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# A Review: Research Trends on Interactive Web-Based STEM-PjBL Hybrid Model of Material Physics with Deep Learning Approach to Improve Critical Thinking Skills

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**Abstract:** The rapid advancement of digital technology and artificial intelligence has reshaped the landscape of physics education, emphasizing the need for instructional models that effectively promote students' critical thinking skills. This study aims to synthesize and map the development of Hybrid STEM–Project-Based Learning (STEM–PjBL) models supported by web-interactive learning environments and deep learning approaches in physics material education. A hybrid review method was employed, integrating a Systematic Literature Review (SLR) and bibliometric analysis of 30 peer-reviewed articles indexed in Scopus and SINTA from 2020 to 2026. The SLR results indicate that STEM-oriented PjBL consistently enhances students' critical thinking, problem-solving, and conceptual understanding, particularly when implemented through authentic and interdisciplinary projects. Bibliometric findings reveal a growing research trend toward web-based learning and artificial intelligence, with deep learning emerging as a promising yet underexplored component within STEM–PjBL frameworks. However, empirical integration of adaptive deep learning mechanisms in physics material learning remains limited. This study contributes by highlighting critical research gaps and proposing a conceptual Hybrid STEM–PjBL Web-Interactive Model with Deep Learning, which integrates pedagogical design, digital interactivity, and intelligent adaptability to optimize critical thinking development. The findings provide theoretical, practical, and methodological insights for advancing AI-enhanced STEM education.

**Keywords:** Critical thinking; Deep learning; Physics education; Project-based learning; STEM education; Web-interactive learning

## Introduction

The rapid development of science and technology in the era of the Industrial Revolution 4.0 and the transition toward Society 5.0 necessitate fundamental transformations in educational systems, particularly in fostering 21st-century skills (Muliyadi et al., 2023). One of the most essential skills emphasized in contemporary education is critical thinking, defined as the ability to analyze information, evaluate arguments, and make rational, evidence-based decisions. In physics education, critical thinking plays a crucial role because physics not only emphasizes conceptual mastery but also scientific reasoning, problem solving, and the application of concepts to real-world phenomena (Crossette et al., 2021). However, numerous international and national studies have reported that students' critical thinking skills in physics learning remain at low to moderate levels. This condition is largely attributed to the dominance of conventional instructional approaches

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that rely heavily on lectures, routine problem-solving exercises, and limited opportunities for active student engagement (Mebert et al., 2020). In the Indonesian context, this challenge is further compounded by the tendency of physics instruction to present abstract concepts without meaningful connections to authentic contexts, resulting in superficial conceptual understanding among students (Haryanti et al., 2020).

One instructional approach that has been widely recognized as effective in addressing these challenges is Project-Based Learning (PjBL). PjBL emphasizes active student involvement through the completion of authentic projects that require investigation, collaboration, and reflection (Susilawati et al., 2025). A growing body of empirical evidence demonstrates that PjBL significantly enhances students' critical thinking skills, creativity, and conceptual understanding compared to traditional instructional models (Syawaludin et al., 2022). Nevertheless, the effectiveness of PjBL can be further strengthened when it is integrated with the STEM (Science, Technology, Engineering, and Mathematics) approach, which enables students to examine problems from interdisciplinary and systemic perspectives (Castro & Collins, 2021). The integration of STEM with PjBL (STEM–PjBL) has emerged as a global trend in science and physics education. Research indicates that STEM–PjBL effectively promotes critical thinking, problem-solving skills, and scientific literacy by engaging students in connecting physics concepts with technology, engineering design, and mathematical reasoning within real-world problem contexts (Sihombing & Yohandri, 2025). In Indonesia, several studies published in SINTA-indexed journals have also confirmed the positive impact of STEM–PjBL on students' critical thinking skills and physics learning outcomes, particularly for abstract and conceptually demanding topics (Roslina et al., 2024; Yusra et al., 2025; Yulianti et al., 2025).

Despite these promising findings, the implementation of STEM–PjBL in classroom practice continues to face several challenges, including limited instructional time, insufficient learning resources, and suboptimal integration of digital technology. Meanwhile, advancements in digital technology have created substantial opportunities for the development of interactive web-based learning environments that are flexible, adaptive, and learner-centered. Web-based learning platforms facilitate multimodal content presentation, interactive simulations, and online collaboration, all of which can enrich students' learning experiences (Ahmad et al., 2024). Empirical studies have shown that interactive web-based physics learning significantly enhances students' motivation, conceptual understanding, and critical thinking skills (Rizki et al., 2025). Nevertheless, the use of web-based learning within STEM–PjBL contexts often remains fragmented and insufficiently grounded in robust pedagogical frameworks. Many digital platforms function merely as content delivery tools rather than as environments designed to foster deep cognitive engagement and reflective thinking (Ginting et al., 2024). Consequently, there is a pressing need for pedagogical approaches that can meaningfully guide the integration of digital technologies to support higher-order thinking processes.

