

Bibliometric Mapping of Games and SDGs: Positioning Traditional Games for Joyful Learning and Social Interaction in SDG 4

* Laily Masrurin Nisa, Mallevi Agustin Ningrum, Sri Setyowati, Ruqoyyah Fitri, Mohammad Syahidul Haq, Nurul Istiqfaroh

Early Childhood Education Department, Faculty of Education, Universitas Negeri Surabaya, Surabaya, Indonesia.

*Corresponding Author e-mail: 25011545049@mhs.unesa.ac.id

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Abstract

This study aims to map global scientific developments and research trends at the intersection of game-related studies and the Sustainable Development Goals (SDGs), while identifying the position and future potential of traditional games within SDG 4. A quantitative descriptive bibliometric approach was applied using data retrieved from the Scopus database. The search was conducted using the query TITLE-ABS-KEY (("Traditional Games" OR "Game* Theory" OR "Game-Based Learning") AND ("Sustainable Development Goals" OR "SDG*")), covering publications indexed from 2016 to May 2026. Based on the inclusion criteria, a final corpus of 114 documents was retained for bibliometric analysis. Data analysis and network visualization were conducted using VOSviewer to identify keyword co-occurrence, geographical contributions, and thematic structures within the scientific landscape. The results reveal a marked increase in publication volume and accumulated citations during the study period, particularly between 2022 and 2025. China, India, and the United States emerged as the leading contributing countries. The bibliometric network further identified thematic clusters linking SDG-oriented research with low-carbon supply chain management, Stackelberg decision modeling, sustainability-related decision making, and educational approaches involving gamification and collaborative learning. These findings indicate that game-related SDG research remains predominantly oriented toward industrial sustainability and macro-environmental applications, whereas traditional games grounded in local wisdom remain weakly represented in the indexed literature. This underrepresentation highlights an important research opportunity to position traditional games as culturally grounded approaches to joyful learning, social interaction, and quality education within SDG 4.

Keywords: Bibliometric Analysis; Game-Based Learning; Joyful Learning; SDG 4; Traditional Games

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INTRODUCTION

Scientific literacy is a fundamental competency in biology education because it enables students to understand scientific information and apply scientific knowledge when addressing problems in everyday life (Niate & Paidi, 2025). Broadly, scientific literacy involves the ability to use scientific knowledge and evidence to identify problems, explain phenomena, evaluate information, and draw evidence-based conclusions about the natural world and changes resulting from human activities (Bórquez-Sánchez, 2025; Sjöström, 2025). These competencies are important because scientific understanding becomes meaningful when students can use it to reason

about problems and make informed decisions (Niate & Paidi, 2025). Therefore, scientifically literate students should not only understand biological concepts but also be able to apply scientific knowledge and process skills to analyze problems, evaluate evidence, and justify decisions scientifically.

Sustainable Development Goal 4 (SDG 4) focuses on ensuring inclusive and equitable quality education and promoting lifelong learning opportunities for all. In the educational context, SDG 4 provides an important foundation for developing learning systems that are accessible, meaningful, and responsive to learners' developmental needs (Abera, 2023; Küfeoğlu, 2022). Education for Sustainable Development (ESD) further extends this agenda by encouraging learners to develop the knowledge, values, competencies, and agency required to engage with social, environmental, and economic dimensions of sustainability (Hedefalk et al., 2015; Güler Yıldız et al., 2021). Within this framework, early childhood education is particularly important because experiences during the early years contribute to cognitive, social, emotional, language, and character development and establish foundations for subsequent learning (Rafiyya et al., 2024; Walog et al., 2024). Research on sustainability in early childhood education likewise emphasizes that sustainability-oriented learning should begin early and be embedded in developmentally appropriate, participatory, and meaningful pedagogical experiences (Ardoin & Bowers, 2020; Rodrigues-Silva & Alsina, 2023).

Early childhood education is a fundamental phase that can determine the trajectory of individual development (Saracho, 2023). Children aged 5–6 years are in an important developmental period in which language, social interaction, self-regulation, and symbolic thinking continue to expand rapidly. From a Piagetian perspective, children at this age are generally within the pre-operational stage, in which they increasingly represent experiences through language, images, and imagination while continuing to benefit from concrete and contextual experiences (Zavareh & Hedayatzadeh, 2024). Accordingly, effective early childhood learning should not rely exclusively on abstract or teacher-directed instruction but should provide opportunities for children to explore, interact, communicate, and construct meaning through developmentally appropriate experiences. Play-based pedagogies are particularly compatible with these developmental characteristics because they combine active participation, child agency, social interaction, and opportunities for guided learning (Pyle et al., 2017; Yogman et al., 2018; Skene et al., 2022).

