Journal of Education for Sustainability and Transformation
Volume 1, Number 4, 2026.
E-ISSN: 3125-0130
https://journal.serral.org/jestra

A Bibliometric Analysis of STEM-Based Interactive Modules in Physics Education: Research Trends, Thematic Structures, and Emerging Directions (2010–2026)

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Article Info

Keywords:
Bibliometric analysis
Interactive modules
Physics education
STEM education
Technology-enhanced learning

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Abstract

ABSTRACT
STEM education and interactive learning technologies are increasingly converging in physics education through e-modules, simulations, e-learning, virtual laboratories, augmented reality, virtual reality, and related digital environments. This study maps research trends, thematic structures, and emerging directions in STEM-based interactive modules in physics education from 2010 to 2026. A bibliometric analysis of 127 Scopus-indexed documents was conducted using Bibliometrix/Biblioshiny in RStudio, covering annual production, citations, publication sources, term frequency, trend topics, co-occurrence networks, density mapping, and thematic mapping. Publication output accelerated after 2019. The field was dominated by students, physics education, STEM, engineering education, STEM education, e-learning, virtual reality, and learning systems. The thematic map identified STEM education, virtual reality, curricula and students, STEM, engineering education as motor themes, while physics education, teaching, e-learning formed a basic theme. Computational thinking, mixed reality, gamification, and science technologies remained less consolidated but showed emerging potential. The findings suggest that future research should move beyond technology adoption by strengthening pedagogical coherence, meaningful interactivity, and explicit cross-disciplinary STEM integration.

Received: 6 September 2026; **Received in revised form** 19 September 2026**; Accepted:** 26 September 2026

To cite this article: Dewi, B. P., Wibowo, F. C., Nasbey, H. (2026). A Bibliometric Analysis of STEM-Based Interactive Modules in Physics Education: Research Trends, Thematic Structures, and Emerging Directions (2010–2026). *Journal of Education for Sustainability and Transformation, 1*(4), 49-64.

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INTRODUCTION

Science, Technology, Engineering, and Mathematics (STEM) has increasingly been conceptualized as an instructional framework that connects knowledge and practices from science, technology, engineering, and mathematics through authentic contexts. STEM integration should not be reduced to the juxtaposition of several disciplines; rather, it requires meaningful

interdisciplinary connections through problem solving, inquiry, modelling, and engineering design. Kelley and Knowles (2016) identified authentic contexts and disciplinary integration as foundational elements of integrated STEM, whereas English (2016) emphasized that the quality of interdisciplinary connections, rather than the mere use of the STEM label, is central to meaningful STEM implementation.

In practice, STEM integration has increasingly been combined with interactive modules and related learning resources. Interactive modules can integrate text, visualizations, simulations, variable manipulation, virtual experimentation, feedback, and learner-controlled navigation within a structured instructional environment. These affordances are particularly relevant to physics education because many physics concepts are abstract, dynamic, and dependent on multiple representations. Rutten et al. (2012) showed that computer simulations can support science learning when they are appropriately embedded in instruction, while Thees et al. (2020) demonstrated that immersive technologies such as augmented reality can enrich physics laboratory experiences, although their benefits depend on pedagogical design and the management of cognitive load.

The development of STEM-based interactive modules reflects a broader convergence between pedagogical innovation and the digital transformation of education. E-modules, virtual laboratories, virtual reality, augmented reality, interactive simulations, game-based learning, and learning systems represent increasingly diverse modes of implementation. Although these technologies share interactive characteristics, they serve different instructional functions; therefore, the presence of digital features alone should not be treated as evidence of instructional quality. The central research challenge is not simply to expand technology use, but to ensure coherence among interactivity, task structure, STEM integration, and intended learning outcomes.

The growing literature on STEM and interactive learning is distributed across multiple terms, platforms, and pedagogical approaches. Some studies use labels such as e-learning or digital learning, whereas others emphasize simulations, virtual laboratories, virtual reality, augmented reality, gamification, or computer-aided instruction. This terminological fragmentation makes it difficult to determine how STEM-based interactive modules have evolved as a coherent research domain, which technologies occupy central positions, and which themes are emerging as new directions. Reviews of STEM-based physics education likewise indicate rapid technological and pedagogical development, while also noting the need for greater conceptual clarity regarding how the components of STEM are integrated in practice (Putri et al., 2026).

The dataset analyzed in this study indicates high visibility for terms such as STEM, STEM education, physics education, e-learning, virtual reality, learning systems, and augmented reality, whereas computational thinking, mixed reality, gamification, and science technologies occupy more peripheral or less consolidated positions. This pattern suggests that the field has established a strong foundation in STEM integration and technology-enhanced learning, but the development of interactive modules remains dispersed across immersive technologies, computation, curriculum design, and learner-engagement strategies. A systematic mapping of the thematic structure is therefore needed to distinguish core, basic, niche, and potentially emerging themes.

Bibliometric analysis is well suited to this purpose because it combines performance analysis with science mapping. Performance analysis can characterize the evolution of scientific production, citation patterns, and publication sources, whereas science-mapping techniques can reveal conceptual relationships through co-word analysis, thematic mapping, thematic evolution, and term co-occurrence networks (Donthu et al., 2021). The Bibliometrix package and its Biblioshiny interface provide an integrated R-based environment for conducting these analyses and visualizing the conceptual structure of a research field (Aria & Cuccurullo, 2017).

Against this background, the present study maps the development of research on STEM-based interactive modules in physics education from 2010 to 2026, with particular attention to publication growth, scientific sources, dominant themes, conceptual structure, and emerging research directions. Rather than privileging a single learning outcome, the study examines how STEM integration and interactivity are constructed across the research landscape. To maintain alignment among the study objectives, analytical procedures, and reported findings, the research questions are presented in Table 1.

