases, this restriction may have led to the exclusion of relevant studies indexed in other databases such as Web of Science, ERIC, or Google Scholar. As a result, some potentially valuable contributions to the field of multiple representations in physics learning may not have been captured.

Second, this study included only peer-reviewed journal articles published in English. Other types of publications, such as conference proceedings, books, and book chapters, as well as non-English publications, were excluded. This may introduce publication and language bias, particularly considering that innovative instructional practices are often first reported in conference venues or local-language journals.

Third, the analysis was confined to a specific time span (2020–2025), which, although reflecting recent developments, may not fully capture earlier foundational studies or the most recent publications beyond

the data collection period. Given the rapid advancement of technology-enhanced learning and digital representations, future studies should consider expanding the temporal scope.

Fourth, the categorisation of representation types, learning approaches, and research focuses was based on the authors' interpretation during the content analysis process. Despite efforts to ensure consistency through iterative coding and discussion, a degree of subjectivity remains inherent in qualitative synthesis, which may influence the classification outcomes.

Fifth, the bibliometric analysis conducted in this study focuses on publication trends, citation patterns, and keyword co-occurrence, rather than evaluating the effectiveness of instructional interventions. Therefore, the findings should not be interpreted as direct evidence of the pedagogical impact of multiple representations on student learning outcomes.

Finally, the included studies employed diverse research designs, contexts, and measurement approaches, which limit the possibility of direct comparison across studies. Variations in educational levels, physics topics, and representational formats may also affect the generalisability of the findings.

Despite these limitations, this study provides a comprehensive overview of current trends and reported effects of multiple representations in physics learning, offering valuable insights for future research and instructional design.

Declarations

Author Statement

The authors declare that there is no conflict of interest.

