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Innovation Trends In Multirepresentational Digital Worksheets Research For Physics Education

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Abstract

General Background Digital technologies provide unprecedented opportunities to integrate abstract, visual, verbal, and mathematical elements into physics education materials. **Specific Background** Although product-specific case studies demonstrate the feasibility of digital media, a comprehensive systematic visualization linking thematic shifts, research saturation, and institutional collaboration patterns regarding multirepresentational tools has not been firmly established. **Knowledge Gap** Existing bibliometric mapping either focuses broadly on digital tools or isolates representation theories without examining the intersection and thematic evolution specifically within digital worksheets. **Aims** This study maps the publication trends, dominant research topics, structural collaboration networks, and thematic evolution surrounding multirepresentationaldigital worksheets in physics education from 2016 through mid-2026. **Results** Bibliometric analysis of 35 documents reveals a fluctuating but generally upward publication trend peaking in 2026. Network visualization identified five dominant clusters revolving around product development, validity testing, cognitive assessment using N-Gain, and student engagement strategies. Thematic shifts indicate a transition from COVID-19 emergency tools to sophisticated R&D product testing focused predominantly on mechanics and thermodynamics. However, collaboration structures remain isolated within narrow, localized institutional networks. **Novelty** This mapping highlights the saturation of classical mechanics topics and quantitatively pinpoints low-density research areas requiring urgent investigation. **Implications** Consequently, future studies must expand institutional partnerships, address abstract modern physics concepts, and integrate adaptive learning algorithms or augmented reality to advance multimodal physics education.

Highlights

- Multirepresentational digital worksheet research experienced significant upward momentum, peaking in 2026.

- Current literature demonstrates heavy saturation within classical mechanics and localized collaboration.

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• Augmented reality and modern physics applications represent high-value opportunities for future studies.

Keywords

Bibliometric Analysis; Digital Worksheet; Multirepresentational; Physics Education; Thematic Evolution

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INTRODUCTION

Learning physics requires students to understand phenomena through various forms of representation, such as verbal, visual, graphical, and mathematical. The ability to interpret and connect these representations is important because each form of representation presents different information that complements one another in explaining physics concepts [1][2]. However, students still face difficulties in making connections between representations, especially when translating physical phenomena into graphs and mathematical equations. A study by Ate et al. (2025) identified that the difficulty in organizing representations in a structured manner remains a challenge in physics learning [3], while Rasyid et al. (2025) demonstrate that the development of multirepresentational skills can be supported through learning models, media, instructional materials, learning approaches, and instructional design tools [4]. These findings indicate that the development of instructional materials that facilitate connections between representations is a crucial aspect of innovation in physics education [3][4].

Advances in digital technology provide opportunities to integrate various forms of representation into interactive learning environments. One type of instructional material that can support these needs is the digital worksheet, which allows for the integration of content, inquiry-based questions, visualizations, simulations, and learning activities within a single learning environment. In physics education, digital worksheets have been used to support a variety of learning objectives. Wati et al. (2024), for example, examined the use of digital worksheets in dynamic fluid mechanics to develop problem-solving skills [5], while Distrik et al. (2024) developed problem-based learning-oriented digital worksheets using 3D PageFlip to support conceptual understanding and digital literacy [6].The study shows that digital worksheets can be designed to support structured learning activities, rather than simply presenting material electronically [5][6].

The integration of multirepresentation into digital worksheets is relevant because the digital environment allows students to observe phenomena through visualizations, explore changes in variables through simulations, interpret results in graphical form, and connect them to verbal explanations and mathematical equations. Evidence of the application of multirepresentation-based digital instructional materials is beginning to emerge in research on the development and implementation of learning. Furqon et al. (2025), for example, developed a multirepresentation-based digital worksheet using Liveworksheets on the topic of Newton's Laws, with high validity and practicality [7]. Other studies have also reported the use of multirepresentation-based digital worksheets via Liveworksheets to support students' science process skills on the same topic [7]. Nevertheless, product development research primarily provides information regarding the characteristics, feasibility, or results of a product's application as such, it does not, in and of itself, provide a comprehensive overview of the structure and development of the literature in that field. Therefore, a literature mapping approach is needed to complement the findings of empirical research and product development that have already been conducted.