Table 1. Research Questions and Corresponding Biblioshiny Analyses

RQ	Research Question	Biblioshiny Analysis
RQ1	How did research on STEM-based interactive modules in physics education evolve from 2010 to 2026 in terms of scientific production and citation patterns?	Annual Scientific Production; Average Citations per Year
RQ2	Which publication sources were most prominent in the development of research on STEM-based interactive modules?	Most Relevant Sources; Source Productivity
RQ3	Which themes and interactive technologies were most prominent, and how did they evolve over time?	Most Frequent Words; Word Cloud; Words' Frequency over Time; Trend Topics
RQ4	What conceptual structure and interrelationships among themes characterized research on STEM-based interactive modules?	Co-occurrence Network; Density Map; Thematic Map
RQ5	Which themes remained emerging or insufficiently consolidated, and how do they inform the next research agenda for STEM-based interactive modules?	Thematic Map; Trend Topics; Synthesis of Conceptual Structure

METHOD

Research Design

This study employed a bibliometric approach to examine the development, publication patterns, and conceptual structure of research on STEM-based interactive modules in physics education. Bibliometric analysis was selected because it integrates measures of scientific performance with science mapping, enabling the field to be examined in terms of productivity, thematic relationships, and emerging research directions (Donthu et al., 2021; Aria & Cuccurullo, 2017).

Data Source and Search Strategy

Bibliographic data were retrieved from the Scopus database and exported on 7 October 2026. The search window covered 2010–2026 to capture more than a decade of development in STEM integration and interactive learning technologies. Although the search period began in 2010, the earliest publication in the retrieved dataset appeared in 2011. Records from 2026 were treated as partial-year data because data extraction occurred before the end of the calendar year.

The search strategy was structured around three conceptual blocks: (1) the context of physics education, physics learning, or physics teaching; (2) STEM, STEAM, or integrated STEM; and (3) interactive modules or functionally equivalent interactive instructional resources, including e-

modules, digital modules, simulations, virtual laboratories, virtual reality, augmented reality, multimedia, game-based learning, and interactive learning environments. This structure was retained to capture the intersection between STEM integration and interactive instructional formats in physics-related educational contexts.

PCC Framework and Eligibility Criteria

The Population–Concept–Context (PCC) framework was used to operationalize the scope and eligibility criteria. PCC was considered more appropriate than PICOS because the study does not compare the effectiveness of an intervention against a comparator; instead, it maps the structure and development of a research field. Population referred to publications situated in physics education, Concept referred to STEM-based interactive modules or related interactive instructional resources, and Context covered globally indexed Scopus publications from 2010 to 2026 (Peters et al., 2020).

Table 2. PCC Framework Used to Define the Review Scope

Component	Operational Definition
Population	Publications substantively addressing physics education, physics teaching, physics learning, or the learning of physics concepts.
Concept	STEM/STEAM-based interactive instructional modules or resources, including e-modules, digital modules, simulations, interactive multimedia, virtual or remote laboratories, VR/AR environments, educational games, and structured interactive learning environments.
Context	Global literature indexed in Scopus during 2010–2026.

Table 3. Inclusion and Exclusion Criteria

Dimension	Inclusion Criteria	Exclusion Criteria
Publication period	2010–2026	Before 2010 or after the final search date in 2026
Document type	Journal article and full conference paper	Editorial, letter, note, erratum, short review, or conference abstract only
Educational domain	Physics education, learning, or teaching constituted a substantive context	Physics was mentioned only incidentally
STEM relevance	STEM, STEAM, or integrated STEM constituted a substantive framework or instructional component	STEM appeared only as an index term or general background reference
Interactivity	The resource incorporated simulation, manipulation, feedback, interactive multimedia, VR/AR, virtual/remote laboratories, games, or other digital interaction	Static media without substantive interactivity

Dimension	Inclusion Criteria	Exclusion Criteria
Instructional function	The module or resource was used in a structured instructional role	General-purpose software or hardware without a clear instructional function
Module/interactivity focus	The module or resource had an identifiable structured instructional function and interactive component	Technology was mentioned only as a device or tool without a clearly defined instructional function
Metadata	Bibliographic metadata were sufficient for the planned analyses	Metadata were insufficient for bibliometric analysis
Duplicates	One unique bibliographic record	Duplicate DOI or title

Rayyan Screening and PRISMA Reporting

The retrieved records can be imported into Rayyan to support duplicate checking, title-and-abstract screening, Include/Exclude/Maybe decisions, and the consistent documentation of exclusion reasons (Ouzzani et al., 2016). Screening was designed as a two-stage process comprising title-and-abstract screening followed by full-text eligibility assessment. Study selection was reported in accordance with PRISMA 2020 principles to ensure transparency across identification, screening, eligibility assessment, and inclusion (Page et al., 2021). At the time this manuscript was prepared, the Biblioshiny outputs supplied for analysis were still based on the complete initial dataset of 127 documents; therefore, the screening and full-text counts in Figure 1 must be updated using the final Rayyan decisions before submission.

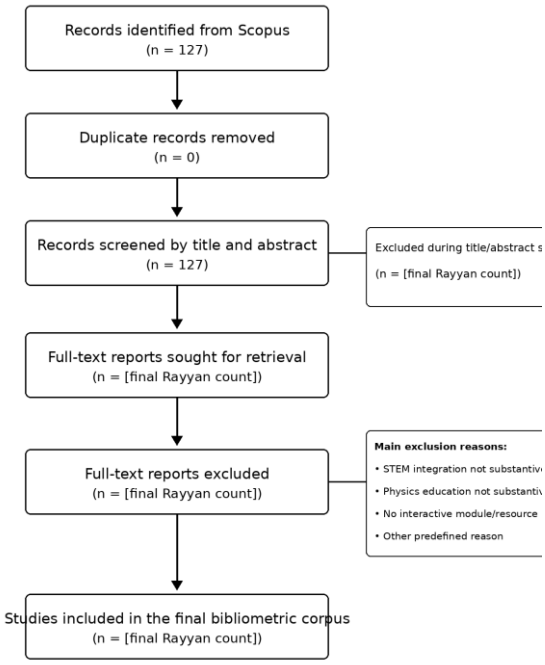


Figure 1. PRISMA flow diagram for the study. Screening and eligibility counts should be updated after the final Rayyan decisions.

