



# Research Trends Material Physics E-Module Based on Synthesis and Characterization of Barium M-Hexaferrite using PjBL Model to Enhance Student Creativity (A Review)

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**Abstract:** The rapid development of material physics research, particularly in the synthesis and characterization of barium M-hexaferrite ( $\text{BaFe}_{12}\text{O}_{19}$ ), has not been optimally integrated into higher education physics learning. At the same time, Project-Based Learning (PjBL) and digital e-modules have been widely reported to enhance students' creativity, yet their application remains largely limited to basic physics topics. This study aims to map and synthesize existing research related to PjBL-based e-modules, student creativity, and BaM hexaferrite material studies, in order to identify research trends, gaps, and opportunities for interdisciplinary integration. A Hybrid Review methodology was employed, combining a Systematic Literature Review (SLR) guided by PRISMA 2020 and a Bibliometric Review. Literature published between 2018 and 2026 was collected from Scopus and SINTA databases. A total of 38 eligible articles were included for qualitative synthesis and bibliometric mapping. The SLR examined research focus, methodologies, learning outcomes, and material synthesis approaches, while the bibliometric analysis explored publication trends, keyword co-occurrence, collaboration networks, and thematic structures. The results indicate that PjBL-based e-modules are consistently effective in fostering creativity and higher-order thinking skills. However, bibliometric evidence reveals a clear separation between physics education research and BaM hexaferrite material studies, with minimal thematic overlap. This finding highlights a significant research gap and underscores the novelty of integrating BaM hexaferrite synthesis and characterization into a PjBL-oriented e-module. The study provides a strong conceptual foundation for developing research-based digital learning materials that promote authentic scientific creativity in higher education physics.

**Keywords:** Barium M-hexaferrite; Creativity; E-module; Hybrid Review; Physics Education; Project-Based Learning.

## Introduction

The rapid advancement of materials physics in recent decades has been closely linked to the growing demand for functional materials with superior physical properties and strong relevance to modern technological applications. Among these materials, magnetic ferrites—particularly barium M-type hexaferrite ( $\text{BaFe}_{12}\text{O}_{19}$ )—have attracted significant attention due to their high magnetocrystalline anisotropy, large

coercivity, excellent thermal stability, and complex hexagonal crystal structure (Pullar, 2012; Af'idah et al., 2023). These properties make barium M-hexaferrite highly suitable for applications in permanent magnets, microwave absorbers, electromagnetic devices, and energy-related technologies (Gunanto et al., 2024; Sah et al., 2024).

Recent studies have demonstrated that the structural and magnetic properties of  $\text{BaFe}_{12}\text{O}_{19}$  are strongly influenced by synthesis methods, thermal

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treatment conditions, and chemical composition, including the substitution of transition metal dopants such as Zn, Co, Ni, and La to tailor crystallite size, morphology, and magnetic response (Naibaho et al., 2024; Pangga et al., 2024; Susilawati et al., 2025). Synthesis techniques such as co-precipitation, sol-gel, mechanical milling, and wet chemical methods have been widely employed to control microstructural features, which in turn affect the functional performance of the material (Adnyana et al., 2023; Dudziak et al., 2023). Consequently, a comprehensive understanding of synthesis and characterization processes has become an essential competency for undergraduate and graduate students in materials physics and applied science.

Despite the scientific importance of these topics, the complexity of material synthesis and characterization often poses challenges in higher education learning environments. Physics instruction that relies heavily on lectures and conventional textbooks frequently fails to bridge the gap between theoretical knowledge and experimental practice, resulting in limited student engagement and insufficient development of scientific creativity (Millen & Supahar, 2023; Pangestu et al., 2025). Creativity is widely recognized as a crucial 21st-century skill in science education, as it underpins students' ability to design experiments, analyze data, and generate innovative solutions to scientific problems (Anisa et al., 2025).

In this context, Project-Based Learning (PjBL) has emerged as a pedagogical model well suited to addressing these challenges in materials physics education. PjBL emphasizes student-centered learning through engagement in authentic projects that integrate conceptual understanding, scientific process skills, and higher-order thinking abilities, including creativity and collaboration (Farkhan et al., 2025). Numerous studies have reported that the implementation of PjBL in physics education significantly enhances students' creative thinking, problem-solving skills, and conceptual mastery compared to traditional instructional approaches (Pangestu et al., 2025; Ginting et al., 2025).