A number of previous studies have mapped the development of multirepresentation in physics education. Addawiyah et al. (2024) conducted a bibliometric analysis of 121 Scopus-indexed articles from 2013 to 2023 to map research on multirepresentation in physics learning [8]. Meanwhile, Ate et al. (2025) analyzed 45 articles from 2019 to 2023 to identify trends, opportunities, and challenges in the use of multirepresentation [3]. Latifah et al. (2024) also conducted a systematic literature review of 30 articles on multirepresentation-based physics learning media published between 2015 and 2023 [9]. A study by Latifah et al. (2024) found that research on development predominated, with modules being the most widely used medium [9]. Overall, these studies provide an important foundation for understanding the development of multirepresentation, but their scope focuses on multirepresentation-based learning or media in general, rather than specifically on multirepresentation-based digital worksheets [8][9][3].

On the other hand, research on digital worksheets in physics education has also begun to be analyzed using a bibliometric approach. Saepudin et al. (2026) mapped 61 documents published between 2015 and 2025 to identify publication trends, author contributions, and dominant keywords in research on digital worksheets in physics education. This study provides an overview of the development of publications and research topics related to the use of digital worksheets. However, digital worksheet mapping in general does not necessarily explain specifically how multiple representations are integrated into these teaching materials, what themes emerge at the intersection of the two fields, or how patterns of collaboration and relationships between themes are formed. Thus, the study by Saepudin et al. (2026) and bibliometric research on multirepresentation provide a foundation for this study to connect two fields that have traditionally been examined through different lenses.

Based on previous research, there is an opportunity to conduct a more focused mapping of multirepresentational digital worksheets in physics education. A study by Addawiyah et al. (2024) and Ate et al. (2025) focus on multirepresentation in physics learning [8][3], while Latifah et al. (2024) reviewed multirepresentation-based physics learning media [9]. On the other hand, Saepudin et al. (2026) mapped the use of digital worksheets in physics education without making the integration of multiple representations the primary focus. Development studies such as those by Furqon et al. (2025) have demonstrated the application of multirepresentation-based digital worksheets, but these studies were not intended to map the bibliometric structure and the overall development of research themes [7]. This difference in focus highlights the need for a study that integrates both domains to identify publication trends, dominant themes, collaborative networks, and thematic evolution in the field of multirepresentation-based digital worksheets. This gap is framed as a need for more specific and integrated mapping, not as a claim that no research has ever addressed a similar topic.

To address this need, this study combines a Systematic Literature Review (SLR) with bibliometric analysis. The literature selection process followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, while bibliographic data were collected using Publish or Perish and analyzed bibliometrically using VOSviewer. The analysis

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was conducted to map the development of annual publications, keyword connections, thematic evolution, and collaboration networks. The combination of these two approaches enables this study not only to identify publication patterns but also to examine the intellectual structure and thematic developments in the literature on multirepresentation-based digital worksheets.

Based on this background and the existing research gaps, this study aims to map the development and structure of research on multirepresentational digital worksheets in physics education. Specifically, this study seeks to answer the following four research questions:

RQ1: How have research publications on multirepresentation-based digital worksheets in physics education evolved over time?

RQ2: What are the dominant research themes and topics in the field of multirepresentation-based digital worksheets in physics education?

RQ3: What are the patterns of collaboration and the structure of research networks in this field?

RQ4: How can thematic trends in research and opportunities for future research directions be identified based on developments in the literature?

This study is expected to provide an integrated overview of the development of publications, thematic structures, and collaboration patterns in research on multirepresentation-based digital worksheets in physics education. The results are expected to help researchers recognize research trends, identify research gaps, and formulate directions for future research.

METHOD

This study employs a Systematic Literature Review (SLR) approach combined with bibliometric analysis to map the development of research on multirepresentation and digital worksheets in relation to conceptual understanding in physics education. This approach can systematically identify publication trends, thematic structures, and patterns of collaboration. The SLR was used to select and synthesize relevant literature using the “Publish or Perish” (PoP) method subsequently, data were extracted and subjected to bibliometric analysis to interpret the research trends shaping the research landscape in this field.