Bibliometric Analysis with Biblioshiny

The Scopus dataset was analyzed using Bibliometrix/Biblioshiny in RStudio. The analytical workflow included Annual Scientific Production, Average Citations per Year, Most Relevant Sources, Most Frequent Words, Word Cloud, Words' Frequency over Time, Trend Topics, Co-occurrence Network, Density Map, and Thematic Map. In the thematic map, cluster positions were determined using Callon centrality and Callon density. Centrality indicates the degree to which a theme is connected to the overall structure of the field, whereas density reflects the level of internal development within a theme (Cobo et al., 2011).

RESULTS AND DISCUSSION

RQ1. Evolution of Scientific Production and Citation Patterns

The analysis identified 127 publications within the 2010–2026 search window, with the first publication appearing in 2011. Scientific output remained limited during the early phase: two documents were published in 2011, none in 2012, two in 2013, and only one to two publications per year between 2014 and 2018. Growth became more visible in 2019 with five publications, followed by 12 in 2020 and 13 in 2021. After fluctuating to 11 documents in 2022 and nine in 2023, output increased to 17 in 2024, 24 in 2025, and 26 in 2026. This trajectory indicates that interest in the intersection of STEM and interactive learning technologies in physics education expanded primarily during the second half of the study period. However, the 2026 value represents partial-year data and should not be interpreted as a complete annual publication count.

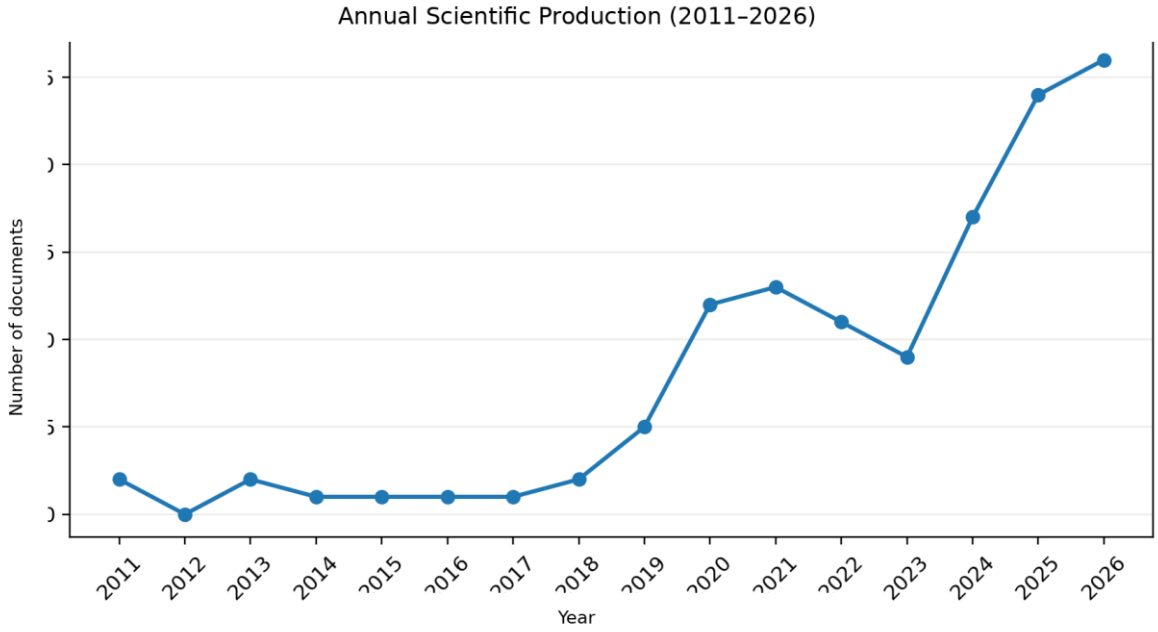


Figure 2. Annual scientific production on STEM and interactive learning in physics education.

Citation patterns varied markedly across publication years. Publications from 2013 received an average of 248.5 total citations per article, while the single publication from 2017 received 177 citations. These values, however, are based on only two documents and one document, respectively. By contrast, publications from 2025 and 2026 averaged 1.96 and 0.08 citations per article because they had substantially shorter citation windows. These results underscore the need to consider both yearly document counts and citation-window bias when comparing citation impact across publication years.