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Figures

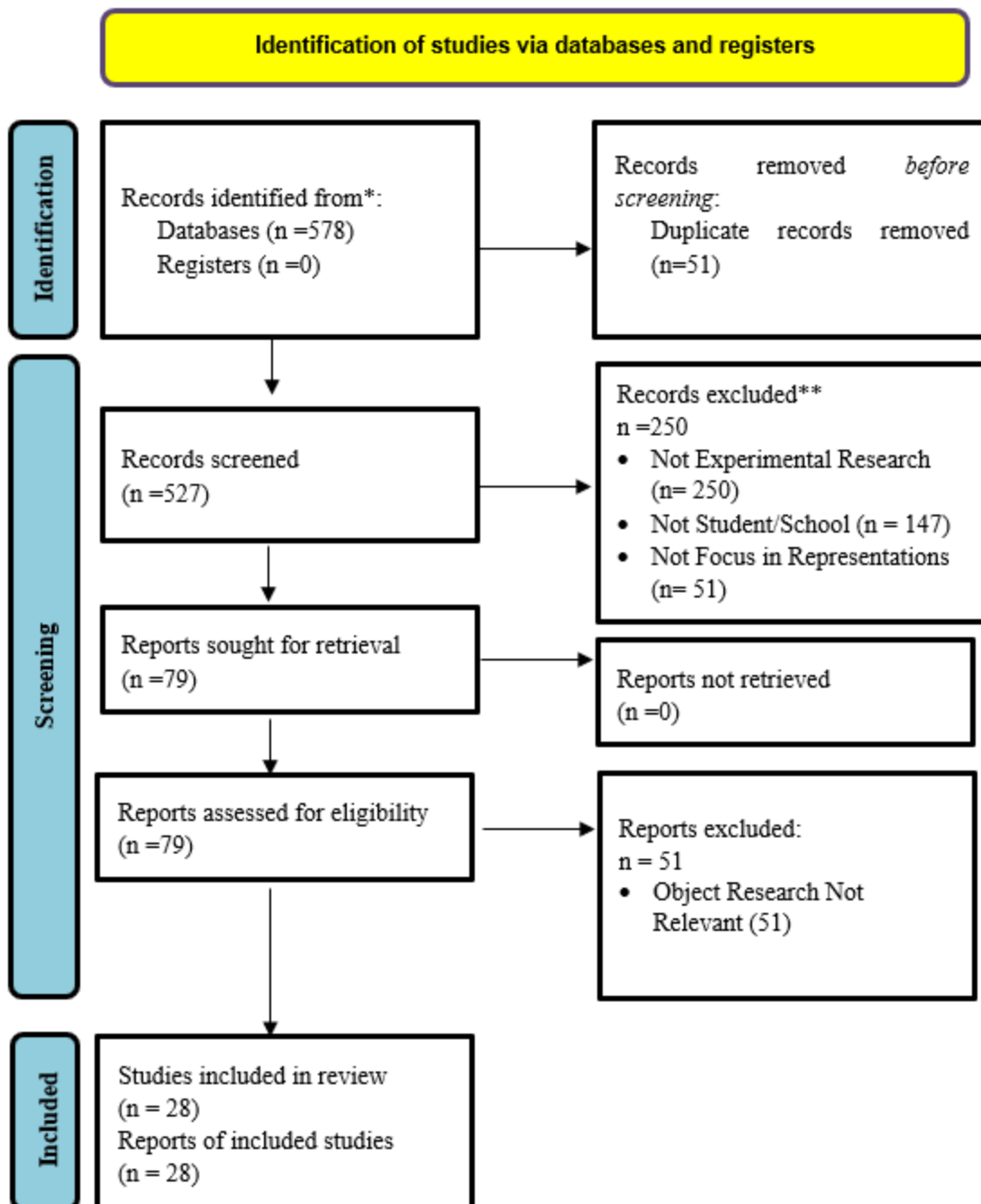


Figure 1

PRISMA Method and Bibliometrix