The deep learning approach in education offers a relevant framework for addressing these challenges. In pedagogical terms, deep learning emphasizes profound conceptual understanding, critical reflection, and the transfer of knowledge to new situations, as opposed to surface learning that prioritizes memorization (Nafi'ah & Faruq, 2025). Recent studies suggest that deep learning–oriented pedagogy, whether implemented as an instructional strategy or supported by artificial intelligence–based technologies, has significant potential to enhance critical thinking skills and overall learning quality (Rubenstein et al., 2022). In the context of materials physics, the deep learning approach is particularly relevant because this subject requires students to understand the relationships among material structure, properties, and applications at both macroscopic and microscopic levels. Materials physics is often perceived as challenging due to its abstract nature and complex conceptual demands. Integrating STEM–PjBL with interactive web-based learning and a deep learning approach enables students to visualize abstract phenomena, analyze experimental and simulation data, and design project-based solutions in a more meaningful and contextualized manner (Anggraini et al., 2025).

A review of the existing literature reveals a significant research gap concerning the development of instructional models that comprehensively integrate STEM–PjBL, interactive web-based learning, and deep learning pedagogy in materials physics education. Most prior studies have focused on partial implementations, such as STEM–PjBL without web-based support or web-based learning without an explicit deep learning pedagogical framework (Wintachai & Prathom, 2021; Hamidah et al., 2025). Furthermore, empirical investigations that specifically examine the impact of such integrated models on students' critical thinking skills remain limited. Therefore, this research wants to know the research trend on interactive web-based STEM-PjBL hybrid model of material physics with deep learning approach to improve critical thinking skills.

## Method

*Research Design*

This study adopted a Hybrid Review methodology, integrating a Systematic Literature Review (SLR) and a

Bibliometric Review to comprehensively examine research trends, theoretical foundations, and empirical evidence related to Hybrid STEM–Project-Based Learning (STEM–PjBL), interactive web-based physics learning, deep learning pedagogy, and critical thinking skills. The hybrid review approach was selected to combine the methodological rigor and depth of SLR with the quantitative mapping and visualization strengths of bibliometric analysis, allowing for a holistic understanding of the research landscape (Donthu et al., 2021). This methodological integration enables not only the identification of research gaps and dominant themes but also the exploration of intellectual structures and publication dynamics within the field.

*Data Sources and Research Strategy*

The literature search was conducted using two primary databases: Scopus and SINTA (Science and Technology Index) from google scholar. The Google Scholar database was chosen as a place to search for documents because Google Scholar applies consistent standards in selecting documents to be included in its index, and Google Scholar displays more documents than the top databases. Others, especially research in the field of education (Hallinger & Chatpinyakoop, 2019; Hallinger & Nguyen, 2020; Zawacki-Richter et al., 2019). Scopus was selected to represent internationally recognized, high-impact journals, while SINTA was used to capture nationally accredited Indonesian journals relevant to physics education and STEM-based learning (Roslina et al., 2024). The search process covered publications from 2020 to 2026, aligning with the global shift toward digital transformation and 21st-century learning paradigms. A comprehensive search string using Boolean operators was applied as follows: (“STEM education” OR “STEM learning”) AND (“Project-Based Learning” OR “PjBL”) AND (“physics education” OR “materials physics”) AND (“critical thinking”) AND (“web-based learning” OR “interactive learning”) AND (“deep learning approach”). Only peer-reviewed journal articles written in English or Indonesian were considered. This strategy is consistent with best practices in systematic review research to ensure coverage, relevance, and replicability (Page et al., 2021). To see research trends in recent years, app.dimensions.ai is also used to filter data that has been collected via Publish or Perish, researchers used the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.

*Inclusion and Exclusion Criteria*

To ensure the quality and relevance of the reviewed studies, explicit inclusion and exclusion criteria were applied. Inclusion criteria: Journal articles published between 2020 and 2026: Articles indexed in Scopus or accredited by SINTA; Studies focusing on STEM, PjBL, or STEM–PjBL in science or physics education; Research addressing critical thinking skills, higher-order thinking skills, or deep learning pedagogy; Studies employing web-based, digital, or interactive learning environments

Exclusion criteria: Conference proceedings, book chapters, dissertations, or theses; Studies outside educational or learning contexts; Articles lacking empirical data or theoretical relevance; Duplicate records across databases. The use of explicit inclusion and exclusion criteria enhances transparency and minimizes selection bias in systematic reviews (Moher et al., 2009).