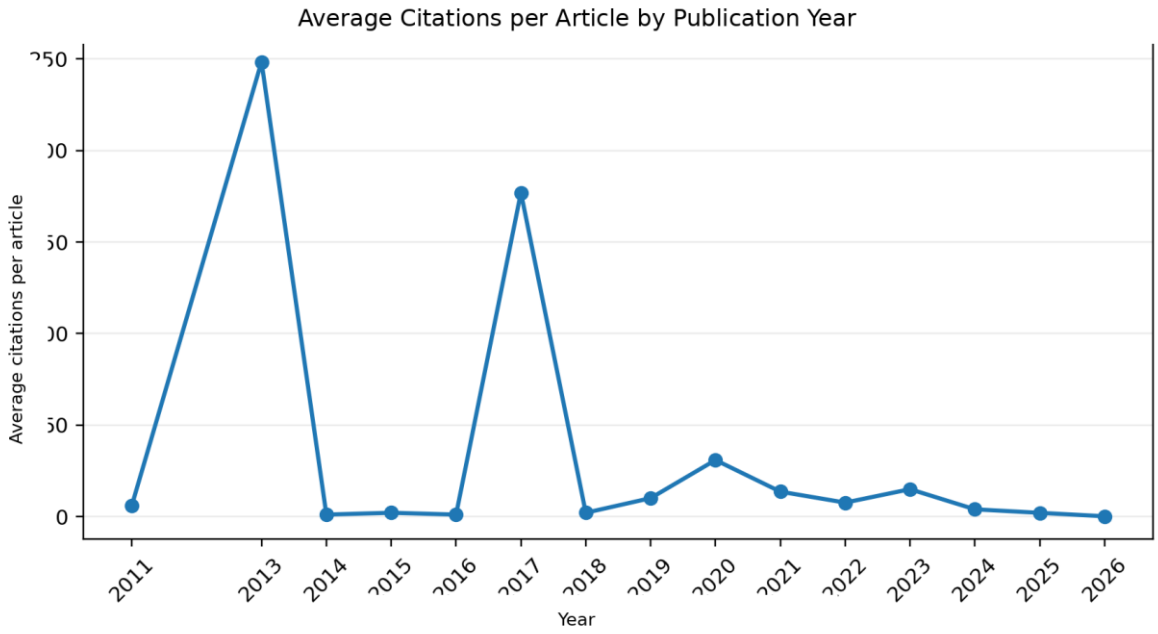


Figure 3. Average total citations per article by publication year.

RQ2. Dominant Publication Sources

Source distribution showed that the Journal of Physics: Conference Series was the most productive outlet with 14 documents, followed by the ASEE Annual Conference and Exposition, Conference Proceedings with 10 documents, AIP Conference Proceedings with six, and Frontiers in Education with five. Communications in Computer and Information Science and the IOP Conference Series: Earth and Environmental Science each contributed three documents. This distribution indicates that the discourse spans physics education, engineering education, educational technology, and instructional innovation.

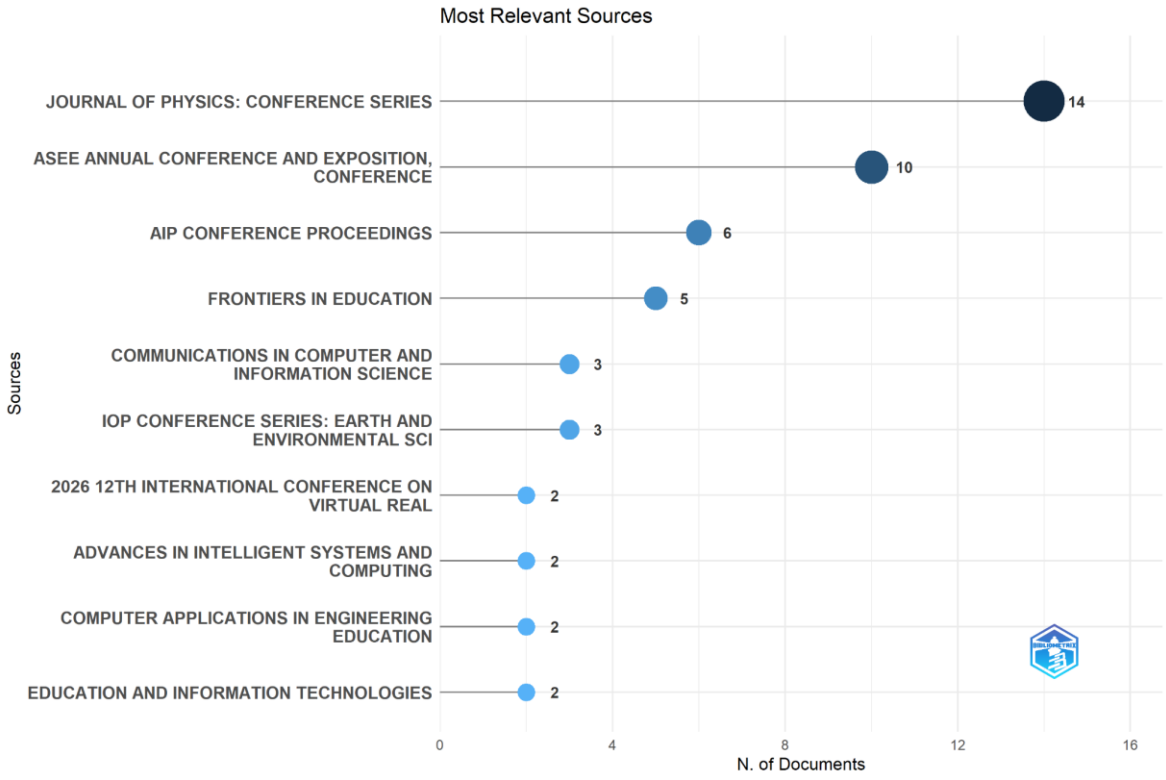


Figure 4. Most relevant publication sources by number of documents.

The prominence of conference proceedings should be interpreted in light of the inclusion criteria, which admitted full conference papers. Consequently, the share of conference publications should not be used in isolation to infer the maturity of the field. Rather, the pattern suggests that conferences constitute important dissemination venues for rapidly evolving technological and pedagogical innovations, while journal outlets in physics education and educational technology provide complementary channels for more extended empirical and conceptual development.

RQ3. Dominant Themes, Interactive Technologies, and Temporal Development

Term-frequency analysis identified students as the most frequent term (51 occurrences), followed by physics education (38), STEM (science, technology, engineering and mathematics) (36), engineering education (33), STEM education (25), and teaching (25). Terms directly associated with interactive learning were also prominent, including e-learning (20), learning systems (18), virtual reality (17), education computing (16), computer-aided instruction (14), augmented reality (13), as well as simulation, virtual laboratories, gamification, and mixed reality. This distribution indicates that research on STEM-based interactive modules extends beyond the e-module format to a broader ecosystem of interactive instructional technologies.



Figure 5. Word cloud of the most frequent terms in the dataset.