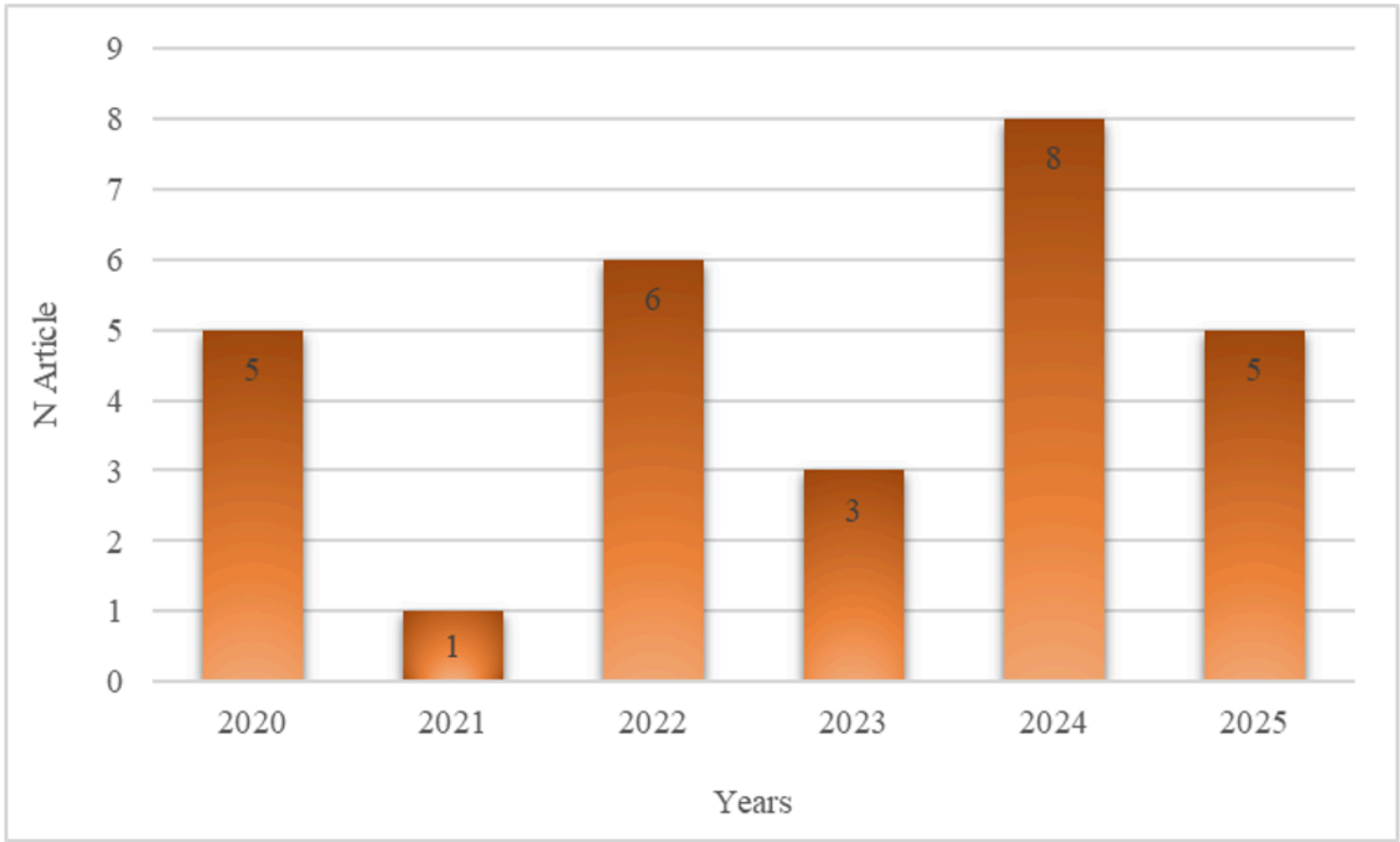


Figure 2

Number of documents by year based on Scopus data from 2020 to 2025.