Language development is closely connected to the quality and frequency of children's social interactions. Hoff (2021) emphasized the importance of responsive conversational experiences for children's language development, while the use of vocabulary-rich, expressive, and contextual language in everyday interactions is positively associated with children's language learning (Rowe & Snow, 2020). In early childhood education settings, responsive teacher-child communication and interaction can create conditions that support children's language development (Mashburn et al., 2022). Through play, storytelling, book reading, singing, and simple discussions, children have opportunities to listen, understand, interpret, and use language naturally (Neuman & Dickinson, 2011; Wasik & Hindman, 2020). Peer interaction provides an additional language-learning context because children must listen, respond, negotiate meaning, coordinate activities, and communicate intentions with others. Reviews of preschool peer interaction similarly indicate that peers can constitute important language resources within early learning environments (Purtell

et al., 2021; Washington-Nortey et al., 2022). Difficulties in social interaction can also constrain children's participation in early-learning settings, underscoring the importance of socially responsive learning environments (Putri et al., 2025). Thus, social interaction and language learning should not be viewed as isolated developmental processes; they can develop concurrently through meaningful and socially situated learning experiences.

Games provide a natural context for such socially situated learning because children interact directly with peers while negotiating roles, rules, goals, and shared experiences (Buyukozturk & Shay, 2024). While playing, children learn to cooperate, communicate, share, and respect rules and the perspectives of others. Traditional games may further encourage sportsmanship, empathy, and responsibility through forms of bodily and social interaction embedded within collective play (Dugas & Ben Ali, 2023). Recent empirical studies also indicate that culturally grounded traditional games can facilitate communication, cooperation, sharing, conflict resolution, empathy, and broader social-emotional competencies in childhood settings (Lathifah et al., 2025; Özcan & Sakız, 2025). Traditional-game-based learning has also been discussed as a way to connect local wisdom with character education (Hanifa & Aryanti, 2025). These characteristics are educationally important because traditional games combine play with face-to-face interaction, cultural practices, shared rules, and collective participation rather than functioning solely as entertainment. Play activities may also help manage cognitive demands in learning environments (Zhong, 2022), while evidence on guided play suggests that appropriately structured playful experiences can support several dimensions of children's learning and development (Skene et al., 2022).

The educational value of play is closely related to the concept of joyful learning, in which learning experiences are designed to be engaging, meaningful, participatory, and emotionally supportive. Fun learning through games can create an active and interactive learning atmosphere (Ashari et al., 2023). Rather than positioning enjoyment as separate from academic learning, playful approaches can combine clear learning purposes with exploration, collaboration, interaction, and learner agency. This approach emphasizes students' active involvement through interactive, collaborative, and hands-on experiences and can support communication, confidence, and meaningful engagement with learning tasks (Siregar et al., 2025). Meaningful learning environments may be further strengthened when active participation, enjoyment, and appropriate technology are intentionally integrated into pedagogical design (Hsbollah & Hassan, 2022). A broader body of research on game-based and play-based learning also suggests that educational games can involve cognitive, motivational, affective, and social processes that contribute to learning when game activities are aligned with pedagogical objectives (Plass et al., 2015). Similarly, meta-analytic evidence indicates that gamification can produce positive cognitive, motivational, and behavioral learning outcomes, although its effectiveness depends on how game elements are designed and implemented within the learning context (Sailer & Homner, 2020).

However, several game-related concepts need to be distinguished when examining their contribution to the SDGs. Traditional games, game-based learning, gamification, and game theory represent related but conceptually different research domains. Game-based learning refers broadly to the use of games as learning environments, while gamification typically involves applying game-design elements

within activities that are not necessarily games themselves (Plass et al., 2015; Sailer & Homner, 2020). Traditional games, by contrast, are culturally situated forms of play that may embody local practices, social relationships, collective memories, and community values. Mathematical game theory has a substantially different meaning: it is primarily an analytical framework for examining strategic interactions and interdependent decision making among actors. In sustainability research, for example, game-theoretic models are extensively applied to supply-chain coordination, environmental decision making, and other strategic sustainability problems (Wu et al., 2025). Consequently, a high bibliometric prominence of the term “game theory” should not automatically be interpreted as evidence of extensive research on educational games or traditional children’s play.

This conceptual distinction is particularly important because contemporary game-related research connected with sustainability has developed strongly around simulations, serious games, technological learning environments, and strategic decision models. Previous reviews have demonstrated a growing body of research on simulations and serious games for sustainability education (Stanitsas et al., 2019; Hallinger et al., 2020), while educational research has also increasingly examined game-based learning, gamification, and digital learning environments (Alotaibi, 2024; Mikrouli et al., 2024). Nevertheless, traditional games and culturally grounded forms of play occupy a less clearly established position within this broader international research landscape. In bibliographic indexing, studies concerned with play may be distributed across broader terms such as game-based learning, educational games, serious games, gamification, sporting games, or other disciplinary labels. As a result, the visibility of traditional games as a distinct educational and cultural research domain may be substantially lower than that of more established game-related concepts.