*Systematic Literature Review Procedure*

The SLR process followed the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines, which consist of four stages: identification, screening, eligibility, and inclusion. During the identification stage, all records retrieved from Scopus and SINTA were compiled, and duplicate articles were removed. In the screening stage, titles and abstracts were reviewed to assess relevance to the research focus. Articles that met the inclusion criteria proceeded to the eligibility stage, where full-text assessments were conducted. The final set of included articles was analyzed using qualitative content analysis, focusing on: Learning models and instructional designs; Integration of STEM, PjBL, and digital technologies; Application of deep learning pedagogy; Research methods and educational contexts; Reported impacts on students’ critical thinking skills. Narrative synthesis was employed to identify recurring patterns, theoretical frameworks, and research gaps relevant to the development of the proposed hybrid learning model (Snyder, 2019).

*Bibliometric Review Procedure*

Following the SLR phase, a bibliometric review was conducted to quantitatively analyze publication patterns and intellectual structures within the selected literature corpus. Bibliographic metadata—including authors, publication years, journals, affiliations, citations, and keywords—were exported in compatible formats from the databases. The bibliometric analysis focused on: Annual publication trends to identify research growth patterns; Most productive and influential authors and journals; Keyword co-occurrence analysis to detect dominant and emerging themes; Co-citation and bibliographic coupling analysis to map intellectual relationships. Visualization and network analyses were conducted using bibliometric tools such as VOSviewer, which is widely used for mapping scientific knowledge domains (Van Eck & Waltman, 2010; Aria & Cuccurullo, 2017).

## Result and Discussion

This research aims to describe research trends on interactive web-based STEM-PjBL hybrid model of material physics with deep learning approach to improve critical thinking skills. Figure 1 is presented below regarding research trends on the interactive web-based STEM-PjBL hybrid model of material physics with deep learning approach to improve critical thinking skills in the las ten years (obtained from app.dimensions.ai). Figure 1 shows that the trend in research on the interactive web-based STEM-PjBL hybrid model of material physics with deep learning approach to improve critical thinking skills experiencing increases. Below are also table 1 presented research of interactive web-based STEM-PjBL hybrid model of material physics with deep learning approach to improve critical thinking skills based on the type of publication.

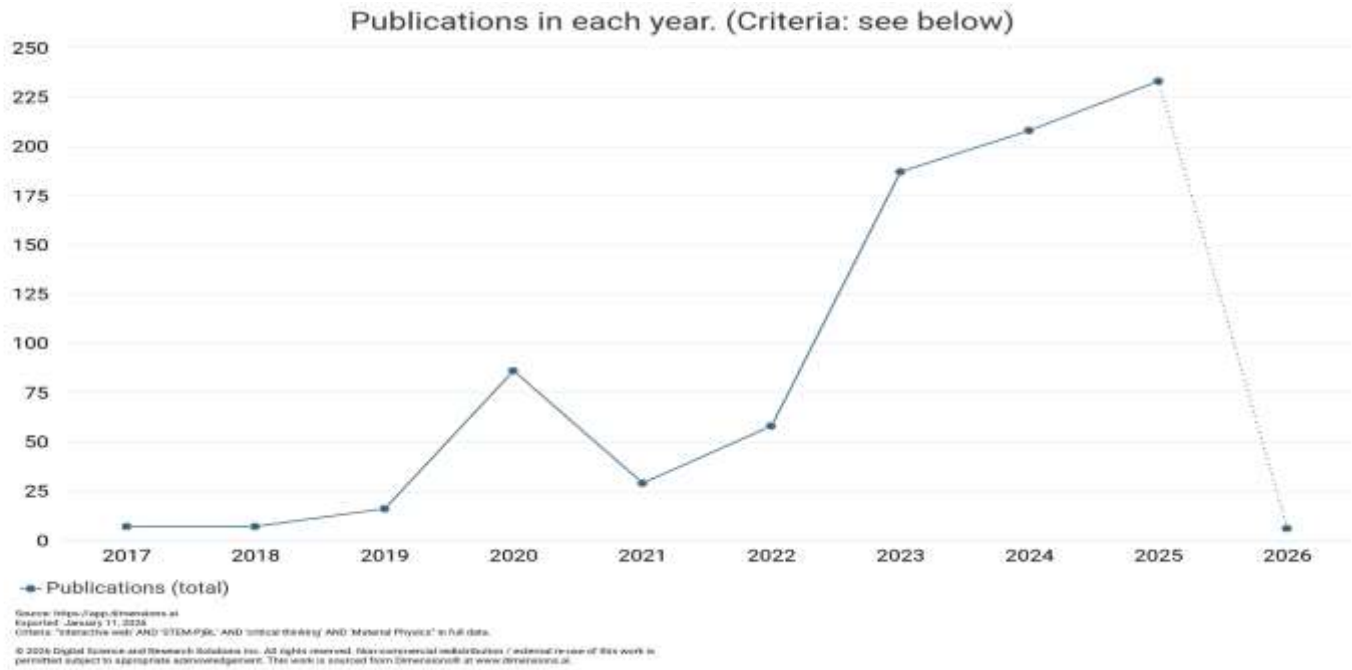


**Figure 1.** Research trends in interactive web-based STEM-PjBL hybrid model of material physics with deep learning approach to improve critical thinking skills (app.dimensions.ai)