Alongside pedagogical innovation, the digital transformation of higher education has accelerated the development of technology-based instructional materials. E-modules have become a prominent form of digital learning resources due to their flexibility, interactivity, and accessibility, which support both independent and collaborative learning (Prihatiningtyas & Sholihah, 2020; Rahman et al., 2025). When designed using a PjBL framework, e-modules can guide students systematically through project stages, including problem identification, experimental planning, material synthesis, characterization, data analysis, and scientific reporting (Yulkifli et al., 2022; Novianti et al., 2025).

Previous studies on PjBL-based e-modules in physics education—covering topics such as mechanics, fluid dynamics, and modern physics—have consistently demonstrated their validity, practicality, and effectiveness in improving students' creativity and learning outcomes (Melati et al., 2024; Rahman et al., 2025; Situmeang et al., 2025). However, most of these studies have focused on fundamental physics topics, while relatively little attention has been given to advanced materials physics, particularly in relation to the synthesis and characterization of magnetic materials grounded in contemporary research.

At the same time, research on barium M-hexaferrite has advanced rapidly, yet these scientific developments are rarely integrated into instructional materials for higher education. As a result, a disconnect persists between cutting-edge materials research and classroom learning practices. Students often encounter magnetic materials only at a theoretical level, without sufficient exposure to research-based synthesis and characterization processes that reflect real scientific practice (Gunanto et al., 2024; Sah et al., 2024).

Integrating materials science research content into PjBL-based e-modules therefore represents a strategic approach to bridging this gap. Through project activities involving the synthesis and characterization of barium M-hexaferrite, students can develop a deeper understanding of crystal structures, magnetic properties, and characterization techniques such as X-ray diffraction (XRD) and scanning electron microscopy (SEM), while simultaneously cultivating creative thinking skills through experimental design and data interpretation (Dudziak et al., 2023; Naibaho et al., 2024). This approach aligns with the principles of 21st-century science education, which emphasize inquiry-based learning, research integration, and higher-order cognitive skill development.

Based on a comprehensive review of the literature, it is evident that studies focusing on the development of PjBL-based materials physics e-modules that explicitly address the synthesis and characterization of barium M-hexaferrite remain limited. Existing research tends to examine either instructional innovation without deep materials science integration or materials synthesis research without pedagogical implications. This indicates a clear research gap that warrants further investigation.

Accordingly, this study aims to develop a Project-Based Learning e-module in materials physics centered on the synthesis and characterization of barium M-hexaferrite and to examine its impact on enhancing university students' creativity. The proposed e-module is expected to serve as a research-based, contextual, and innovative learning resource that contributes both theoretically and practically to the advancement of

materials physics education and project-based instructional design in higher education.

Therefore, this research wants to know the research trend on material physics e-module based on synthesis and characterization of barium m-hexaferrite using PjBL model to enhance student creativity.

## Method

### *Research design*

This study employed a Hybrid Review methodology, integrating a Systematic Literature Review (SLR) and a Bibliometric Review, to comprehensively analyze research trends related to physics material e-modules, barium M-hexaferrite ( $\text{BaFe}_{12}\text{O}_{19}$ ) synthesis and characterization, Project-Based Learning (PjBL), and student creativity enhancement. The hybrid approach enables both in-depth qualitative synthesis of selected studies and quantitative mapping of publication patterns, research hotspots, and intellectual structures within the field (Donthu et al., 2021; Aria & Cuccurullo, 2017).

The use of a hybrid review is particularly relevant for interdisciplinary research that combines materials science and physics education, as it allows the identification of research gaps, methodological tendencies, and emerging themes while ensuring transparency and reproducibility in the review process (Kitchenham & Charters, 2007; Zupic & Čater, 2015).

### *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 et al., 2019, 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 (Pratama et al., 2025; Roslina et al., 2023). The search process covered publications from January 2018 to January 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:

("e-module" OR "digital module" OR "electronic learning material") AND ("project-based learning" OR "PjBL") AND ("barium hexaferrite" OR " $\text{BaFe}_{12}\text{O}_{19}$ " OR "M-type hexaferrite") AND ("creativity" OR "creative

thinking") AND ("physics education" OR "material physics").