The Words' Frequency over Time analysis showed a clear acceleration in the cumulative occurrence of major terms after 2019. Physics education increased from two cumulative occurrences in 2019 to 15 in 2024, 26 in 2025, and 38 in 2026. STEM education rose from one occurrence in 2019 to 11 in 2024 and 25 in 2026, whereas e-learning increased from no occurrence before 2020 to 11 in 2024 and 20 in 2026. Their simultaneous growth indicates an increasing convergence among STEM integration, physics-education contexts, and interactive digital learning.

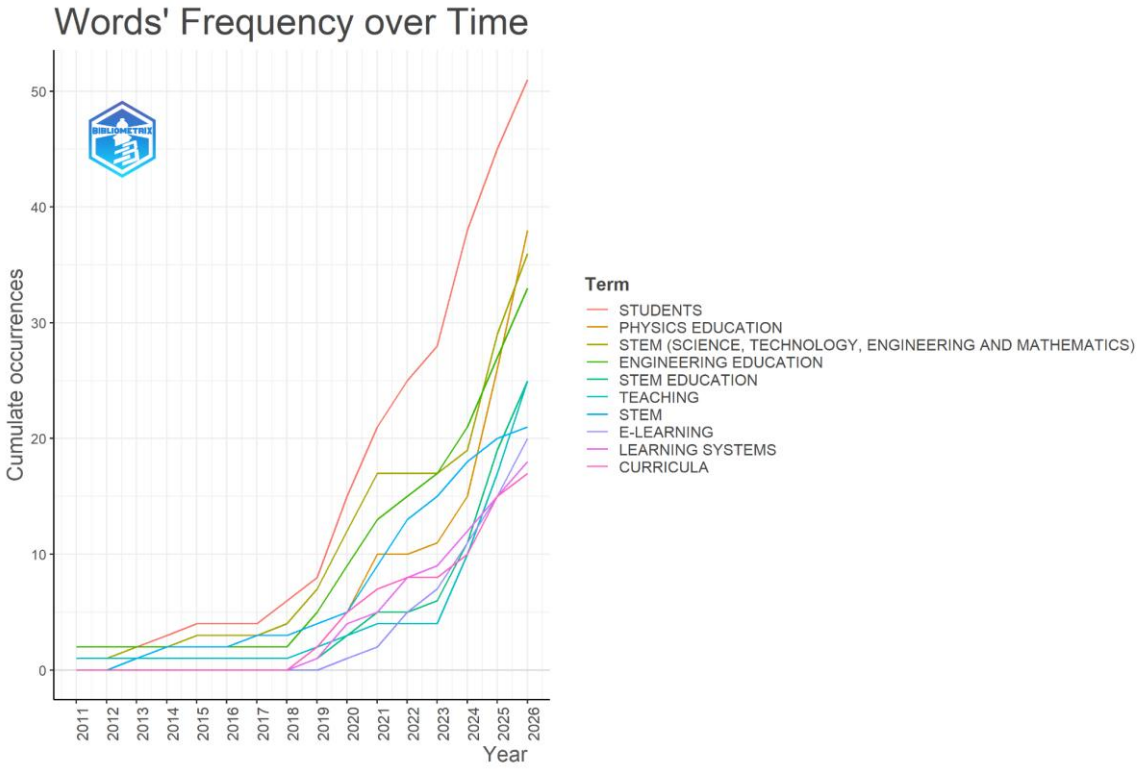


Figure 6. Cumulative frequency of major terms over time.

Trend Topics further revealed a shift from relatively broad early themes toward increasingly specific topics related to technology and instructional integration. Visualization had the longest temporal span, with a median around 2014. Physics learning and critical thinking were centered around 2021, whereas STEM, physics, and simulation were centered around 2022. Students, engineering education, and augmented reality strengthened around 2023; STEM, e-learning, and learning systems around 2024; and physics education, teaching, and STEM education around 2025. The pattern suggests that recent research has moved toward more explicit STEM integration with digital systems, immersive technologies, and simulation-based learning experiences.