This condition creates an important academic gap. Existing reviews have separately mapped early childhood education for sustainability (Hedefalk et al., 2015; Güler Yıldız et al., 2021), game-based learning in early childhood education (Alotaibi, 2024), and simulations and serious games for sustainability education (Stanitsas et al., 2019; Hallinger et al., 2020). However, these strands of scholarship do not yet provide a sufficiently integrated account of where traditional games are positioned within the wider intellectual landscape connecting games and the SDGs, particularly SDG 4. This gap is important because emerging research suggests that traditional games can combine social interaction, cultural values, cooperation, and playful learning experiences (Dugas & Ben Ali, 2023; Özcan & Sakız, 2025; Lathifah et al., 2025). Traditional games have therefore been proposed as culturally grounded learning resources that may complement contemporary approaches to joyful and meaningful education rather than merely preserve recreational practices from the past (Eriani et al., 2025). Their limited visibility in the broader indexed literature should consequently be interpreted as a research opportunity that warrants systematic mapping rather than as evidence of limited educational relevance.

To address this gap, the present study conducts a bibliometric analysis of Scopus-indexed literature published from 2016 to May 2026. Rather than assuming that traditional games already constitute a dominant research stream, the study maps the broader game-SDG scientific landscape and examines the position and future opportunities of traditional games within that landscape. The analysis is guided by the following research questions:

1. **RQ1:** What is the trend of publication volume and annual citation accumulation related to the corpus of traditional games, game-based learning, game-related research, and SDGs from 2016 to May 2026?
2. **RQ2:** What is the distribution of geographical contributions and collaboration networks between countries in this field of research?
3. **RQ3:** What are the main thematic clusters identified through keyword co-occurrence analysis?
4. **RQ4:** What are the characteristics and thematic focus of the documents with the highest citation impact within the extracted corpus?
5. **RQ5:** What research opportunities can be identified for integrating traditional games into future SDG 4-oriented educational research based on the academic gaps revealed by the bibliometric landscape?

Through quantitative data-based evaluation and network visualization using VOSviewer software, this study aims to map publication development, geographical contributions, thematic relationships, and emerging research directions across the relevant scientific literature (Pratiwi et al., 2026). Beyond describing publication patterns, the study seeks to clarify the conceptual position of traditional games within a field currently spanning mathematical game theory, sustainability research, game-based learning, and gamification. By identifying where traditional games remain weakly represented, the study provides a knowledge base for future research examining culturally grounded joyful learning, children's social interaction, and educational innovation in support of SDG 4.

METHOD

Research Design

This study employed a bibliometric analysis supported by a structured Systematic Literature Review (SLR) procedure to systematically identify, select, and evaluate scientific literature related to games and the Sustainable Development Goals (SDGs). The SLR procedure provided a transparent framework for literature identification and screening, whereas bibliometric analysis was used as the primary quantitative approach for examining patterns within the selected scientific corpus. The use of literature drawn from multidisciplinary and interdisciplinary fields makes a systematic review approach particularly suitable for examining broad and interconnected research domains (Newman, 2024).

The bibliometric component analyzed numerical and bibliographic indicators, including publication year, publication volume, citation counts, keyword occurrence, geographical contributions, and collaboration patterns, to identify the development and structure of the research field (Hassan & Duarte, 2024). Bibliometric analysis also enables the mapping of relationships among publications, authors, countries, and research themes. VOSviewer was used to support text mining, keyword co-occurrence analysis, network construction, and visualization of relationships among bibliographic elements (Pratiwi et al., 2026). Through this combined approach, the study systematically mapped dominant themes, influential publications, publication trends, and emerging research directions within the broader game-SDG literature while examining the position of traditional games within this scientific landscape.

Data Source and Search Strategy

The study focused on international scientific publications addressing game-related research and the SDGs, with particular attention to the potential position of traditional games within educational research. Scopus was selected as the primary bibliographic database because it provides structured bibliographic metadata suitable for quantitative bibliometric analysis and network visualization.

The database search covered publications indexed from 2016 to May 2026. To maintain consistency with the scope defined in the Abstract and research objectives, the Scopus search was conducted using the following query: TITLE-ABS-KEY (("Traditional Games" OR "Game* Theory" OR "Game-Based Learning") AND ("Sustainable Development Goals" OR "SDG*")). The initial keyword-based screening produced 121 potentially relevant documents. After applying the publication-period criterion, 114 documents remained and constituted the full corpus used for the bibliometric analysis. Scopus therefore served as the primary data source, while VOSviewer was used as the principal bibliometric mapping and visualization tool (Lintangesukmanjaya et al., 2025). Because the 2026 records were retrieved in May 2026, the publication volume for that year represents only a partial-year dataset and should not be interpreted as a complete annual count.

Literature Selection and PRISMA Procedure

The literature-identification and selection process followed the principles of PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) to improve transparency in the reporting of article identification, screening, eligibility assessment, and inclusion (Cacciamani et al., 2023; Helbach et al., 2023). The complete selection pathway is presented in Figure 1.