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 (Kitchenham & Charters, 2007; 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 were:

1. Peer-reviewed journal articles indexed in Scopus or SINTA
2. Publications between 2018–2026
3. Studies focusing on PjBL, e-modules, physics/material education, or BaM hexaferrite synthesis
4. Articles written in English or Indonesian
5. Empirical studies, development research, or review articles

Exclusion criteria included non-empirical studies, duplicated records, and articles lacking methodological clarity (Page et al., 2021). 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 (Page et al., 2021).

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.

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:

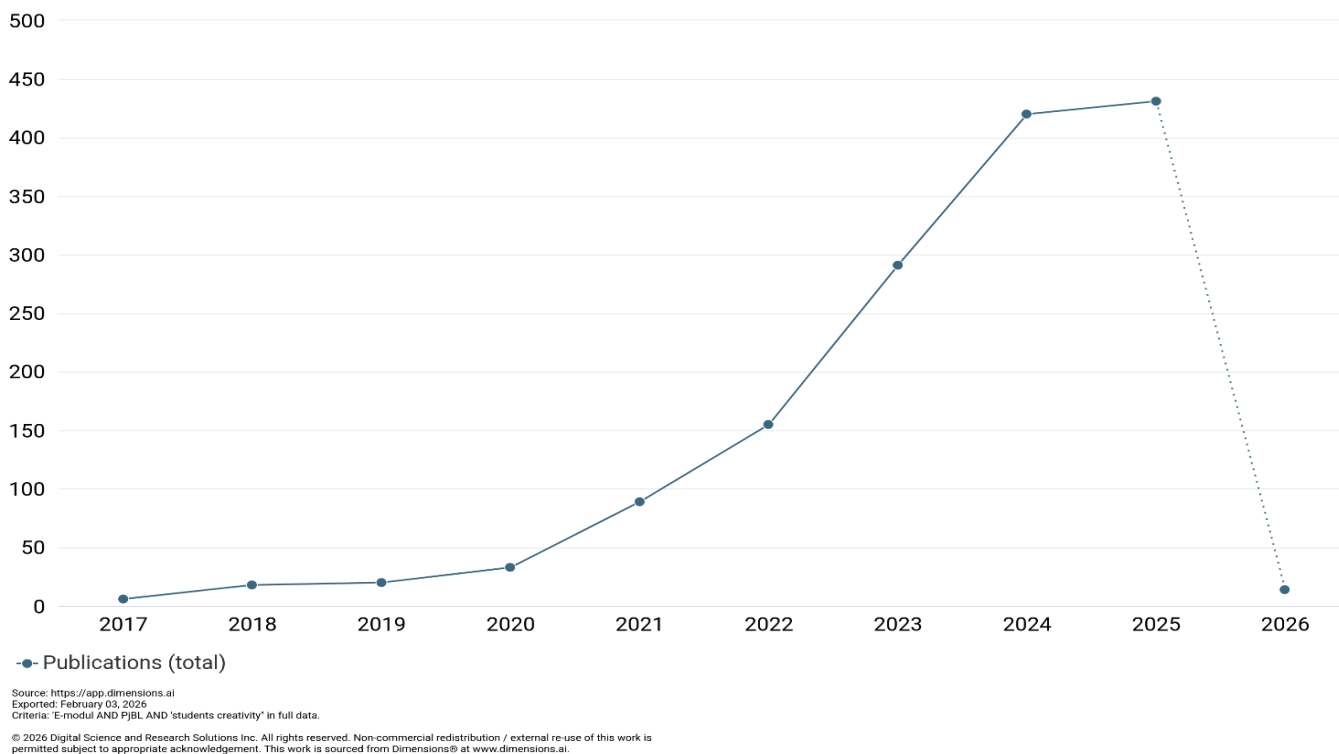
- Annual publication trends to identify research growth patterns
- Most productive and influential authors and journals
- Keyword co-occurrence analysis to detect dominant and emerging themes
- Co-citation and bibliographic coupling analysis to map intellectual relationships

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 material physics e-module based on synthesis and characterization of barium m-hexaferrite using PjBL model to enhance student creativity. Figure 1 is presented below regarding research trends on the material physics e-module based on synthesis and characterization of barium m-hexaferrite using PjBL model to enhance student creativity in the las ten years (obtained from app.dimensions.ai).