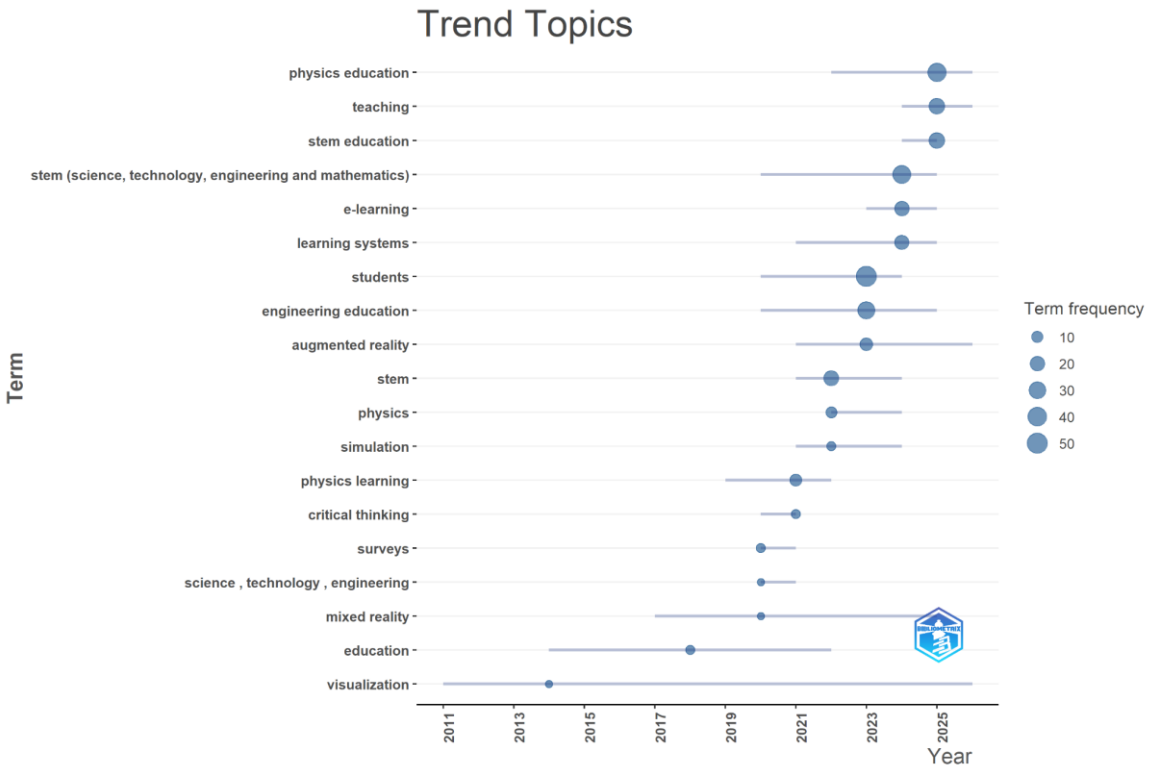


Figure 7. Trend topics across the study period.

RQ4. Conceptual Structure of STEM and Interactive Modules

The co-occurrence network revealed four major conceptual groupings. The first cluster was centered on students, STEM, and engineering education and was connected to augmented reality, physics learning, critical thinking, science technologies, and visualization. The second cluster was organized around physics education, teaching, e-learning, learning systems, education computing, and computer-aided instruction. The third cluster linked STEM education, curricula, virtual reality, virtual laboratories, laboratories, simulation, and physics laboratories. The fourth cluster connected STEM, physics, mixed reality, computational thinking, and game-based learning. Taken together, these structures indicate three broad developmental pathways for STEM-based interactive modules: digital learning systems, immersive and virtual environments, and computational or game-based learning.

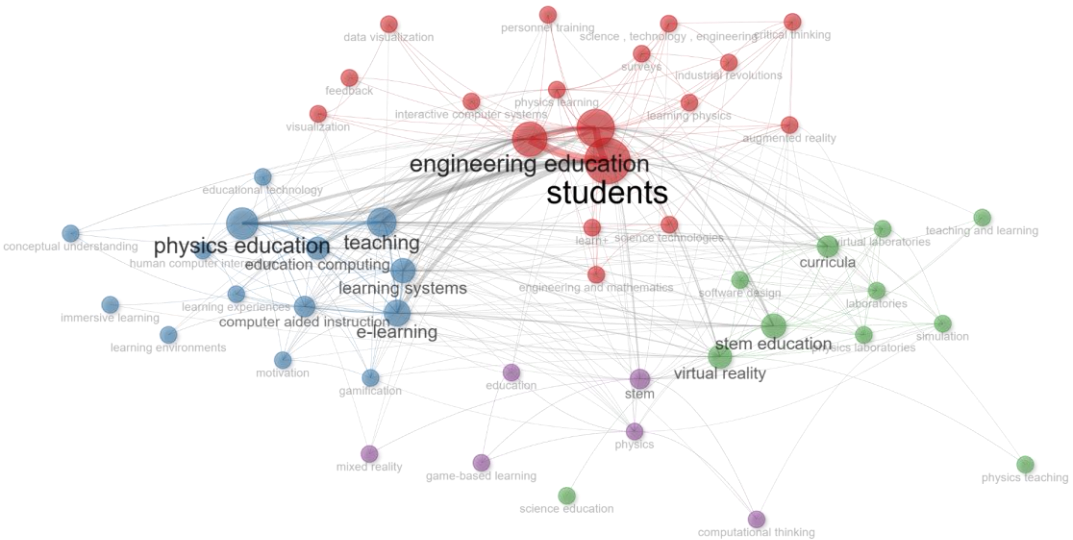


Figure 8. Term co-occurrence network for the analyzed dataset.

The co-occurrence density map reinforced this structure. The highest-intensity regions were concentrated around students, engineering education, physics education, teaching, STEM education, virtual reality, and e-learning. These concentrations suggest that the field is primarily organized around relationships among learners, instructional context, STEM integration, and digital technologies. By contrast, computational thinking, gamification, mixed reality, and science technologies occupied more peripheral regions and therefore represent less consolidated areas with potential for further development.

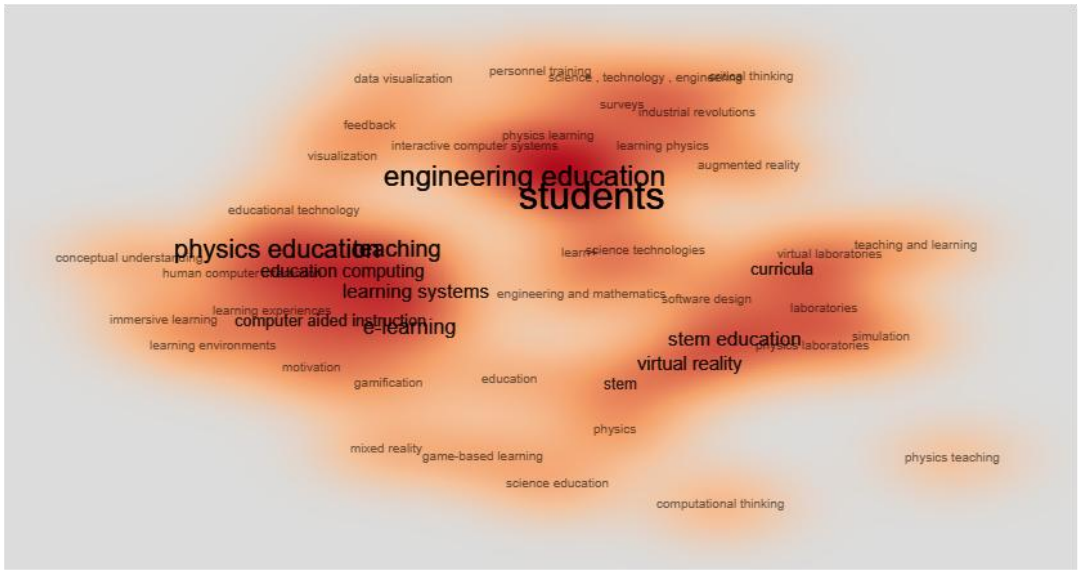


Figure 9. Density map of term co-occurrence.