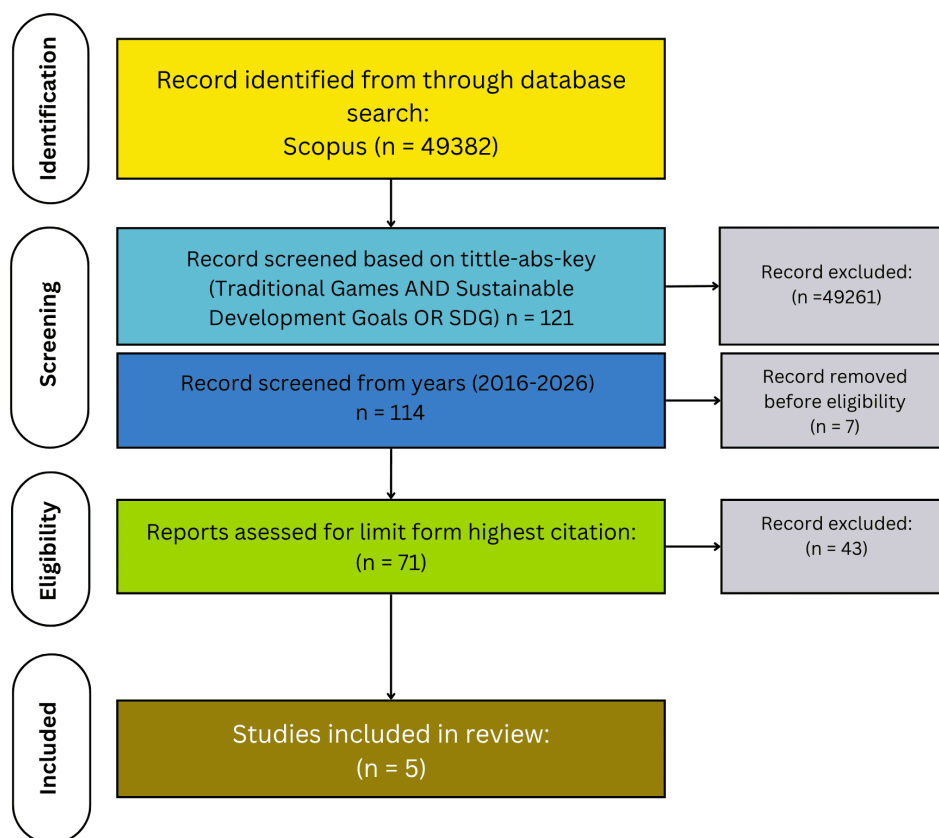


Figure 1. PRISMA Design

As illustrated in Figure 1, the selection process consisted of four sequential stages: identification, screening, eligibility assessment, and inclusion. At the identification stage, 49,382 records were initially retrieved from the broader database search. During the first screening stage, records were evaluated according to their relevance to game-related concepts and the Sustainable Development Goals, resulting in 121 documents, while 49,261 records were excluded as outside the intended scope.

The second screening stage applied the publication-period criterion of 2016 to May 2026, resulting in 114 documents, with seven records removed because they fell outside the specified period. These 114 documents constituted the complete bibliometric corpus and were retained for analyses of publication trends, citation patterns, geographical contributions, keyword co-occurrence, and network visualization.

A subsequent eligibility assessment was conducted specifically to identify publications suitable for focused qualitative interpretation. At this stage, the documents were assessed according to citation impact and topical relevance, resulting in 71 documents, while 43 documents were not retained for this focused assessment. From these 71 eligible publications, five highly cited and thematically relevant articles were selected for detailed qualitative interpretation. Thus, the five articles did not replace the 114-document bibliometric corpus; instead, they represented a focused subset used to examine the characteristics and substantive orientation of the most influential publications within the mapped research landscape.

This distinction between the full bibliometric corpus ($n = 114$) and the focused qualitative subset ($n = 5$) was maintained throughout the analysis to ensure that quantitative mapping and qualitative interpretation served complementary but analytically distinct purposes.

Data Extraction and Preparation

Article data were collected through the structured Scopus search and exported in bibliographic formats compatible with bibliometric processing, including CSV or RIS formats (Helbach et al., 2023; Pratiwi et al., 2026). The exported metadata included information required for the analyses conducted in this study, such as publication year, citation information, author keywords, country or affiliation information, and other bibliographic fields available in the Scopus export.

Before network visualization, the exported dataset was imported into VOSviewer for bibliometric processing and mapping. This procedure enabled the study to examine relationships among keywords, publications, and collaboration patterns through text-mining, co-occurrence, and network-visualization techniques (Bukar et al., 2023). The use of structured bibliographic metadata reduced reliance on subjective manual categorization and supported a reproducible, data-driven description of the scientific landscape.

Bibliometric Analysis and Network Visualization

The bibliometric analysis was conducted in several complementary stages. First, descriptive analysis was used to examine annual publication volume and citation accumulation during the 2016–May 2026 period. Second, the geographical distribution of publications was analyzed to identify countries contributing most strongly to the research corpus. Third, keyword co-occurrence analysis was performed to identify frequently occurring concepts, their total link strengths, and the thematic clusters formed by relationships among keywords.