Figure 1 shows that the trend in research on the material physics e-module based on synthesis and characterization of barium m-hexaferrite using PjBL model to enhance student creativity experiencing increases. Below are also table 1 presented research of material physics e-module based on synthesis and characterization of barium m-hexaferrite using PjBL model to enhance student creativity based on the type of publication.



**Figure 1.** Research trends in material physics e-module based on synthesis and characterization of barium m-hexaferrite using PjBL model to enhance student creativity (app.dimensions.ai)

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

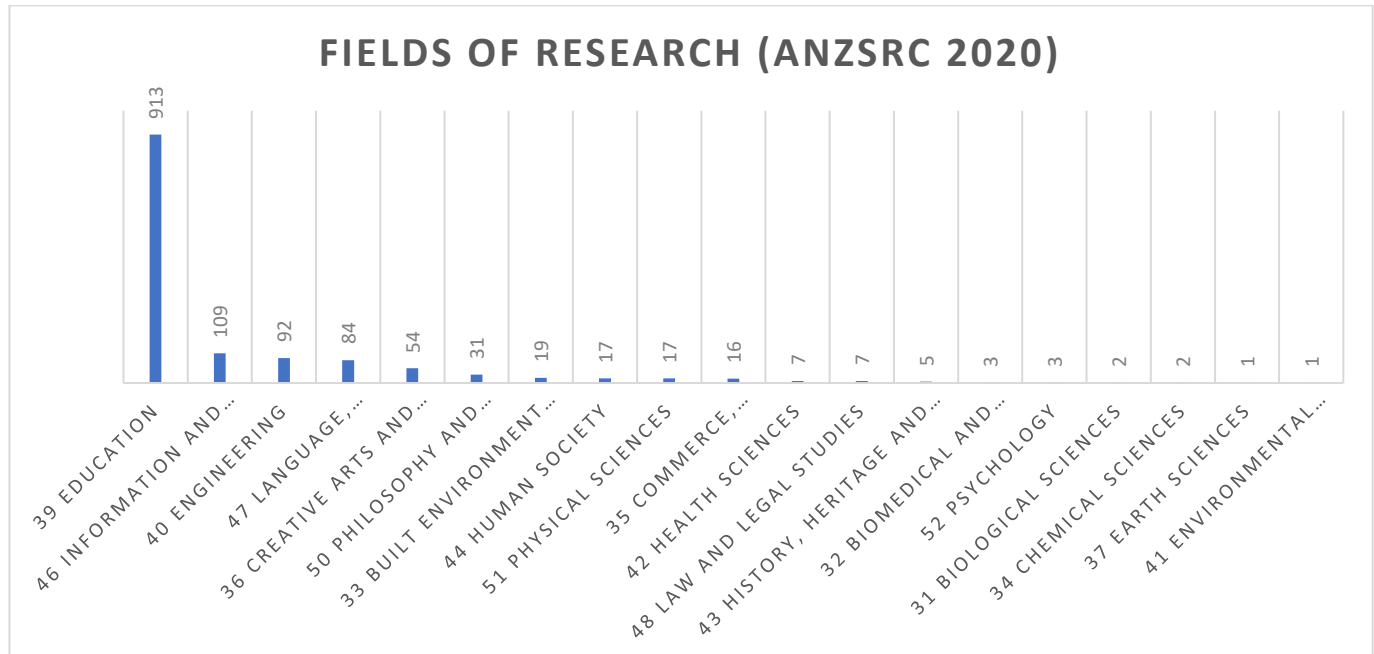
| Publication Type | Publications |
|------------------|--------------|
| Article          | 1,314        |
| Edited Book      | 97           |
| Chapter          | 29           |
| Proceeding       | 29           |
| Preprint         | 10           |

Based on Table 1, it is known that research trend by app.dimensions.ai contained in 5 types of publications. In the form of articles there were 1,314 documents, chapters as many as 29 documents, proceedings as many as 29 documents, edited books as many as 97 documents and 10 publications for preprint. Research trends in article form is the type of publication that contains the most research material physics e-module based on

synthesis and characterization of barium m-hexaferrite using PjBL model to enhance student creativity compared to other types of publications. Meanwhile, the type of publication contains the least amount of research results material physics e-module based on synthesis and characterization of barium m-hexaferrite using PjBL model to enhance student creativity is preprint. Research conducted by Oltarzhevskiy (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 et al., 2020).