**Table 1.** Trends Research Based on Publication Types (app.dimensions.ai)

| Publication Type | Publications |
|---|---|
| Article | 439 |
| Edited Book | 232 |
| Chapter | 135 |
| Monograph | 22 |
| Preprint | 14 |
| Proceeding | 14 |

Based on Table 1, it is known that research trend by app.dimensions.ai contained in 6 types of publications. In the form of articles there were 439 documents, chapters as many as 135 documents, proceedings as many as 14 documents, edited books as many as 232 documents, 22 documents of monograph and 14 publications for preprint and proceeding. Research trends in article form is the type of publication that contains the most research about interactive web-based STEM-PjBL hybrid model of material physics with deep learning approach to improve critical thinking skills compared to other types of publications. Meanwhile, the type of publication contains the least amount of research results interactive web-based STEM-PjBL hybrid model of material physics with deep learning approach to improve critical thinking skills is preprint and proceeding. Research conducted by (2019) states that an article is a complete factual essay of a certain length created for publication in online or print media (via newspapers, magazines or bulletins) and aims to convey ideas and facts that can convince and educate. These articles are usually published in scientific journals both in print and online (Suseno & Fauziah, 2020). Below are also figure 2 presented the fields research trends in interactive web-based STEM-PjBL hybrid model of material physics with deep learning approach to improve critical thinking skills.

Figure 2 shows the most fields of research for research trend of interactive web-based STEM-PjBL hybrid model of material physics with deep learning approach to improve critical thinking skills, namely in the criteria of education, with 531 publications. The most publishers are Advances in Social Science, Education and Humanities Research with 78 publications. The proceedings series Advances in Social Science, Education and Humanities Research aims to publish proceedings from conferences on the theories and methods in fields of social sciences, education and humanities. All proceedings in this series are open access, i. e. the articles published in them are immediately and permanently free to read, download, copy & distribute. The online publication of each proceeding is sponsored by the conference organizers and hence no additional publication fees are required.

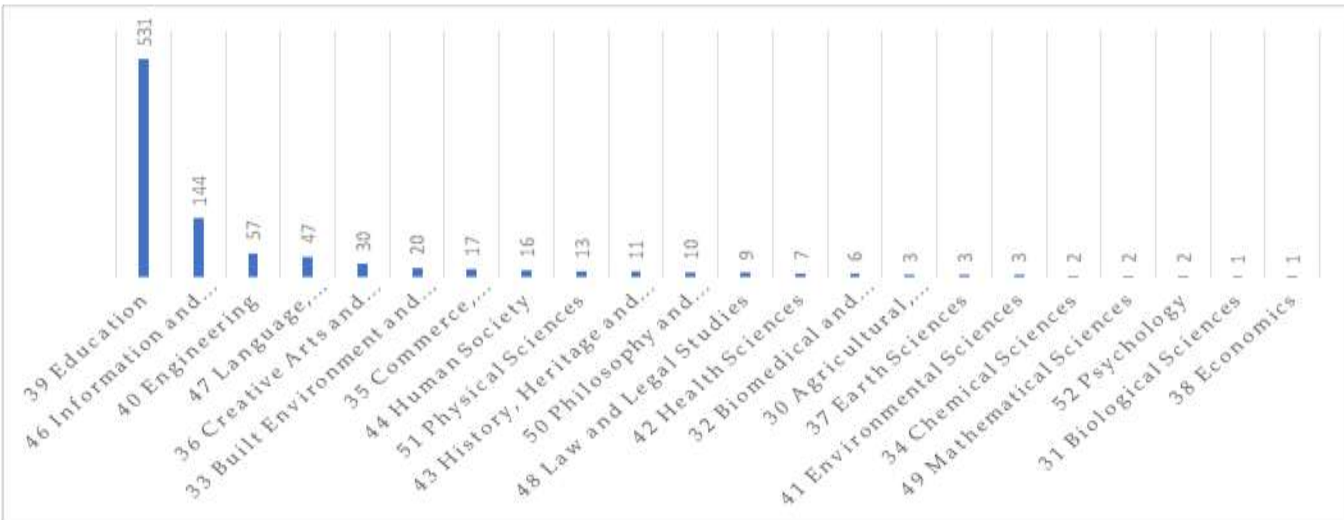


**Figure 2.** Research fields of trend interactive web-based STEM-PjBL hybrid model of material physics with deep learning approach to improve critical thinking skills research