VOSviewer was used to generate network visualizations that represent the strength and proximity of relationships among bibliographic elements. In these maps, larger or more strongly connected nodes indicate terms or entities with greater occurrence or network connectivity, whereas clusters represent groups of closely related research themes. This approach allowed the study to identify dominant research orientations and to examine whether traditional games appeared as a distinct theme or remained positioned within broader domains such as game theory, game-based learning, gamification, sustainability, and educational research.

Finally, citation information was used to identify the publications with the highest citation impact within the extracted corpus. The five articles retained through the focused qualitative selection process were subsequently examined to distinguish their original substantive contributions from their relevance to the present study's interpretation of games, sustainability, and potential educational applications. Taken together, the Scopus-based bibliographic dataset, the structured PRISMA-guided selection procedure, and VOSviewer-based bibliometric mapping provided a systematic framework for describing the development, intellectual structure, and thematic direction of game-related SDG research and for identifying the underrepresented position of traditional games as a potential future research area.

RESULTS AND DISCUSSION

The bibliometric analysis was conducted on the complete corpus of 114 Scopus-indexed documents retained after the screening process. The results are organized into six subsections covering publication and citation trends, subject-field distribution, geographical contributions, keyword co-occurrence, thematic network structure, and the characteristics of the most highly cited publications. This organization corresponds to the research questions concerning temporal development, geographical distribution, thematic structure, and citation impact.

Publication and Citation Trends

The annual development of the 114-document corpus shows a clear upward pattern in both publication volume and accumulated citations during the 2016–May 2026 study period. The strongest growth in annual publication output occurred between 2022 and 2025, when the number of documents increased consistently from year to year. Citation accumulation also increased across the study period, indicating growing scholarly attention to research connecting game-related topics with the Sustainable Development Goals (SDGs). This development is consistent with the increasing relevance of SDG-oriented research across multiple disciplines (Lintangesukmanjaya et al., 2025).

The 2026 value should be interpreted cautiously because the bibliographic data were extracted in May 2026 and therefore represent only a partial publication year. Consequently, the lower publication count recorded for 2026 cannot be directly compared with the complete annual output for 2025. The use of a structured literature-review procedure further supports transparent reporting of the scientific corpus and its development over time (Cacciamani et al., 2023). The annual distribution of publications and accumulated citations is presented in Figure 2.

As shown in Figure 2, publication activity and citation accumulation increased markedly across the observation period, with the most visible publication growth occurring during 2022–2025. Within the 114-document corpus, scientific articles represented the largest document type, accounting for 52.9% of the dataset, or

approximately 60 documents. Conference papers and books represented the smallest reported document types, each accounting for approximately 2.5%, or about three documents.

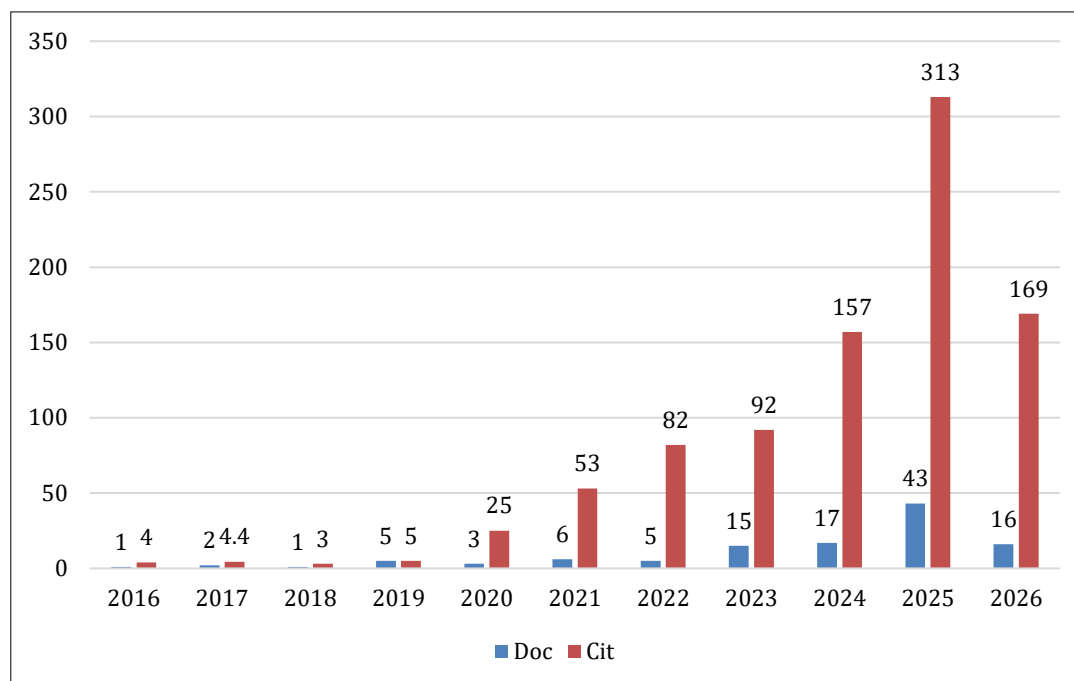


Figure 2. Total data and 10 year citations

Distribution of the Corpus by Subject Field

In addition to temporal trends, the corpus was examined according to its disciplinary distribution. The numerical distribution across the aggregated subject fields is presented in Table 1.