RQ5. Thematic Map and Emerging Directions for STEM-Based Interactive Modules

The thematic map identified seven clusters with different levels of centrality and density. The students cluster had a Callon centrality of 10.69 and a density of 104.05, whereas the STEM education cluster had a centrality of 9.87 and a density of 167.37. Both were located in the motor-themes quadrant, indicating themes that are relatively well developed and strongly connected to the broader field. The physics education cluster had the highest centrality (15.20) but a lower density (96.60) and was positioned among the basic themes. This configuration indicates that physics education functions as a highly connected foundation, while its internal development is distributed across teaching, e-learning, learning systems, and computer-aided instruction.

Table 4. Thematic Structure Based on Callon Centrality and Callon Density

Cluster	Centrality	Density	Position	Interpretation
Students	10.69	104.05	Motor theme	STEM, engineering education, AR, physics learning, critical thinking
STEM education	9.87	167.37	Motor theme	Virtual reality, curricula, virtual laboratories, simulation
Physics education	15.20	96.60	Basic theme	Teaching, e-learning, learning systems, computer-aided instruction

Cluster	Centrality	Density	Position	Interpretation
Education	2.19	104.05	Niche theme	Visualization, data visualization, game-based learning
Motivation	3.42	102.14	Niche/borderline	Gamification, online/distance education, engagement
STEM	7.28	95.96	Emerging/declining	Physics, computational thinking, modelling, scaffolding
Science technologies	4.05	74.35	Emerging/declining	Engineering and mathematics, active learning, machine learning

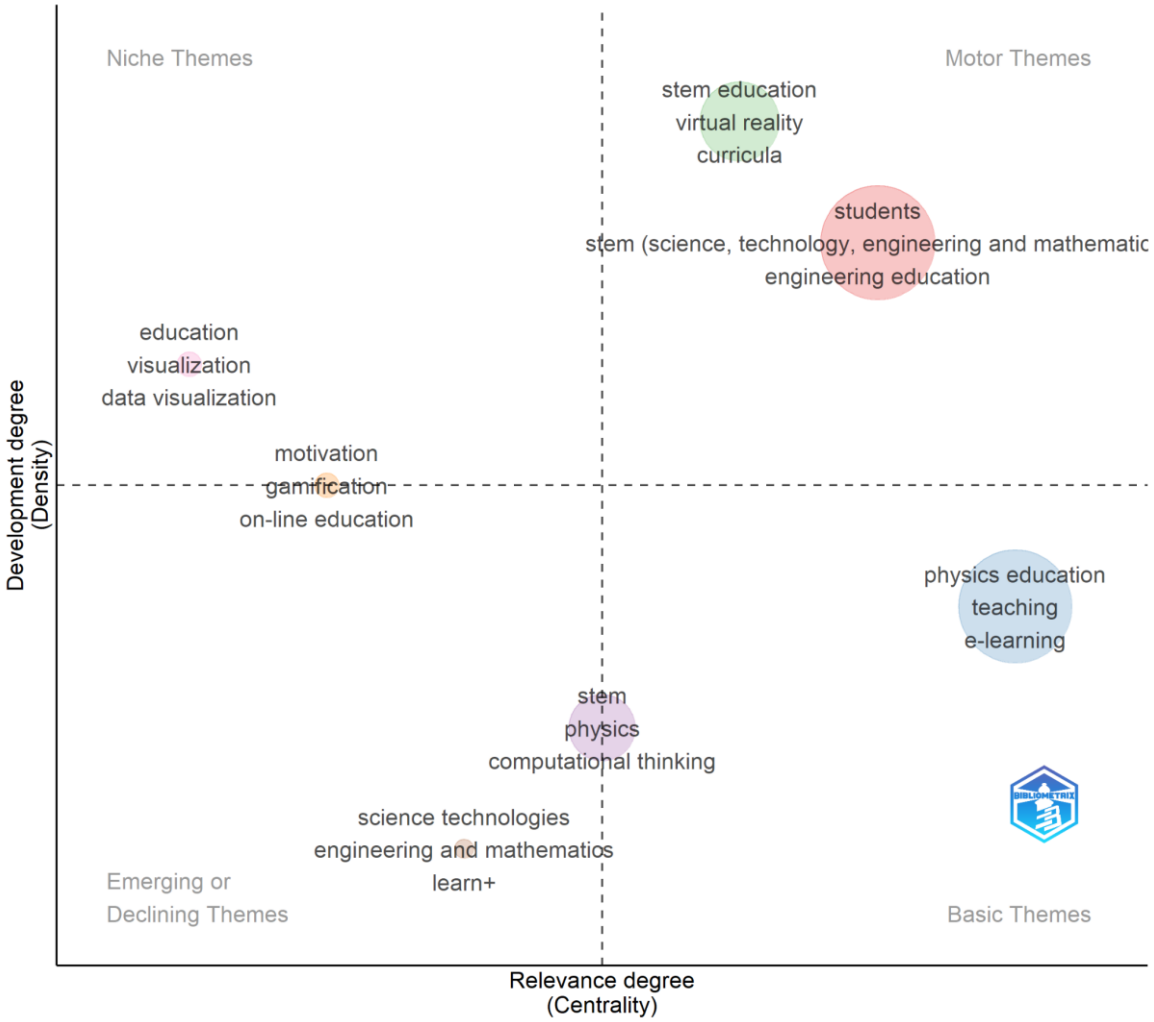


Figure 10. Thematic map based on Callon centrality and Callon density.