Below are also figure 2 presented the fields research trends in material physics e-module based on synthesis and characterization of barium m-hexaferrite using PjBL model to enhance student creativity.



**Figure 2.** Research fields of Trend material physics e-module based on synthesis and characterization of barium m-hexaferrite using PjBL model to enhance student creativity Research

Figure 2 shows the most fields of research for research trend of material physics e-module based on synthesis and characterization of barium m-hexaferrite using PjBL model to enhance student creativity, namely in the criteria of education, with 913 publications. The most publishers are Jurnal Penelitian Pendidikan IPA with 186 publications and 586 citations. Jurnal Penelitian Pendidikan IPA contains scientific articles form of research results that include science, technology, and teaching in the field of science. The first edition were published in 2015. All edition in this journal are open access, i.e. the articles published in them are immediately and permanently free to read, download, copy & distribute.

#### Results of Systematic Literature Review (SLR)

The study selection process followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines to ensure transparency, rigor, and reproducibility. The PRISMA flow diagram summarizes the identification, screening,

eligibility, and inclusion stages of the systematic literature review.

During the identification stage, a total of 340 records were retrieved from two databases: Scopus (n = 214) and SINTA (n = 126). All records were exported to reference management software, where 82 duplicate articles were identified and removed. After duplicate removal, 258 unique records remained for screening.

In the screening stage, titles and abstracts of the 258 records were independently reviewed to assess their relevance to physics education, material physics, project-based learning (PjBL), e-modules, and creativity. As a result, 167 records were excluded because they were not related to the research scope, did not address PjBL or digital learning materials, or did not present empirical research findings.

The remaining 91 articles were subjected to full-text eligibility assessment. At this stage, 53 articles were excluded for several reasons, including lack of integration between educational and material physics perspectives, focus solely on material synthesis without pedagogical relevance, education-oriented studies

without material physics content, and incomplete or inaccessible full texts.

Finally, 38 articles met all inclusion criteria and were included in the systematic literature review. These same 38 articles were also used for the bibliometric analysis to ensure consistency between qualitative synthesis and quantitative mapping. The final dataset provided a comprehensive and balanced representation of research trends at the intersection of physics education, digital learning, project-based learning, creativity, and barium M-hexaferrite material studies.

Methodologically, the reviewed studies were dominated by research and development (R&D) designs, quasi-experimental studies, and experimental material science investigations. Educational studies primarily employed ADDIE, 4D, or design-based research frameworks, while material physics studies relied on experimental synthesis and characterization protocols (Melati et al., 2024; Gunanto et al., 2024).

#### *Bibliometric Results: Research Trends and Knowledge Structure*

Bibliometric analysis reveals a significant increase in publications related to digital learning and PjBL in physics education after 2020, reflecting the broader digital transformation in higher education. In contrast, BaM hexaferrite research exhibits steady growth over the reviewed period, primarily within materials science and applied physics journals (Donthu et al., 2021; Pullar, 2019). The differing growth trajectories suggest parallel but weakly connected research streams, reinforcing the need for interdisciplinary integration.

Keyword co-occurrence mapping identified three dominant clusters:

1. Educational Innovation Cluster: project-based learning, e-module, creativity, digital learning, physics education.
2. Material Science Cluster: barium hexaferrite,  $\text{BaFe}_{12}\text{O}_{19}$ , magnetic properties, synthesis, characterization.
3. Analytical Techniques Cluster: XRD, SEM, microstructure, magnetization.

Limited keyword overlap between clusters 1 and 2 indicates that educational and material research remain largely segregated. This bibliometric pattern quantitatively confirms the research gap identified through SLR.

Co-authorship analysis reveals dense collaboration networks within material physics research, often centered around specialized laboratories. Physics education research, by contrast, shows more localized collaboration patterns. The absence of cross-domain collaboration networks helps explain the lack of integrated educational-material studies.

Citation analysis identifies Pullar (2019) and Donthu et al. (2021) as foundational works shaping material science and bibliometric methodology, respectively, yet their influence rarely intersects within a single study.

#### *SLR Findings on PjBL-Based E-Modules in Physics Learning*

The SLR reveals strong empirical evidence that PjBL-based e-modules significantly enhance students' learning engagement, conceptual understanding, and creativity. Across multiple studies, e-modules integrating PjBL stages—problem definition, project planning, investigation, product creation, and reflection—consistently yielded higher creativity scores compared to conventional instruction (Rahman et al., 2025; Pangestu et al., 2025).