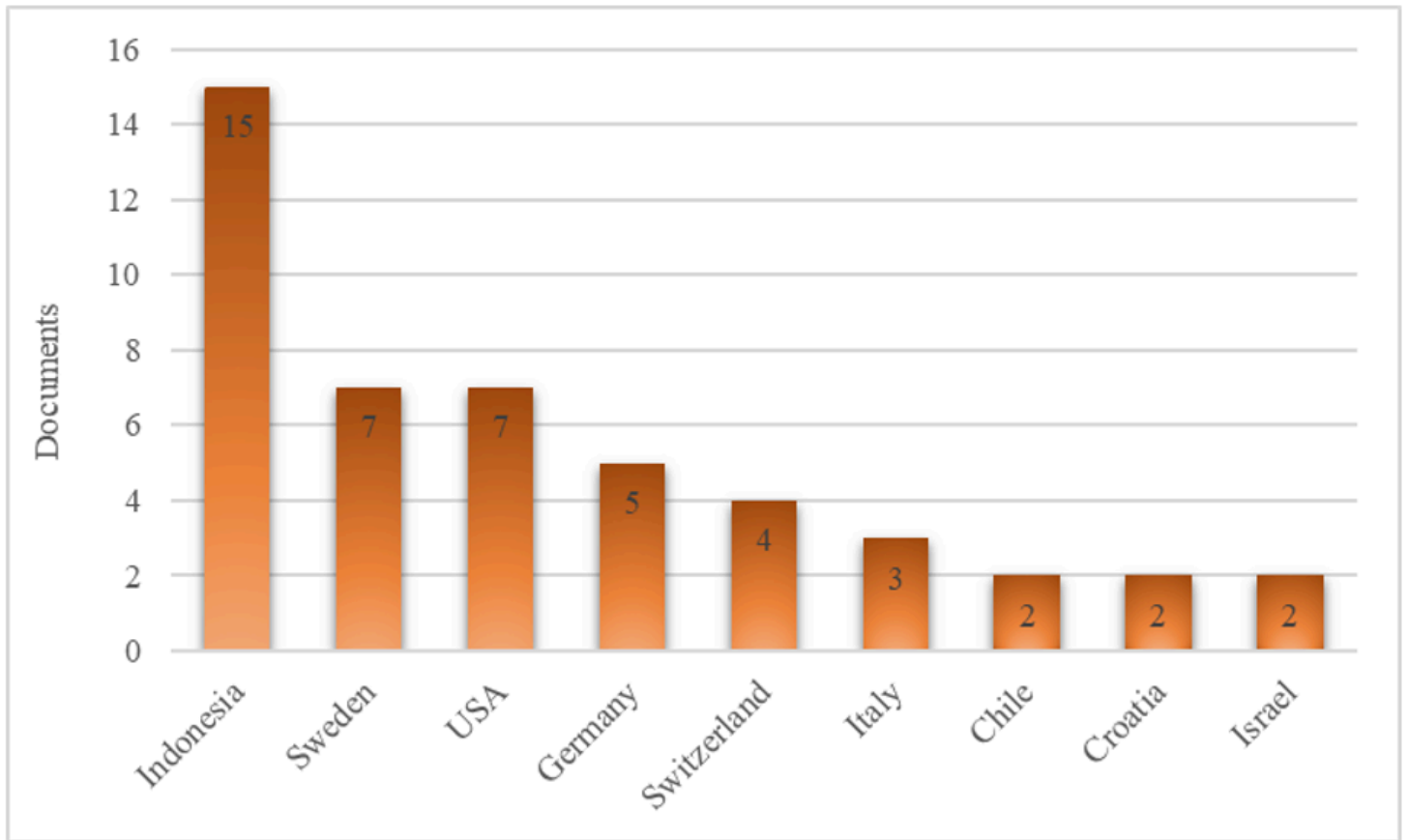


Figure 3

Most Productive Countries