The STEM–physics–computational thinking and science technologies clusters were located in the emerging-or-declining quadrant. This position should not automatically be interpreted as decline because the Trend Topics analysis showed that STEM, physics, computational thinking, mixed reality, and several related digital technologies were concentrated in more recent years.

Accordingly, these clusters are better interpreted as insufficiently consolidated areas that may develop into new research fronts.

A synthesis of the thematic map and Trend Topics suggests four directions for the future development of STEM-based interactive modules. First, immersive technologies are likely to expand through virtual reality, augmented reality, mixed reality, and virtual laboratories. Second, computational approaches may become more prominent through computational thinking, simulation, modelling, and learning systems. Third, learner engagement may be strengthened through gamification, game-based learning, and purposeful interactive activity design. Fourth, the pedagogical architecture of modules needs to make relationships among science, technology, engineering, and mathematics explicit in learning tasks, representations, problem solving, and engineering design rather than treating STEM as a nominal label.

The principal gap in the field therefore does not appear to be a shortage of technologies, but rather the need to consolidate diverse technologies within coherent STEM module designs. The prominence of e-learning, VR/AR, simulations, virtual laboratories, and learning systems demonstrates rapid technological diversification, yet the conceptual structure remains distributed across several clusters. Future research should therefore move beyond technology adoption toward module designs that systematically align learning objectives, explicit disciplinary contributions, interaction mechanisms, scaffolding, feedback, and assessment.

Based on this synthesis, future STEM-based interactive modules can be conceptualized through four integrated layers: (1) STEM disciplinary integration as the conceptual framework; (2) module design as the instructional architecture; (3) interactive technology as a medium for exploration, simulation, visualization, and feedback; and (4) authentic activities that connect modelling, inquiry, computation, and engineering design. These four layers provide a conceptual agenda for future design, development, and evaluation studies of STEM-based interactive modules.

Table 5. Emerging Directions for STEM-Based Interactive Modules Based on the Bibliometric Synthesis

Emerging Direction	Biblioshiny Evidence Base	Implications for STEM-Based Interactive Modules
Immersive technologies	Virtual reality, augmented reality, mixed reality, virtual laboratory	Develop exploratory and experimental experiences that allow learners to manipulate phenomena and representations interactively.
Computation and simulation	Computational thinking, simulation, learning systems	Integrate modelling, data processing, simulation, and decision making based on exploratory results.
Engagement and interactivity	Gamification, game-based learning, motivation	Design interaction mechanisms, challenges, feedback, and user control with explicit pedagogical functions.
Coherent STEM integration	STEM education, curricula, engineering education	Make the contributions of science, technology, engineering, and mathematics explicit in problems, activities, and learning products.

Theoretical and Practical Implications

Theoretically, the findings show that STEM-based interactive learning has developed a substantial technological and pedagogical structure, particularly around STEM education, e-learning, virtual reality, simulation, and learning systems. The contribution of this study lies in mapping the relationships among these themes and identifying research fronts that remain less consolidated. Practically, module developers should ensure that interactive features perform clearly defined instructional functions, support conceptual exploration and representation, and are embedded within authentic STEM activities. Technology should not be treated as a proxy for quality; the quality of an interactive module remains contingent on alignment among content, pedagogy, interactivity, and learning objectives.

Study Limitations

This study has several limitations. First, the dataset was drawn exclusively from Scopus; publications indexed only in other databases were therefore not represented. Second, science-mapping results are sensitive to metadata consistency and keyword variants, as illustrated by the separate occurrence of STEM, STEM education, and STEM (science, technology, engineering and mathematics). Third, both journal articles and conference papers were included, which influenced the observed source distribution. Fourth, the 2026 data represent only part of the publication year and therefore do not constitute a complete annual output or citation window. Fifth, the term interactive module overlaps in the dataset with e-learning, simulations, virtual laboratories, VR/AR, and learning systems; accordingly, interpretation emphasized interactive instructional function rather than product nomenclature alone.

CONCLUSION

The bibliometric analysis of 127 Scopus-indexed publications within the 2010–2026 search window revealed substantial growth in research connecting STEM and interactive learning within physics-education contexts. The knowledge structure was dominated by students, physics education, STEM, engineering education, STEM education, teaching, e-learning, virtual reality, and learning systems. The thematic map positioned STEM education–virtual reality–curricula and students–STEM–engineering education as motor themes, whereas physics education–teaching–e-learning formed a highly central basic theme.

The findings indicate that the field has moved from general uses of interactive technology toward more specific intersections among STEM, digital learning systems, immersive technologies, simulations, and computational activities. Computational thinking, mixed reality, gamification, and science technologies remain insufficiently consolidated but show potential as subsequent research fronts. Future work should therefore prioritize STEM-based interactive modules that are not only technologically innovative, but also pedagogically coherent, explicitly integrative across STEM disciplines, meaningfully interactive, and systematically supported by scaffolding, feedback, and assessment aligned with intended learning objectives.

ACKNOWLEDGMENT

The author gratefully acknowledges [institution/program/funding body] for the support provided during this study. This statement should be revised or removed as appropriate to reflect the actual funding and institutional support received.

AUTHOR CONTRIBUTION STATEMENT

BPD: conceptualization, search strategy, data collection and curation, bibliometric analysis, visualization, interpretation of results, and original draft preparation. [Other author initials]: supervision, methodological validation, critical review, and manuscript revision. This statement should be revised before submission to accurately reflect each author's actual contribution.

AI DISCLOSURE STATEMENT

Generative artificial intelligence (ChatGPT, OpenAI) was used during manuscript preparation to assist with structural organization, language refinement, and drafting support. The bibliographic dataset, Biblioshiny analyses, interpretation of outputs, reference verification, and all scientific judgments were reviewed and validated by the author(s). The author(s) retain full responsibility for the accuracy, originality, and integrity of the manuscript.

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