*Results of Systematic Literature Review (SLR)*

The systematic literature review yielded 132 records retrieved from Scopus (n = 78) and SINTA-indexed journals (n = 54). After removing 34 duplicates, 98 articles were screened based on titles and abstracts. Following this stage, 41 studies were excluded due to misalignment with STEM education, Project-Based Learning (PjBL), physics learning, or critical thinking outcomes. A full-text assessment of 57 articles resulted in 30 empirical studies that satisfied all inclusion criteria and were synthesized qualitatively. Across the reviewed studies, STEM-oriented Project-Based Learning consistently demonstrated a significant positive impact on students' critical thinking skills, particularly within physics and science education contexts (Rehman et al., 2024; Lee & Lee, 2025; Wahdaniyah et al., 2023). The majority of studies employed quasi-experimental and mixed-method designs, using performance-based assessments and standardized critical thinking rubrics aligned with higher-order cognitive domains (Wertheim et al., 2025).

The findings indicate that PjBL enhances critical thinking by engaging learners in authentic problem-solving, inquiry-driven experimentation, and interdisciplinary reasoning, which are core elements of STEM pedagogy (Susiloningsih et al., 2025; Lestari et al., 2024). In physics education, this approach supports conceptual understanding and analytical reasoning, particularly in abstract domains such as material properties and physical systems (Shofiyah et al., 2025). Furthermore, studies integrating web-based interactive environments reported stronger learning outcomes compared to conventional PjBL implementations. Web-based STEM–PjBL facilitates digital collaboration, visualization of abstract concepts, and real-time feedback, which are critical for developing reflective and evaluative thinking processes (Musengimana et al., 2025).

*Bibliometric Results: Research Trends and Knowledge Structure*

The bibliometric analysis revealed a substantial growth in publications after 2020, with a notable increase between 2022 and 2026. This trend reflects the growing global emphasis on digital STEM education and critical thinking development in response to post-pandemic learning challenges (OECD, 2007). The strongest associations were observed between *STEM*, *PjBL*, and *critical thinking*, confirming their central position in the intellectual structure of the field (Bustamante-Mora et al., 2025; Ammar et al., 2024). Emerging keywords such as *deep learning* and *adaptive learning systems* appeared predominantly in studies published after 2023, indicating a shift toward intelligent and personalized learning environments (Yin Zhang et al., 2023).

Co-authorship analysis showed limited international collaboration, with most studies conducted within national contexts. Indonesian scholars contributed significantly through SINTA-indexed journals, particularly in physics education research, while Scopus-indexed publications were dominated by researchers from East Asia and Europe (Rahman et al., 2024). In the articles researched and written by these researchers, there are many terms/keywords related to interactive web-based STEM-PjBL hybrid model of material physics with deep learning approach to improve critical thinking skills. Below are presented five (5) popular keywords related to the trend. Table 2 shows that the keywords that often appear related to research on the interactive web-based STEM-PjBL hybrid model of material physics with deep learning approach to improve critical thinking skills are mathematics 8 times with a level of 2.63. Table 2 also shows that technology is also a keyword that appears frequently in research trends, namely 7 times with a relevance of 2.37.

**Table 2.** Keywords on Trend research

| Terms | Occurrences | Relevance |
|---|---|---|
| Mathematics | 8 | 2.63 |
| Science | 7 | 2.38 |
| Technology | 7 | 2.37 |
| Creativity | 9 | 0.98 |
| Development | 10 | 1.24 |

Below are the visualization is accomplished by generating a landscape map, which offers a visual representation of subjects related to scientific studies. The outcomes of bibliometric mapping for the co-word network in articles related to the topic interactive web-based STEM-PjBL hybrid model of material physics with deep learning approach to improve critical thinking skills are illustrated in Figure 3. Figure 3 shows the results of bibliometric keyword mapping on research trends on the topic interactive web-based STEM-PjBL hybrid model of material physics with deep learning approach to improve critical thinking skills. In Figure 3 there are 27 keyword items that are often used in research on the interactive web-based STEM-PjBL hybrid model of material physics with deep learning approach to improve critical thinking skills. Figure 3 also contains 4 clusters, where the first cluster is colored red and consists of 9 keyword items, namely development, students, skill, etc. The second cluster in green consists of 8 keyword items, namely mathematics, science, technology, etc. The third cluster in blue consists of 6 keyword items, namely stem approach, effect, etc. The fourth yellow cluster consists of 4 keyword items, namely creativity, effectiveness.