A. Data Sources and Search Strategy

The literature search was conducted in October 2026 using Google Scholar via Publish or Perish, which was selected as the primary source because it provides broad and rapid access and features precise search filters to identify relevant scientific publications on multirepresentation-based digital worksheets in physics education, covering publications from 2015 through mid-2026. The data obtained consisted of journal articles discussing multirepresentation digital worksheets and their impact on the understanding of physics concepts.

The article search was conducted using keywords related to multirepresentation-based digital worksheets in the context of physics education. The search process was conducted on titles, abstracts, and keywords. All bibliographic data obtained were exported in CSV format and then analyzed bibliometrically using VOSviewer. This search strategy was developed based on two main concepts underpinning the research focus in physics education: digital worksheets and multirepresentation in physics education. To identify relevant publications, several synonyms and closely related terms were used for each concept. These search terms encompass a wide range of variations. Table 1 lists the core search terms used.

No	Search term pada Google Scholar melalui PoP
1	"digital worksheet" physics
2	"multiple representations" worksheet physics
3	"multiple representation" e-worksheet physics
4	"multiple representation" "digital worksheet" physics
5	"multiple representations" "physics" digital OR e-learning OR interactive

Tabel 1 *Search term*

This search was conducted to broaden the scope of relevant studies while remaining aligned with the research focus, ensuring that no articles were overlooked. Each search was conducted separately on Google Scholar via Publish or Perish, and the bibliographic records obtained were compiled and exported for further screening and analysis.

B. Literature Selection

The selection of literature was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Rodrigues, 2023). PRISMA serves as a guideline to ensure transparent and systematic reporting of the process of identifying, selecting, assessing the eligibility of, and including studies. [11] Several criteria for articles included in the analysis are described in Table 2, namely that they discuss multi-representation digital worksheets in physics education, are published in reputable journals, are available in English or Indonesian, and have complete bibliographic data. Book chapters, conference proceedings, editorials, duplicate documents, and publications not relevant to the research focus were excluded from the analysis.

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Data Types	Inclusion	Exclusion
Publications	Journal Articles	Book chapters, conference proceedings, editorials, and others
Year	2015-2026	Before 2015
Source	Google Scholar	Others
Bidang	Fisika	Others
Subject	Elementary School, Middle School, High School, College Students, and Teachers	Others

Table 2 *Inclusion and Exclusion Criteria*

The selection process consisted of four stages: identification, screening, eligibility, and inclusion, as illustrated in Figure 1. During the identification stage, a data search was conducted using four separate searches on Google Scholar with search terms previously determined through Publish or Perish, yielding a total of 517 articles. Subsequently, during the screening stage, the articles were evaluated to remove duplicate documents, resulting in the removal of 109 duplicate articles and leaving a total of 408 articles. In the eligibility stage, the articles were further screened based on the inclusion and exclusion criteria outlined in Table 2, resulting in the removal of 174 articles and a final set of 234 articles. Next, the titles and abstracts were screened, followed by an assessment of the full-text eligibility and accessibility, which resulted in the removal of 163 articles, leaving 71 articles that met all criteria for further analysis.

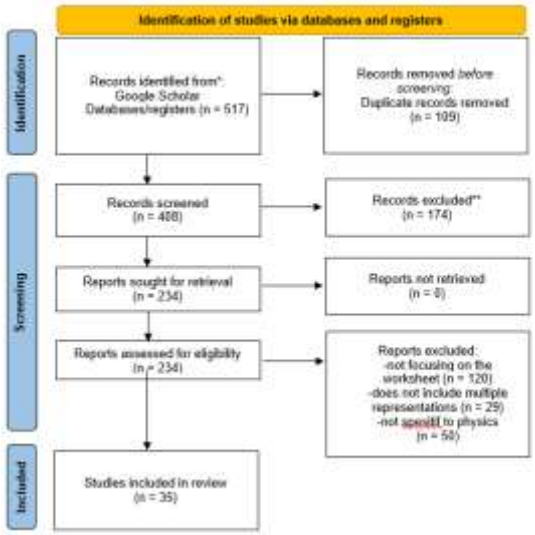
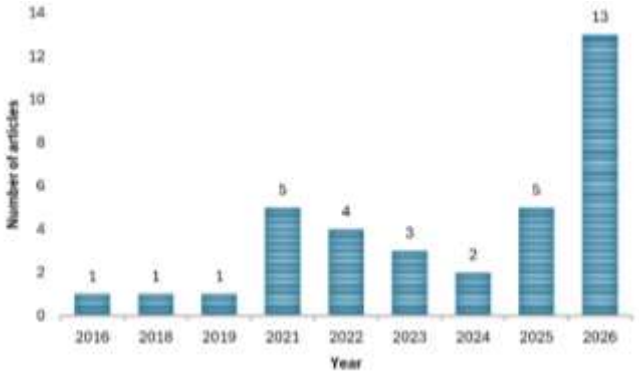