Table 1. Corpus Distribution by Subject Field Scopus

Subject Area	Number of Documents (n)	Percentage (%)
Social Sciences	17	15.20%
Agricultural Sciences	3	2.90%
Materials Science	3	2.90%
Multidisciplinary / Other Sectors	91	79.00%

As shown in Table 1, the largest aggregated category was Multidisciplinary / Other Sectors, comprising 91 documents or 79.00% of the corpus. Social Sciences accounted for 17 documents (15.20%), whereas Agricultural Sciences and Materials Science each contributed three documents (2.90%). Together, the categories reported in Table 1 comprise all 114 documents included in the bibliometric dataset. The disciplinary distribution indicates that the corpus extends beyond education and social science research and includes publications from a broad range of sustainability-related fields. This multidisciplinary profile is consistent with the broad scope of the SDGs and helps explain the presence of both educational and macro-sustainability themes in the subsequent network analysis.

Geographical Contributions

The geographical distribution of the 114-document corpus was analyzed to identify the countries contributing most frequently to the research landscape. The leading country contributions are presented in Figure 3.

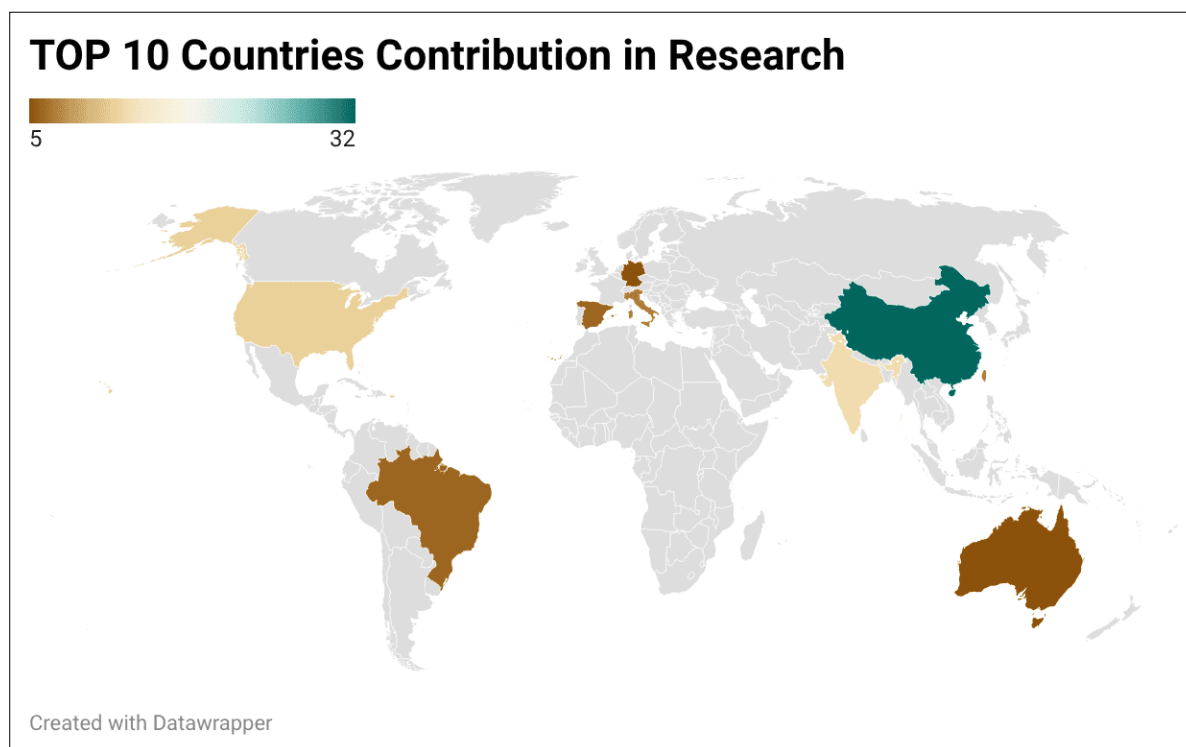


Figure 3. Top Country Contributions in Research

As illustrated in Figure 3, China contributed the largest number of publications, with 32 documents. India ranked second with 13 documents, followed by the United States with 12 documents. Italy and Taiwan each contributed seven documents, while Brazil and Spain each contributed six. Australia and Germany each contributed five documents.

These results demonstrate that the literature is geographically distributed across several regions, although the largest publication contributions were concentrated in Asia, particularly China and India. Bibliometric visualization can be used not only to describe geographical contributions but also to examine relational structures among bibliographic elements such as keywords and collaboration networks (Bukar et al., 2023). The thematic relationships within the corpus were therefore further examined through keyword co-occurrence analysis.