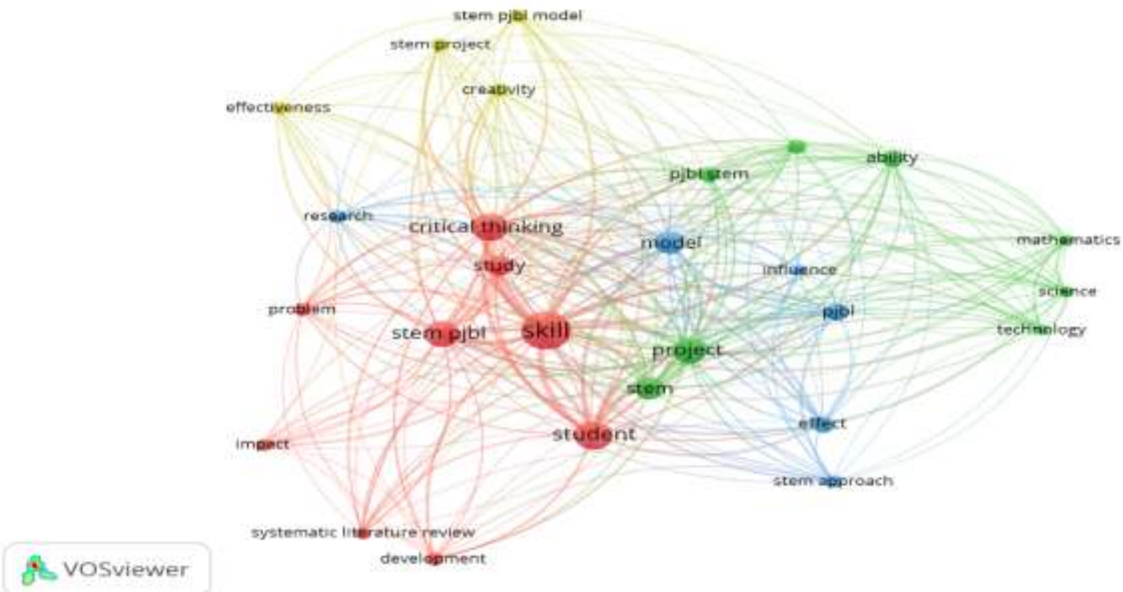


**Figure 3.** Network visualization on trend interactive web-based STEM-PjBL hybrid model of material physics with deep learning approach to improve critical thinking skills research

Figure 3 above also shows that network visualization shows the network between the terms being visualized. Keywords classified into four clusters are arranged in a color chart showing the divisions that are connected to each other. The results of this analysis can be used to determine keyword research trends in the last year. This analysis shows several keywords that are often used in research on the interactive web-based STEM-PjBL hybrid model of material physics with deep learning approach to improve critical thinking skills. The more keywords that appear, the wider the visualization displayed. Below are also presented keywords regarding the interactive web-based STEM-PjBL hybrid model of material physics with deep learning approach to improve critical thinking skills based on overlay visualization. Figure 4 shows the trend of keywords related to research on interactive web-based STEM-PjBL hybrid model of material physics with deep learning approach to improve critical thinking skills in Google Scholar indexed journals. Trends in the themes of writing articles related to the interactive web-based STEM-PjBL hybrid model of material physics with deep learning approach to improve critical thinking skills from the oldest to the newest year are marked with purple, blue themes, turquoise, dark green, light green and yellow.

*Integrated Discussion: Hybrid STEM–PjBL, Web Interactivity, and Deep Learning*

The integration of SLR and bibliometric findings highlights that Hybrid STEM–PjBL models supported by web-interactive platforms and deep learning approaches remain an emerging research domain. While STEM–PjBL has been widely adopted, most implementations remain instructionally static, lacking adaptive mechanisms that respond to learners' cognitive needs (Huang et al., 2022). Web-interactive learning environments partially address this limitation by enabling dynamic simulations, virtual laboratories, and inquiry-based digital projects, which are particularly effective in physics material learning (De Jong et al., 2013). These features support hypothesis testing, data interpretation, and reflective thinking—core components of critical thinking skills. The bibliometric emergence of deep learning suggests a paradigm shift toward data-driven instructional design. Deep learning algorithms enable automated analysis of learner behavior, adaptive scaffolding, and personalized feedback, which can significantly enhance metacognitive regulation and higher-order thinking. However, the SLR results indicate that empirical integration of deep learning within STEM–PjBL frameworks is still limited, especially in physics education. This gap underscores the need for a Hybrid STEM–PjBL Web-Interactive Model with Deep Learning, which integrates pedagogical design, digital interactivity, and intelligent analytics to optimize critical thinking development.