Figure 1 *Article Extraction Workflow*

RESULTS AND DISCUSSION

The literature selection process in this Systematic Literature Review (SLR) followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. An initial search was conducted using the Publish or Perish (PoP) software, covering publications from 2015 to 2026, to ensure a broad scope of the literature during the initial identification phase. After screening for duplicates, assessing inclusion and exclusion criteria, and conducting a quality assessment, no indexed articles were found that met all inclusion criteria in 2015. Consequently, the 35 final articles that met the selection criteria and were subjected to further bibliometric analysis were published between 2016 and 2026.

The bibliographic data from 35 articles that met the criteria were analyzed bibliometrically using VOSviewer software to map the intellectual structure, keyword relationships, thematic shifts, and areas of research topic density related to multirepresentational digital worksheets in physics education. The visualizations were mapped into three main dimensions: network visualization, overlay visualization, and density visualization. The results of the descriptive analysis based on Figure 2 from 2016 to 2026 show that the research trend on multirepresentational digital worksheets in the field of physics education has fluctuated but generally shows an upward trend.



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Figure 2: *Distribution of Annual Publication Trends for Research on*

Multirepresentational Digital Worksheets (2016–2026)

Based on Figure 2, the first publications were identified in 2016, 2018, and 2019, with one article per year in each of those years. The number of publications began to increase significantly in 2021 with 5 articles, followed by 4 articles in 2022, 3 articles in 2023, and 2 articles in 2024. The number rose sharply again in 2025 to 5 articles and peaked in 2026 at 13 articles. The decline in publications from three articles in 2023 to two articles in 2024 indicates that research development in this field has not progressed consistently. This decline may be associated with a shift in research focus from the application of learning technologies, such as electronic modules and augmented reality, toward examining effectiveness, conceptual understanding, and learning outcomes. This shift suggests that research has not only focused on developing instructional media but has also begun to emphasize evaluating their implementation in physics education. Nevertheless, the decrease in publications should not be interpreted as a decline in research interest, but rather as a reflection of the dynamics and changing directions of research during this period.

A. Network Visualization

The results of the network visualization analysis in Figure 3 show the interconnections between keywords, which are divided into five main clusters (represented by the colors red, green, blue, yellow, and purple). The size of the nodes represents the frequency of keyword occurrence, while the thickness of the lines indicates the strength of the links between topics.