Digital features such as interactive simulations, embedded multimedia, reflective prompts, and project worksheets were found to support divergent thinking, idea elaboration, and original problem-solving, which are core dimensions of creativity (Anisa et al., 2025). However, the content scope of most PjBL-based e-modules remains limited to introductory physics topics, with minimal representation of advanced or research-oriented content.

#### *Creativity as an Outcome in Physics Education Research*

Creativity measurement across the reviewed studies predominantly employed indicators adapted from Torrance and Guilford, including fluency, flexibility, originality, and elaboration. Results consistently show that PjBL environments foster creativity by encouraging students to generate multiple solution pathways and design original project outputs (Farkhan et al., 2025; Situmeang et al., 2025).

Nevertheless, creativity in the reviewed literature is often conceptualized as a generic cognitive skill, rather than as discipline-specific scientific creativity. Few studies explicitly assess creativity related to experimental design, parameter optimization, or data interpretation—skills that are essential in material physics research. This limitation indicates a need for learning materials that situate creativity within authentic scientific inquiry contexts.

In the articles researched and written by these researchers, there are many terms/keywords related to material physics e-module based on synthesis and characterization of barium m-hexaferrite using PjBL model to enhance student creativity. 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 material physics e-module based on synthesis and characterization of barium m-hexaferrite using PjBL model to enhance student creativity are e-module development 4 times with a level

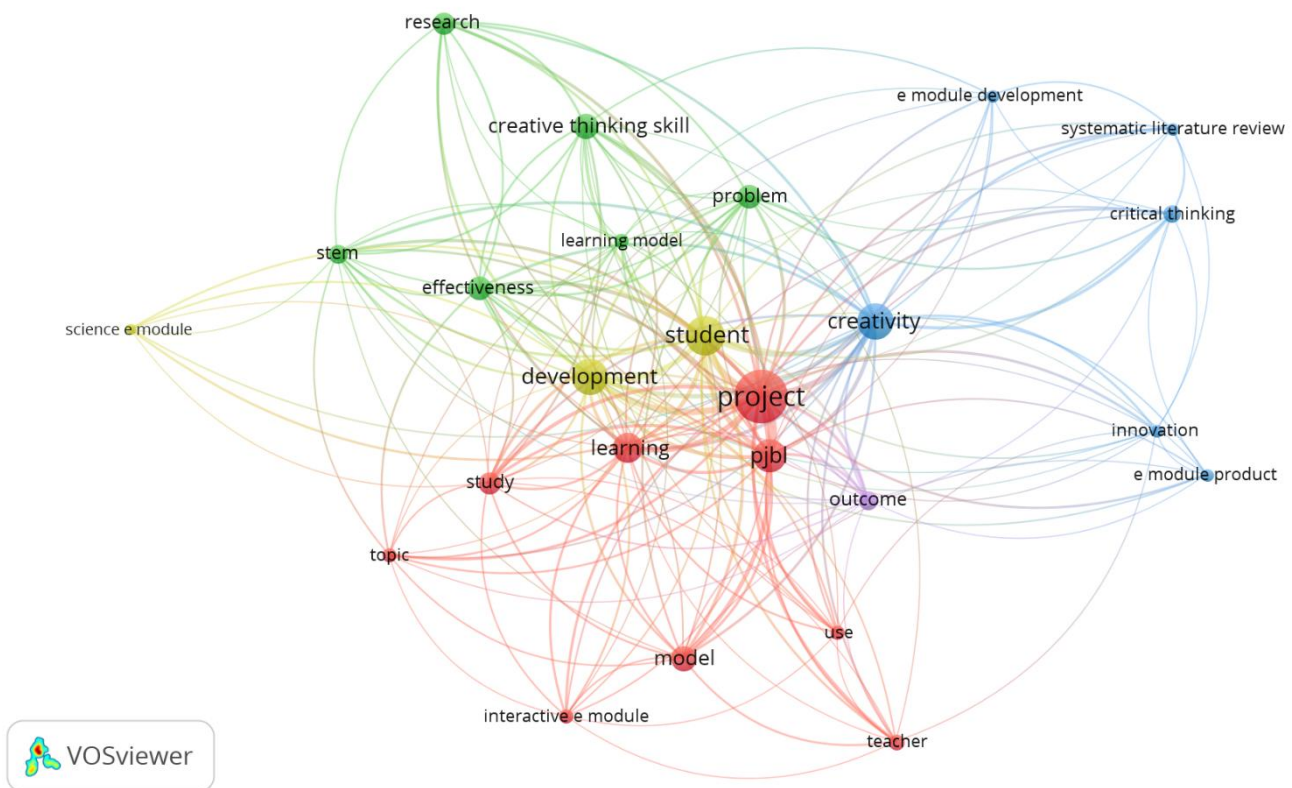
of 3.27. Table 2 also shows that critical thinking is also a keyword that appears frequently in research trends, namely 8 times with a relevance of 2.59.