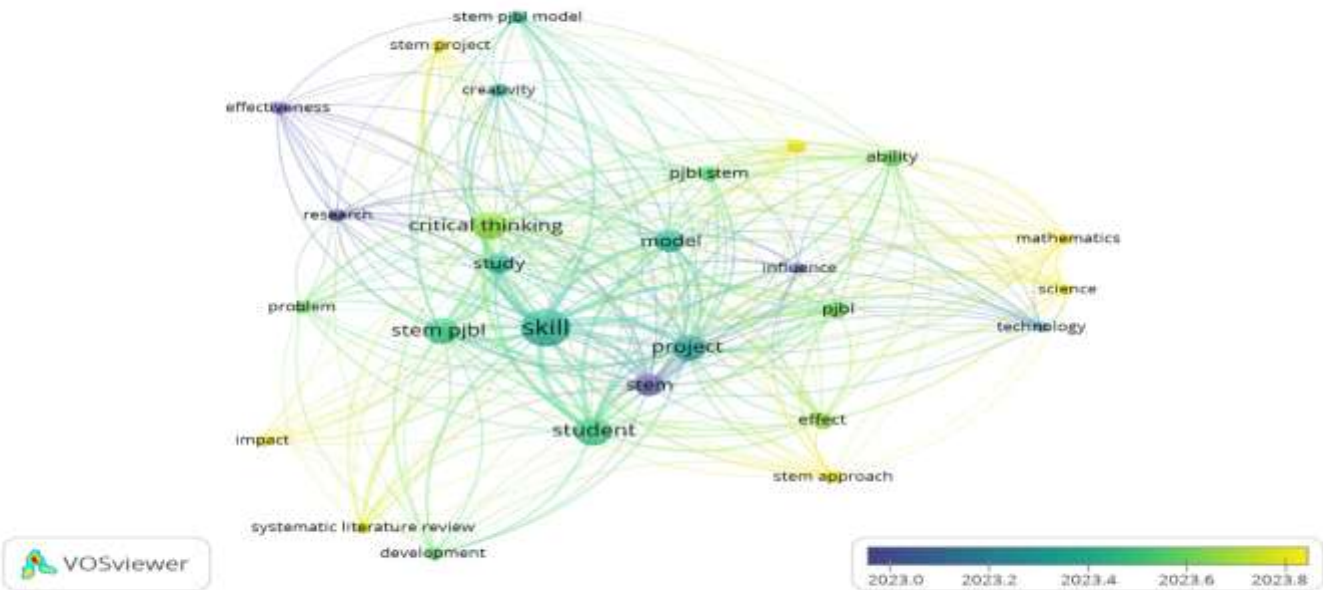


**Figure 4.** Overlay visualization on trend interactive web-based STEM-PjBL hybrid model of material physics with deep learning approach to improve critical thinking skills research

Research on interactive web-based STEM-PjBL hybrid model of material physics with deep learning approach to improve critical thinking skills is one area of research that has developed rapidly in recent years. The following also presents keywords for interactive web-based STEM-PjBL hybrid model of material physics with deep learning approach to improve critical thinking skills research based on density visualization. Figure 5 shows density visualization. The density of research themes is shown in bright yellow. The brighter the colors of a theme, the more research is done. The fainter the color means the theme is rarely researched (Kaur et al., 2022; Liao et al., 2018). Faintly colored themes shows that these keywords can be used as a reference for further research. While yellow indicates keywords that are currently and frequently used in research (Doyan et al., 2024).

*Implications for Physics Material Learning*

Physics material learning requires advanced critical thinking skills, including analytical reasoning, evaluation of experimental data, and application of theoretical principles to real-world problems (Doyan et al., 2025). The reviewed literature indicates that material physics topics are particularly compatible with STEM–PjBL approaches due to their interdisciplinary and problem-oriented nature. However, many studies address STEM, PjBL, and digital learning as isolated components (Oise et al., 2025; Indriyani et al., 2022). The proposed hybrid model offers a coherent instructional framework integrating STEM epistemology, project cycles, web-based interactivity, and deep learning-driven personalization, thereby addressing fragmentation in existing research.