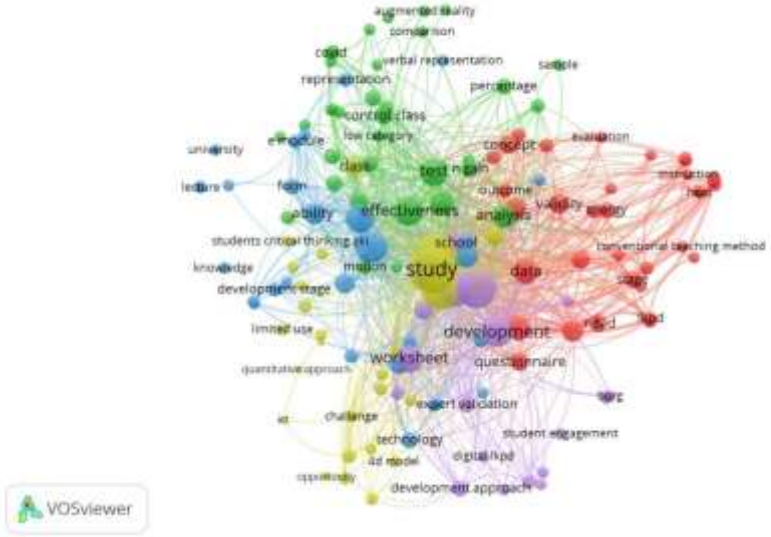


Figure 3 *Network visualization of co-occurrence keywords from VOSviewer*

Based on Figure 3, the results of the network visualization analysis provide an overview of several topics that frequently appear and are closely related to one another in the literature on multirepresentational digital worksheets in physics education. The terms “study,” “effectiveness,” “development,” and “worksheet” have the largest node sizes and are located in the center of the network. This indicates that these topics are the primary focus of research and act as connectors between clusters.

The red cluster focuses on media development and instrument validation. This section includes keywords such as development, R&D, validity, worksheets, data, instruction, questionnaire, stage, heat, energy, and conventional teaching methods. This indicates that most studies begin with research and development (R&D) procedures on physics topics such as temperature and heat (heat & energy), which include instrument validity testing and comparisons with conventional teaching methods.

The green cluster discusses the effectiveness of learning and the analysis of learning outcomes. This section includes keywords such as effectiveness, control class, N-gain, test, analysis, concept, percentage, sample, verbal representation, and augmented reality. This indicates that research on worksheets does not stop at the stage of media development but extends to evaluating their effectiveness through control classes, analysis of conceptual understanding, measurement of learning gains (N-Gain), and the integration of verbal representations and interactive technology.

The blue cluster relates to cognitive abilities and research topics. This section includes keywords such as ability, students’ critical thinking skills, knowledge, motion, e-module, lecture, and university. This section emphasizes the application of digital worksheets and e-modules at the university level to enhance students’ knowledge and critical thinking skills regarding motion. As explained by Prahani et al. (2022), digital worksheets integrated with interactive simulations (such as PhET) make it easier to link graphical representations with mathematical equations in real time [11]. Furthermore, Nieminen et al. (2023) found that students’ failure to solve physics problems is often not due to a lack of mathematical ability but rather an inability to connect visual representations with mathematical symbols—a gap that was successfully bridged by the intervention using multirepresentational digital worksheets [12].

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The yellow cluster focuses on the learning context and study approaches. This section includes keywords such as study, school, quantitative approach, limited use, ICT, challenge, and opportunity. This indicates that field research generally employs a quantitative approach at the school level by exploring the challenges and opportunities of ICT utilization on a limited scale.

The purple cluster covers the design of digital worksheet models and student engagement. This section contains keywords such as worksheet, digital worksheet, technology, 4D model, Borg, expert validation, development approach, and student engagement. This cluster emphasizes an approach to designing digital worksheets using systematic development models (such as the 4D model or the Borg & Gall model), followed by expert validation to foster active student engagement.

B. Overlay Visualization

The results of the overlay visualization analysis in Figure 4 illustrate the thematic evolution and shifts in research focus over time from 2022 to 2026. The color gradients represent the average period of keyword occurrence, ranging from blue-purple (2022–2023), green (2023–2024), to bright yellow (2025–2026).