**Table 2.** Keywords on Trend research

| Terms                | Occurrences | Relevance |
|----------------------|-------------|-----------|
| E-module development | 4           | 3.27      |
| Critical thinking    | 8           | 2.59      |
| Innovation           | 5           | 1.94      |
| Interactive e-module | 6           | 0.91      |
| Learning model       | 5           | 0.86      |

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 material physics e-module based on synthesis and characterization of barium m-hexaferrite using PjBL model to enhance student creativity are illustrated in Figure 3.

Figure 3 shows the results of bibliometric keyword mapping on research trends on the topic material physics e-module based on synthesis and characterization of barium m-hexaferrite using PjBL model to enhance student creativity. In Figure 3 there are 25 keyword items that are often used in research on the material physics e-module based on synthesis and characterization of barium m-hexaferrite using PjBL model to enhance student creativity. Figure 3 also contains 5 clusters, where the first cluster is colored red and consists of 9 keyword items, namely interactive e module, PjBL, etc. The second cluster in green consists of 6 keyword items, namely creative thinking, STEM, etc. The third cluster in blue consists of 6 keyword items, namely e module development, innovation, etc. The fourth yellow cluster only consists of 3 keyword items, namely development, science e module and student. The fifth cluster only consists 1 items namely outcome.



**Figure 3.** Network visualization on trend material physics e-module based on synthesis and characterization of barium m-hexaferrite using PjBL model to enhance student creativity 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/clusters 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 material physics e-module based on synthesis and characterization of barium m-hexaferrite using PjBL model to enhance student creativity. The more keywords that appear, the wider the visualization

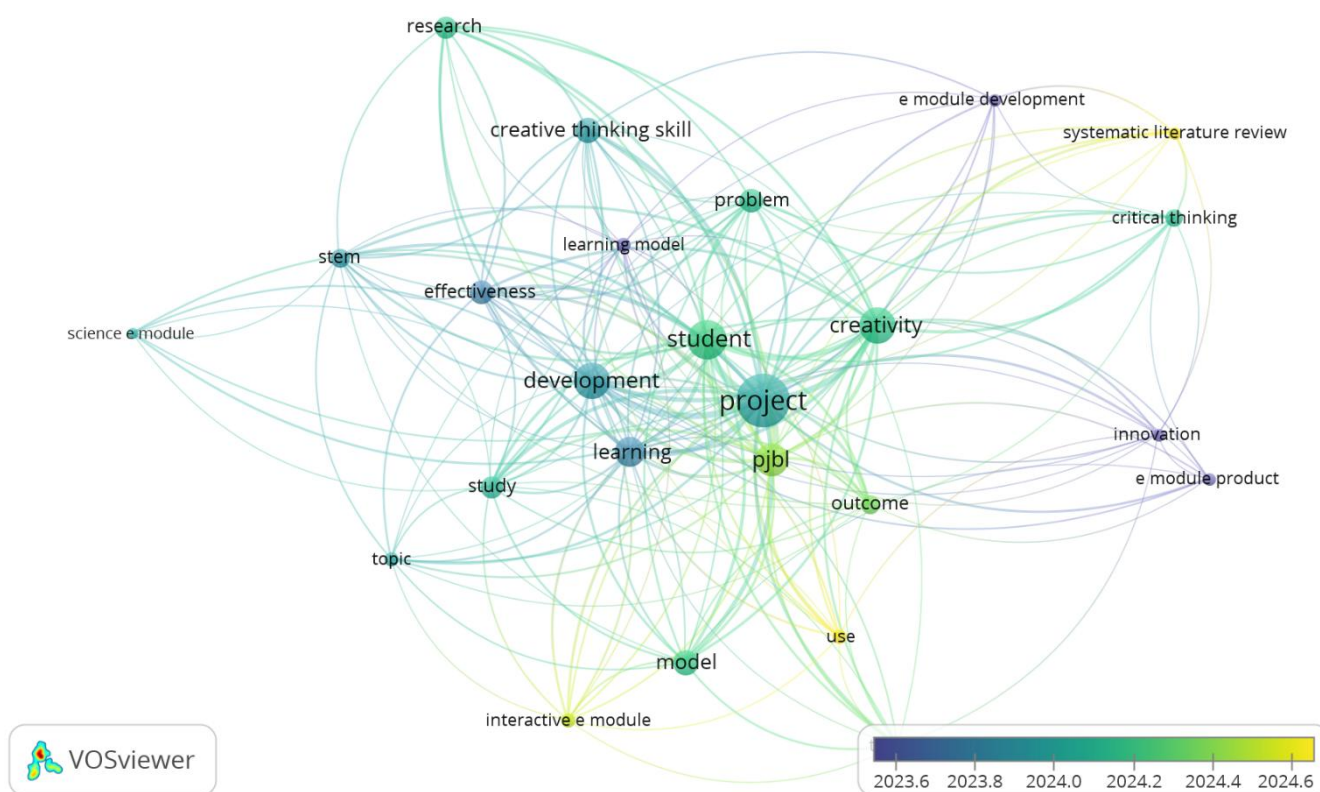
displayed. Below are also presented keywords regarding the material physics e-module based on synthesis and characterization of barium m-hexaferrite using PjBL model to enhance student creativity based on overlay visualization.