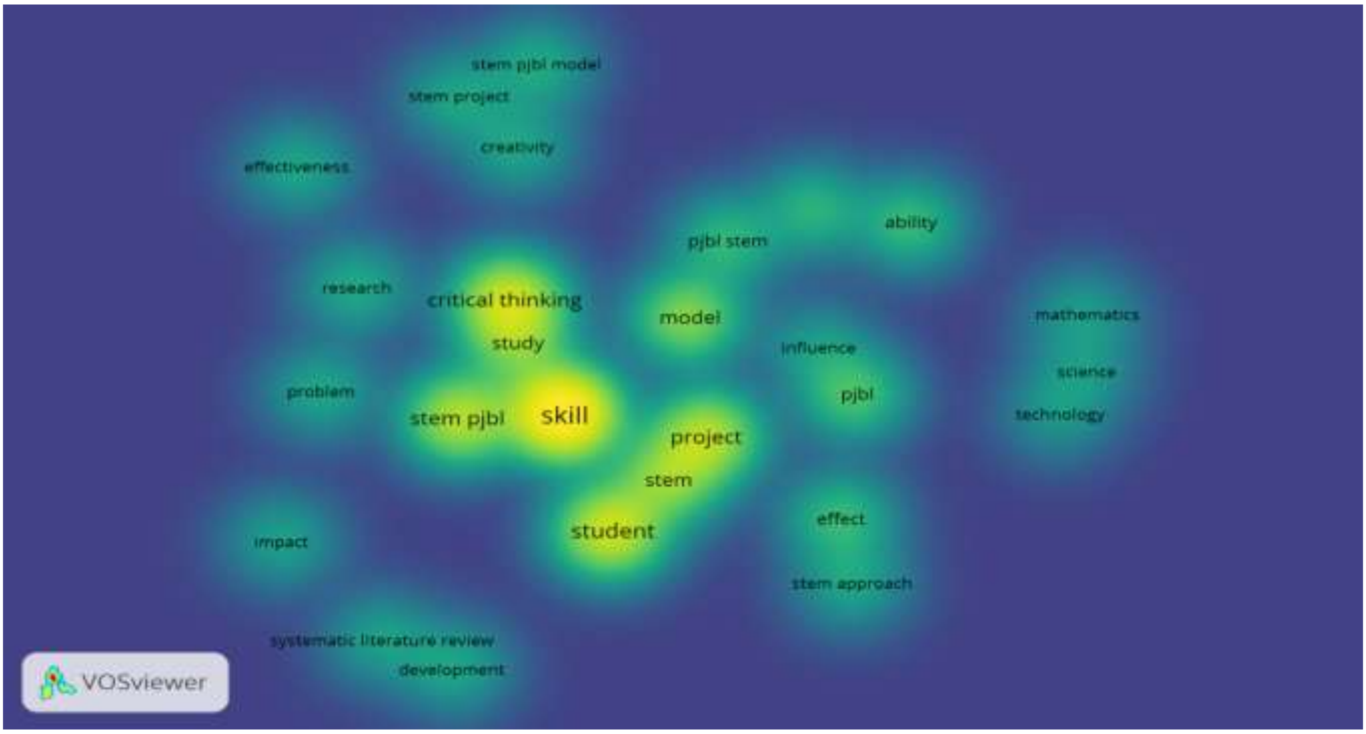


**Figure 5.** Density visualization on interactive web-based STEM-PjBL hybrid model of material physics with deep learning approach to improve critical thinking skills research

*Research Gap and Contribution*

Based on the integrated analysis, three critical gaps are identified: Limited empirical studies on deep learning-supported STEM–PjBL in physics education; Underexplored web-interactive hybrid models for physics material learning; Insufficient alignment between critical thinking indicators and learning analytics. Accordingly (Utomo et al., 2023), this study contributes by advancing a Hybrid STEM–PjBL Web-Interactive Model with Deep Learning to enhance students' critical thinking skills in physics material education.

## Conclusion

This study integrates a Systematic Literature Review (SLR) and bibliometric analysis to examine the development, trends, and effectiveness of Hybrid STEM–Project-Based Learning (STEM–PjBL) models supported by web-interactive environments and deep learning approaches in enhancing students' critical thinking skills, particularly in physics material learning. The findings from the SLR demonstrate that STEM-oriented PjBL consistently produces positive effects on learners' critical thinking, conceptual understanding, and problem-solving abilities. These outcomes are achieved through authentic project engagement, interdisciplinary learning processes, and inquiry-driven activities that align with the cognitive demands of physics education. However, the review also reveals that many existing implementations remain instructionally static, relying heavily on predefined project structures without adaptive mechanisms to address individual learners' cognitive needs. The bibliometric analysis further indicates a rapid growth in research output from 2020 to 2026, with increasing attention toward web-based learning, digital interactivity, and artificial intelligence in education. Keyword co-occurrence and trend analysis highlight the emergence of deep learning and learning analytics as promising yet underutilized components within STEM–PjBL frameworks. Despite their potential to personalize learning and support metacognitive regulation, empirical integration of deep learning into STEM–PjBL—particularly in physics material contexts—remains limited. Taken together, these findings confirm a clear research gap and justify the need for a Hybrid STEM–PjBL Web-Interactive Model with Deep Learning. Such a model is conceptually positioned to combine pedagogical robustness, digital interactivity, and intelligent adaptability, thereby offering a more effective instructional approach for fostering critical thinking skills in physics material education.

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**Author Contributions**

Conceptualization, A. D; methodology,.S; formal analysis, S. A.; investigation, L. S. U.; resources, M. I.; writing—preparation of original draft, N. R. A.; writing—reviewing and editing, A. D.; visualization, S; supervision, S. A.; project administration, L. S. U; obtaining funding, M. I. All authors have read and approved the published version of the manuscript

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**Conflicts of Interest**

No conflict interest.

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