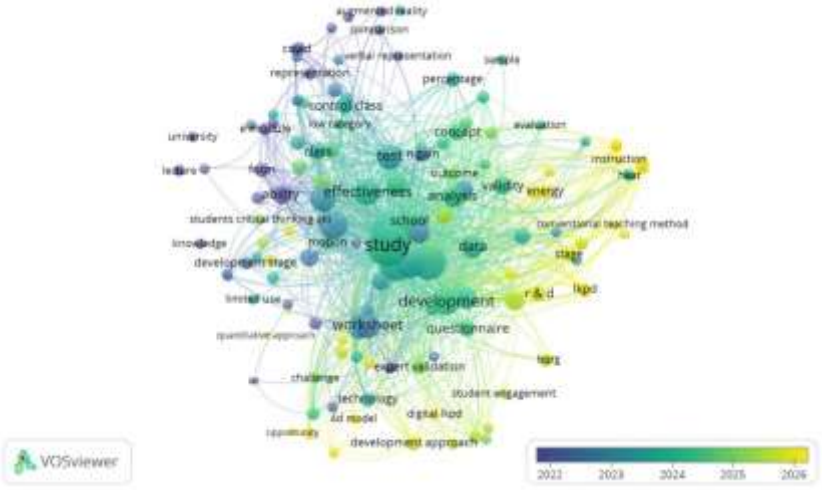


Figure 4 *Overlay visualization of research topics over time from VOSviewer*

Based on Figure 4, the thematic development of the research is divided into three main phases: the Initial Phase (2022–2023), characterized by keywords dominated by shades ranging from purple to dark blue, including COVID, augmented reality, comparison, e-module, form, university, lecture, ability, students' critical thinking skills, knowledge, limited use, quantitative approach, and ICT. In this phase, the research focus was largely related to learning issues during the COVID era, the implementation of e-modules and augmented reality, the quantitative approach, and the measurement of critical thinking skills and knowledge at the university level (university/lecture).

The Transition Phase (2023–2024) consists of keywords highlighted in shades ranging from bluish-green to green, including representation, control class, verbal representation, low category, class, test, N-gain, effectiveness, study, motion, development stage, percentage, sample, concept, evaluation, outcome, analysis, data, school, development, and questionnaire. At this stage, the research shifts to testing control classes, analyzing effectiveness, improving conceptual understanding through n-gain scores, using verbal representations, evaluating samples at the school level, and collecting data using questionnaires.

The last phase is the Current Phase (2025–2026), represented by keywords highlighted in bright yellow, including instruction, heat, energy, conventional teaching methods, stage, validity, R&D, worksheets, expert validation, Borg, student engagement, digital worksheets, technology, the 4D model, challenge, opportunity, and development approach. This indicates that the most recent research trends focus on the development of R&D-based digital LKPDs and worksheets (such as the 4D model and Borg scale), the processes of expert validation and validity, physics topics on heat and energy, comparisons with conventional teaching methods, and analyses of student engagement, challenges, and opportunities.

C. Density Visualization

The results of the density visualization analysis in Figure 5 provide an overview of the saturation level and density of the topics studied in the literature. Areas in light yellow indicate topics that have been studied very frequently, while areas ranging from pale green to dark blue indicate topics that have yet to be explored (research gaps).

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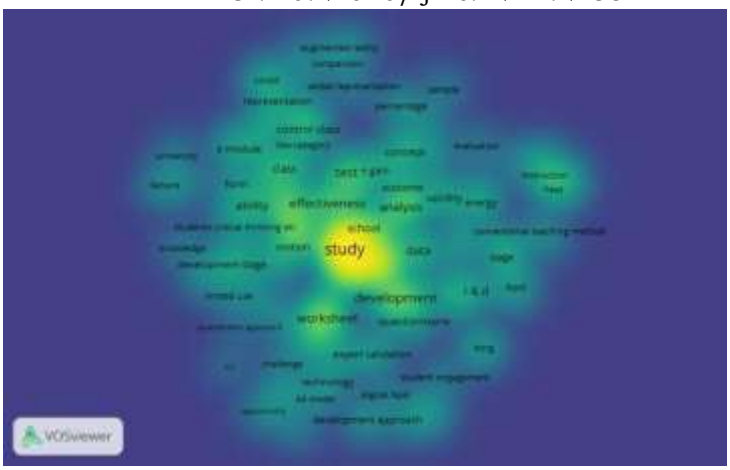


Figure 5 *Density visualization of research topics from VOSviewer*

Based on Figure 5, the main findings from the density visualization include dominant topics highlighted in bright yellow; the words "study," "effectiveness," "school," "development," and "worksheet" have the highest density levels. This indicates that the majority of the research focuses on the development of worksheets and testing their effectiveness in schools. Next, the topic is fairly saturated with bright green; words such as "analysis," "test," "n-gain," "data," "concept," "effectiveness," and "questionnaire" are located in areas of moderate density. These topics represent evaluation instruments and parameters commonly used in the literature. Finally, regarding Research Gaps—shown in colors ranging from pale green to muted blue—keywords such as "digital worksheets," "student engagement," "opportunity," "challenge," "ICT," "verbal representation," "augmented reality," "heat," "energy," and "students' critical thinking skills" are located in the faint areas at the edges of the network. These gaps present significant opportunities for future research to explore the development of interactive digital worksheets on specific topics (such as heat and energy), the integration of augmented reality for multimodal representation, and their impact on student engagement and critical thinking skills.