Keyword Co-occurrence and Dominant Research Concepts

Keyword co-occurrence analysis was used to identify the most frequently occurring concepts and the strength of their relationships with other terms in the bibliometric network. The ten keywords with the highest reported occurrences and total link strengths are presented in Table 2.

Table 2. Top 10 Keywords by Occurrence and Total Link Strength

Keyword	Occurrences	Total Link Strength
Sustainable development	46	305
Game theory	20	158
Decision making	10	96
Sustainable development goal	12	95
Sustainability	18	86
Climate change	12	84
Costs	9	83

Keyword	Occurrences	Total Link Strength
Carbon	8	76
Student	10	74
Gamification	12	69

As shown in Table 2, “sustainable development” was the most prominent keyword, with 46 occurrences and the highest total link strength of 305. “Game theory” ranked second in network strength, with 20 occurrences and a total link strength of 158. Other strongly connected terms included “decision making,” “sustainable development goal,” “sustainability,” “climate change,” “costs,” “carbon,” “student,” and “gamification.”

The coexistence of sustainability-related, strategic decision-making, and educational keywords indicates that the game-SDG corpus spans several disciplinary orientations rather than forming a single homogeneous research field. In particular, the prominence of “game theory” should be distinguished from the educational meanings of game-based learning and gamification because, within the mapped corpus, game theory is strongly associated with strategic decision-making and sustainability-related applications.

Thematic Network Structure

The relationships among keywords and their thematic clustering were further examined using the VOSviewer network visualization shown in Figure 4.

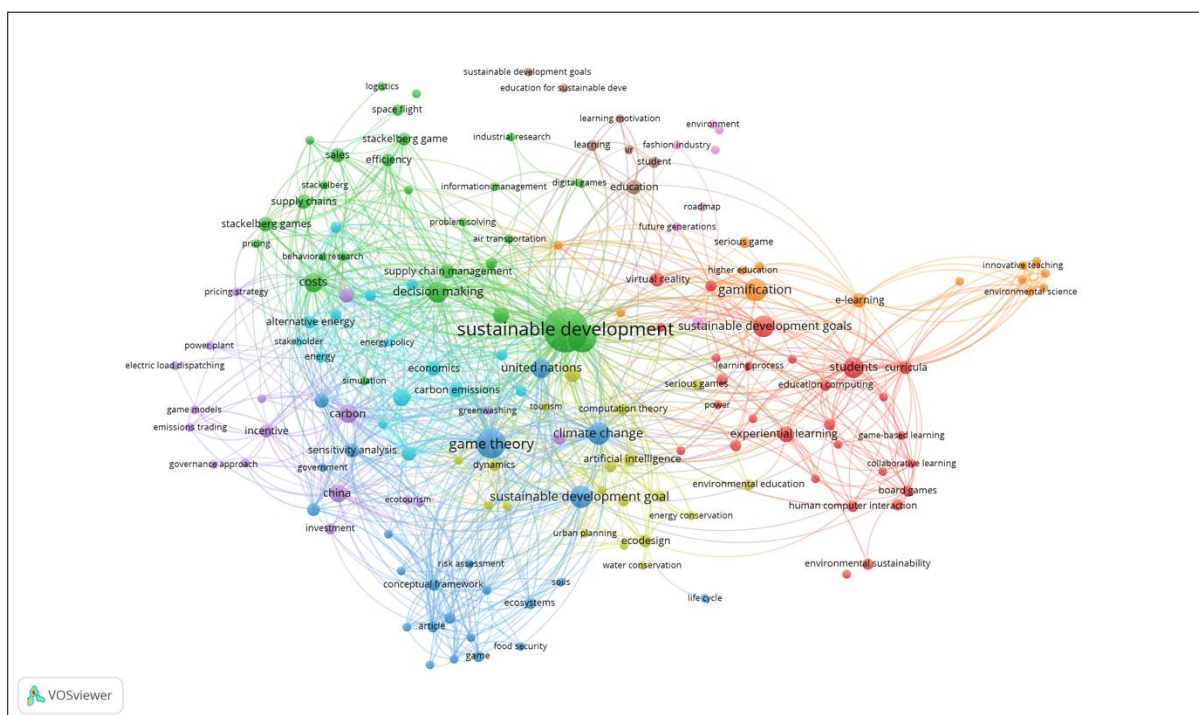


Figure 4. Network Visualization

Figure 4 shows “sustainable development” as the major central node in the network, with strong connections to game theory, climate change, decision making, supply chain management, and education-related concepts. Several thematic clusters can be distinguished from the visualization.

The green cluster contains terms such as sustainable development goals, supply chain management, decision making, efficiency, and carbon emissions, indicating a

concentration of research on industrial sustainability, supply-chain systems, and environmentally oriented decision processes. The blue cluster includes climate change, game theory, investment, risk assessment, and ecosystems, representing research related to environmental economics, sustainability strategy, and strategic modeling.