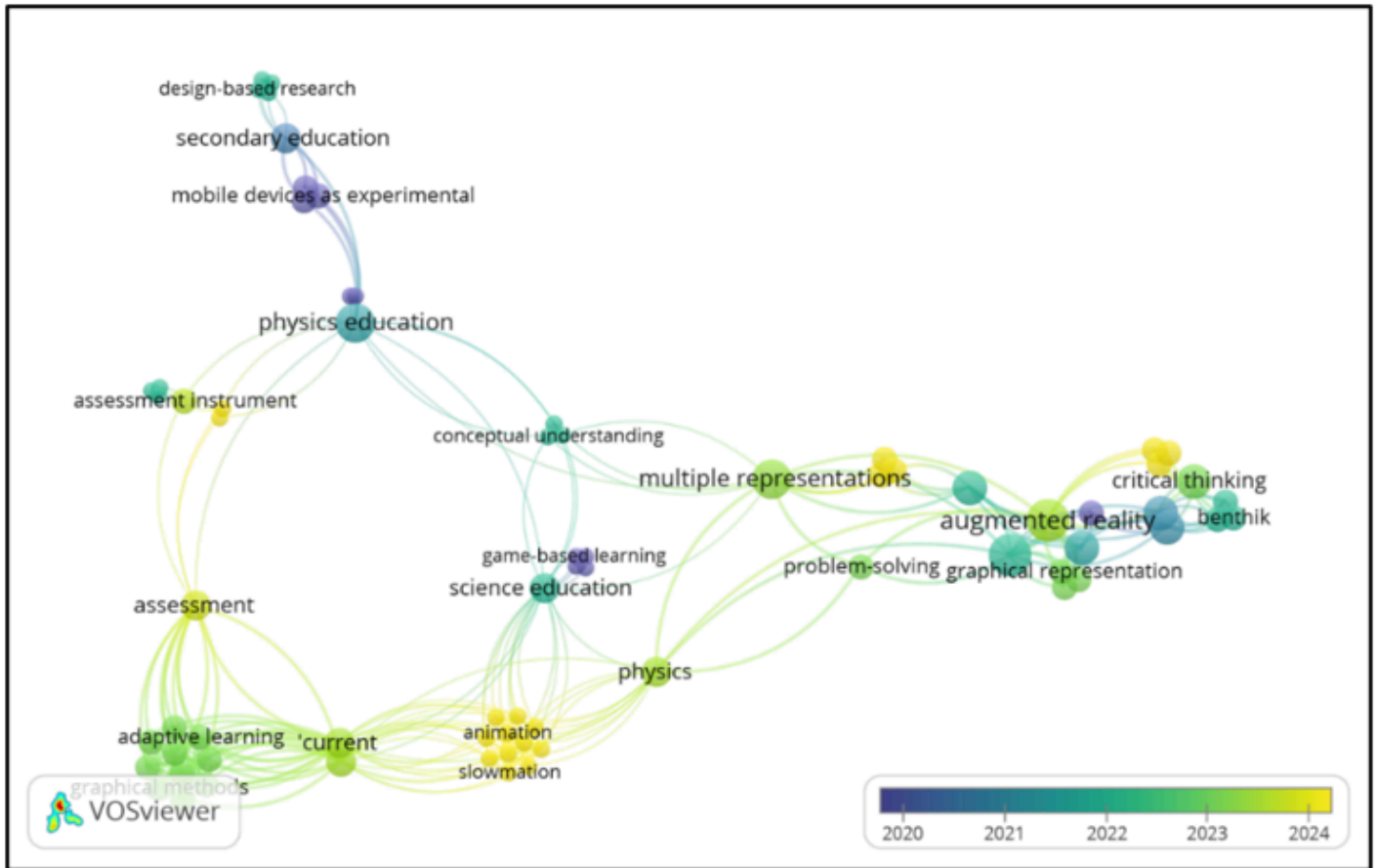


Figure 4

Network visualization related to Multiple representation.