D. Trends in Research Publications on Multirepresentational Digital Worksheets Over Time

To answer RQ1, based on Figure 2, the research results show that the trend in research on multirepresentational digital worksheets in the field of physics education, based on the number of publications from 2016 to 2026, has fluctuated but shows an upward trend over time. As shown in Figure 2, the number of publications surged from 2 articles in 2024 to 5 articles in 2025, reaching a peak of 13 articles in 2026. However, it is important to note that the 2026 publication data has a cutoff limitation because 2026 was still ongoing at the time this study was conducted. There is a time lag in the process of indexing articles in the database, so the annual publication data may continue to grow cumulatively.

This increase is driven by the rapid transformation of digital learning and the need for physics learning materials capable of bridging abstract concepts through various forms of representation. This is consistent with the findings of Ainsworth (2021), which confirm that the use of a combination of representations (verbal, visual, and mathematical) helps reduce students' cognitive load in understanding complex physics phenomena [13]. Furthermore, Opfermann et al. (2021) and Tang et al. (2022) state that digital worksheets that facilitate interactive translation between representations have been shown to be more effective at improving conceptual understanding than conventional print media [14][15].

Developments in the literature during this period demonstrate a diversification of physics topics and the digital platforms developed. One publication in 2023 was developed by Umami et al. (2023), which evaluated the profile and effectiveness of using digital worksheets supported by the Problem-Based Learning (PBL) model on motion and force to address students' low critical thinking skills resulting from learning loss during the COVID-19 pandemic [16]. In 2025, one of the published works was a study by Kasmawati et al. (2025), which discusses the development of a Digital Interactive Worksheet (DIW) based on a differentiated instruction model on the concept of motion to improve students' science literacy [17].

Furthermore, in the latest publication trends (2026), media innovation focuses on the variety of digital platforms and the level of interactivity. A study by Mustofa (2026) designed PBL-based Physics E-LKPDs using the 4D model to test the effectiveness of improving the N-Gain of critical thinking skills among 10th-grade students [18]. In addition, Nurjannah et al. (2026) utilized the Wizer.me digital platform to design digital worksheets on an abstract topic in modern physics, namely Special Relativity [19]. Meanwhile, Kusuma et al. (2026) designed interactive digital worksheets based on the TopWorksheets platform using the Research and Development (R&D) approach from the Borg and Gall model on the topic of Work and Energy [20].

E. Dominant Research Themes and Topics

To answer RQ2, the results of the network visualization analysis in Figure 3 identified five main thematic clusters that dominate the literature. The words "study," "effectiveness," "development," and "worksheet" emerged as central keywords, indicating that the primary focus of the research centers on the design of instructional media and the testing of their impact on physics learning.

The integration of multirepresentational digital worksheets has proven to be a crucial tool for facilitating translation between representations (verbal, visual, graphical, and mathematical). As emphasized by Ainsworth (2021) and Opfermann et al. (2021), providing various forms of representation in digital modules is highly effective for unpacking the complexity of

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abstract physics concepts and reducing students' cognitive load [13][14]. Cluster 1 (red) and Cluster 5 (purple) demonstrate a close relationship between instructional design models (such as Borg & Gall and 4D) and the expert validation stage to ensure the validity of digital worksheets before implementation. Meanwhile, Cluster 2 (green) and Cluster 3 (blue) show that the impact of media use is measured quantitatively through N-Gain scores in the control class, particularly in improving students' critical thinking skills and conceptual understanding of mechanics and modern physics.