Figure 4 shows the trend of keywords related to research on material physics e-module based on synthesis and characterization of barium m-hexaferrite using PjBL model to enhance student creativity in Google Scholar indexed journals. Trends in the themes of writing articles related to material physics e-module based on synthesis and characterization of barium m-hexaferrite using PjBL model to enhance student creativity from the oldest to the newest year are marked with purple, blue themes, turquoise, dark green, light green and yellow.

#### SLR Findings on Barium M-Hexaferrite Research

The SLR identifies a substantial volume of research on  $\text{BaFe}_{12}\text{O}_{19}$  synthesis and characterization, focusing on optimizing magnetic performance through synthesis route selection and chemical substitution. Studies consistently demonstrate that synthesis methods such as sol-gel, coprecipitation, and wet chemical synthesis significantly affect crystallite size, morphology, coercivity, and saturation magnetization (Adnyana et al., 2023; Naibaho et al., 2024).

Characterization techniques including X-ray diffraction (XRD), scanning electron microscopy (SEM), and vibrating sample magnetometry (VSM) are widely employed to establish structure–property relationships (Dudziak et al., 2023; Susilawati et al., 2025). Despite their scientific rigor, these studies rarely consider educational implementation or translation into learning materials.



**Figure 4.** Overlay visualization on trend material physics e-module based on synthesis and characterization of barium m-hexaferrite using PjBL model to enhance student creativity research

Research on material physics e-module based on synthesis and characterization of barium m-hexaferrite using PjBL model to enhance student creativity is one area of research that has developed rapidly in recent years. The following also presents keywords for material physics e-module based on synthesis and characterization of barium m-hexaferrite using PjBL

model to enhance student creativity 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



(BaFe<sub>12</sub>O<sub>19</sub>) synthesis and characterization in physics education. The hybrid methodology enabled a comprehensive understanding of both qualitative evidence and quantitative research patterns.

The findings indicate that PjBL-based e-modules are effective in enhancing student creativity and higher-order thinking skills; however, most existing studies remain focused on basic physics topics and lack integration with advanced material physics research. Bibliometric results further reveal a clear disciplinary separation between physics education research and BaM hexaferrite material studies, with limited thematic overlap and collaboration.

These results highlight a significant research gap and underscore the novelty of integrating BaM hexaferrite synthesis and characterization into a PjBL-oriented e-module. Such integration has strong potential to foster authentic scientific creativity by engaging students in real experimental design, data analysis, and interpretation. This study therefore provides a clear conceptual foundation for future development and empirical validation of research-based digital learning materials in higher education physics.

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#### Author Contributions

All authors contributed to writing this article.

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#### Conflicts of Interest

No conflict interest.

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