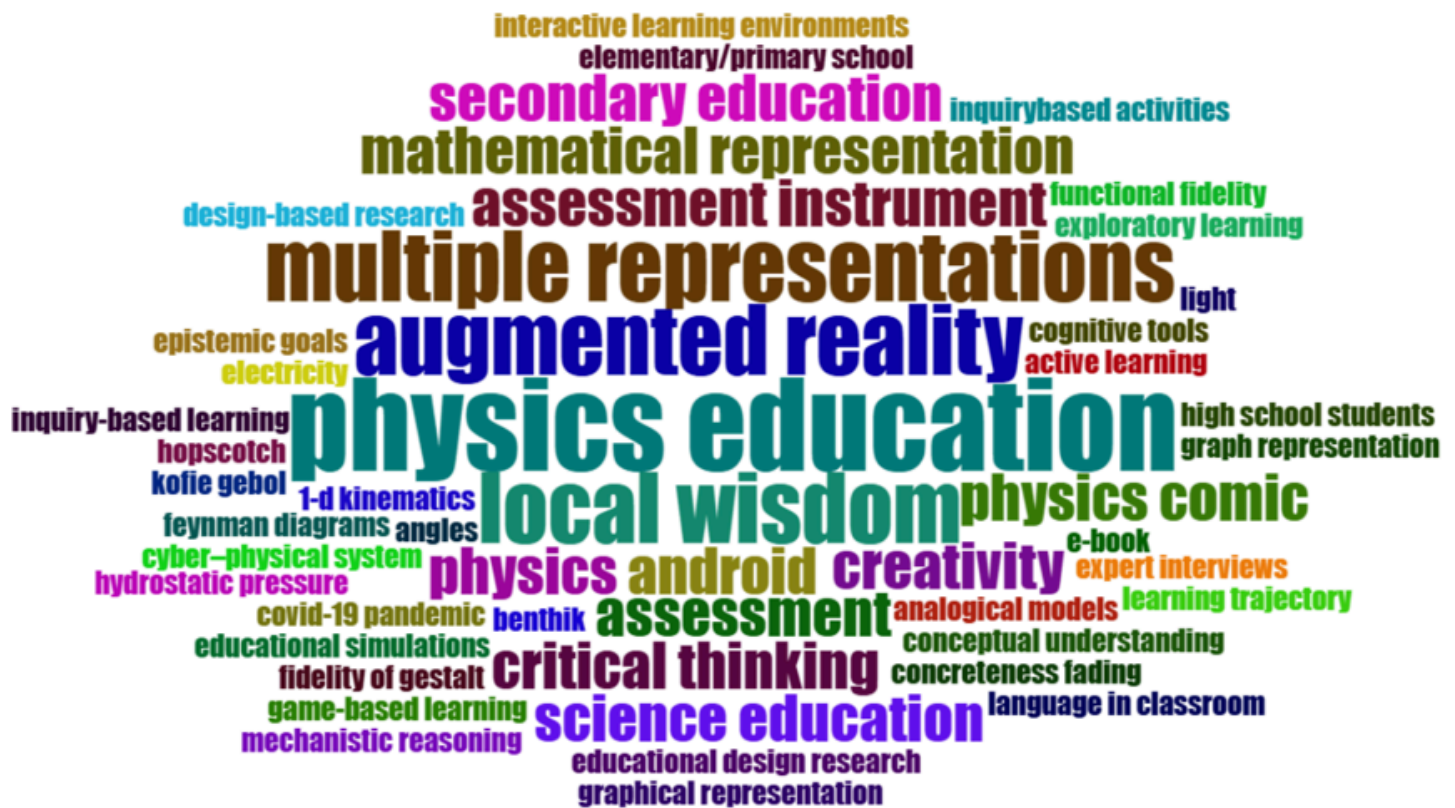


Figure 5

Word Cloud

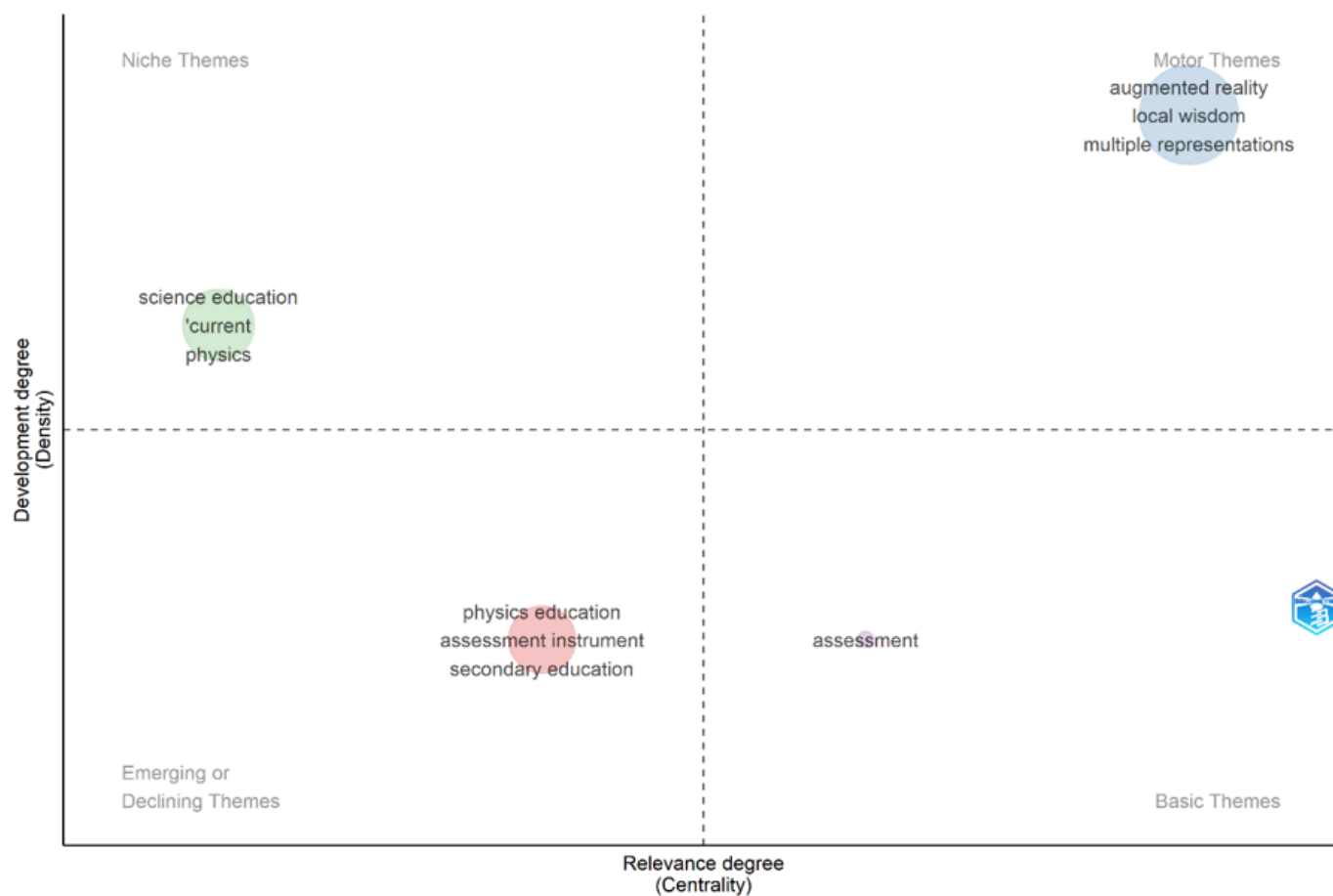


Figure 6

Thematic Map