The dominance of topics in Classical Mechanics (such as the concepts of motion, force, work, and energy) and Thermophysics (temperature and heat) in the dominant cluster indicates that researchers view these topics as the primary foundation of the physics curriculum—and the ones most likely to lead to misconceptions. Multirepresentation-based digital worksheets are designed to address these cognitive barriers by providing dynamic visual bridges that connect abstract phenomena with graphical representations and mathematical modeling.

F. Collaboration Patterns and Research Network Structures

To answer RQ3, the structure of the research collaboration network in this field was analyzed based on a map of co-authorship relationships and institutional affiliations using VOSviewer. The mapping results indicate that collaboration patterns in research on multirepresentational digital worksheets generally remain fragmented into small research clusters. Most collaborations occur internally within the same faculty or university. This finding aligns with the perspective of Donthu et al. (2021), who state that research collaboration limited to the local scope has the potential to create geographical bias and slow down the wider dissemination of educational technology innovations [21]. Therefore, expanding cross-institutional collaboration networks and international partnerships is necessary to strengthen the relevance and broader impact of the development of multirepresentational digital worksheets in physics education

G. Thematic Developments in Research and Opportunities for Future Research Directions

To address RQ4, thematic shifts and opportunities for future research directions were identified based on the overlay visualization (Figure 4) and density visualization (Figure 5). The overlay visualization in Figure 4 shows that research trends have evolved from an initial response to pandemic-induced emergency learning (2022–2023) to an analysis of the effectiveness of N-Gain in conceptual understanding (2023–2024), culminating in the development of concrete, R&D-based products (digital worksheets) that are statistically validated and focused on student engagement (2025–2026). Furthermore, the density visualization in Figure 5 maps research gaps in low-density areas (faded/dull blue).

Several potential avenues for future research include three areas: first, the development of digital worksheets for modern and abstract physics, as most of the current literature still focuses on classical physics topics such as mechanics (motion, work, and energy). As demonstrated by Kozhevnikov et al. (2022), non-intuitive physics concepts such as quantum physics and relativity actually require dynamic visual representations, which can be facilitated through interactive digital worksheets [22]. Second, the integration of AR and AI-based adaptive learning—with keywords such as augmented reality and ICT—remains in a low-density research area. Chiu et al. (2023) emphasize that the future of multirepresentational learning media lies in the integration of intelligent technologies (such as AI and AR) capable of providing automatic, real-time, scaffolded feedback tailored to each student's individual representational needs [23]. Third, enhancing student engagement and 21st-century skills: evaluations of student engagement and long-term cognitive retention resulting from the use of multirepresentational digital worksheets remain very limited in the current literature, making this a highly promising area for further research.

Overall, the findings of this systematic review have practical and theoretical implications for educators and developers of physics instructional media. For educators, the results of this mapping underscore the importance of shifting from static printed worksheets to interactive digital worksheets capable of facilitating the translation between different representations. For future researchers, the identified research gaps—particularly the integration of adaptive AI technology and its application to advanced abstract physics concepts—can serve as key references in designing research focuses with high novelty.

CONCLUSION

The findings reveal an increasing publication trend in research on multirepresentational digital worksheets in physics education since 2016, reaching its peak in 2026, accompanied by the growing diversification of digital learning media, including interactive worksheets integrated with Problem-Based Learning (PBL) and differentiated instruction. Five major research clusters were identified, focusing on research and development (R&D), instrument validation, cognitive effectiveness evaluation using N-Gain, and active student engagement. However, research collaboration remains fragmented, with limited connections among authors and institutions beyond individual research groups. Thematic evolution indicates a shift from studies addressing COVID-19-related learning responses toward the development and validation of digital worksheets for specific physics topics, particularly temperature, heat, work, and energy. These findings highlight the potential of multirepresentational digital worksheets to facilitate connections among verbal, visual, graphical, and mathematical representations in physics learning. Nevertheless, the research landscape remains limited by the reliance on a single bibliographic database and the inclusion of publications only up to 2026. Future research should extend investigations to abstract topics in modern physics, particularly quantum physics and relativity, while exploring the integration of Augmented Reality (AR) and AI-powered adaptive learning. Further studies are also needed to examine their effects on student engagement and long-term cognitive retention.

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