Education-oriented concepts are visible in the red cluster through terms such as students, curriculum, experiential learning, collaborative learning, and game-based learning. An additional orange cluster includes gamification, e-learning, virtual reality, and innovative teaching, indicating the presence of digital and game-related educational approaches within the wider sustainability literature. Purple and yellow clusters contain themes including energy policy, emissions trading, ecodesign, and environmental education, further demonstrating the multidisciplinary nature of the network.

Importantly, although “Traditional Games” was included in the search strategy, the term did not emerge as a dominant node in Figure 4. VOSviewer visualizations are based on the frequency and strength of co-occurrence relationships within article metadata; therefore, terms that occur infrequently or are used inconsistently may not form prominent nodes. The weak visual representation of “traditional games” should consequently be interpreted as limited bibliometric visibility within the analyzed corpus rather than as evidence that traditional games are equivalent to the broader concepts of game theory, gamification, or game-based learning.

Position of Game Theory, Traditional Games, and Educational Games

To examine the position of game-related concepts more closely, Figure 5 focuses on the relationship between game theory and SDG-oriented research.

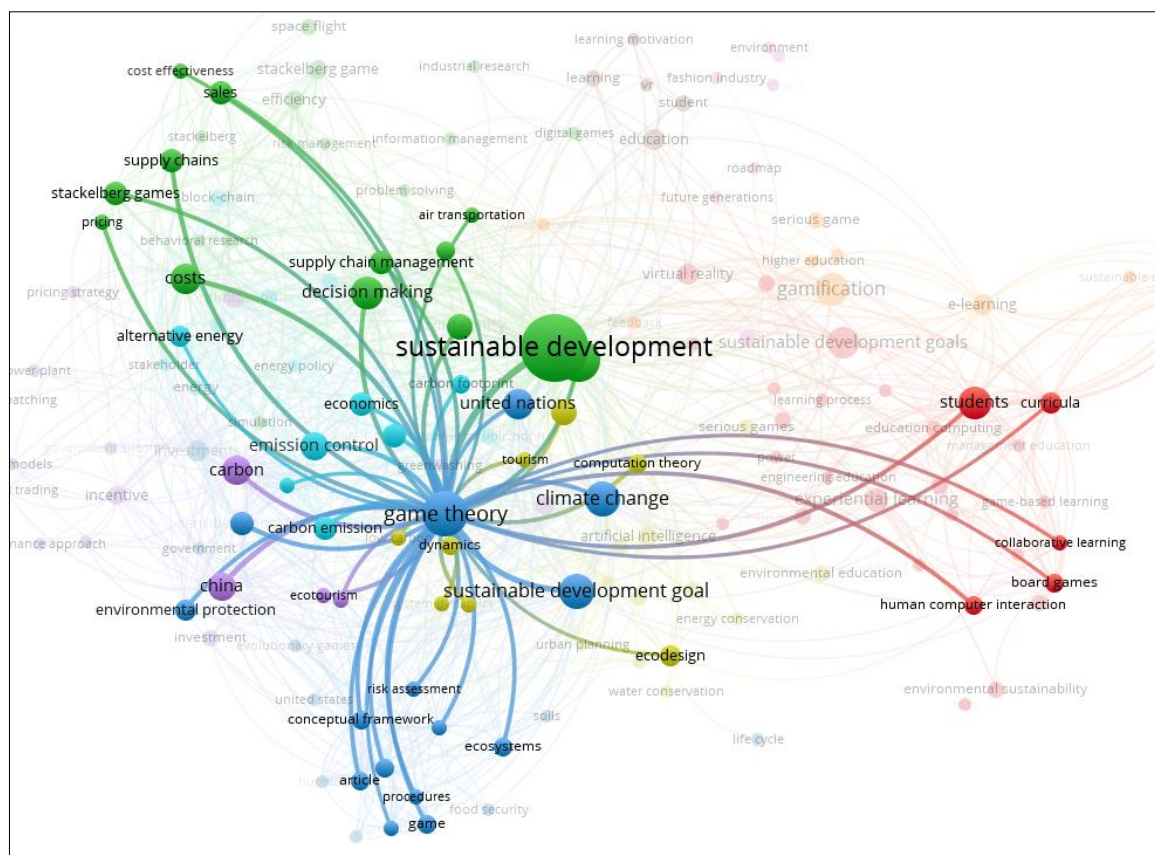


Figure 5. Game Theory and SDGs

As shown in Figure 5, game theory is strongly positioned within the sustainability-oriented region of the network and is associated with themes involving strategic decision making, environmental problems, and sustainability systems. This pattern indicates that a substantial portion of the “game” literature within the SDG corpus refers to mathematical or strategic game theory rather than directly to children’s play or educational games.

Nevertheless, the strategic concepts represented in this part of the network—including cooperation, decision making, problem solving, and interaction among actors—provide conceptual points of comparison for future educational applications. These possibilities should be treated as interpretive research directions rather than as direct evidence that the mapped game-theory studies examined traditional games. The educationally oriented part of the network is further highlighted in Figure 6.

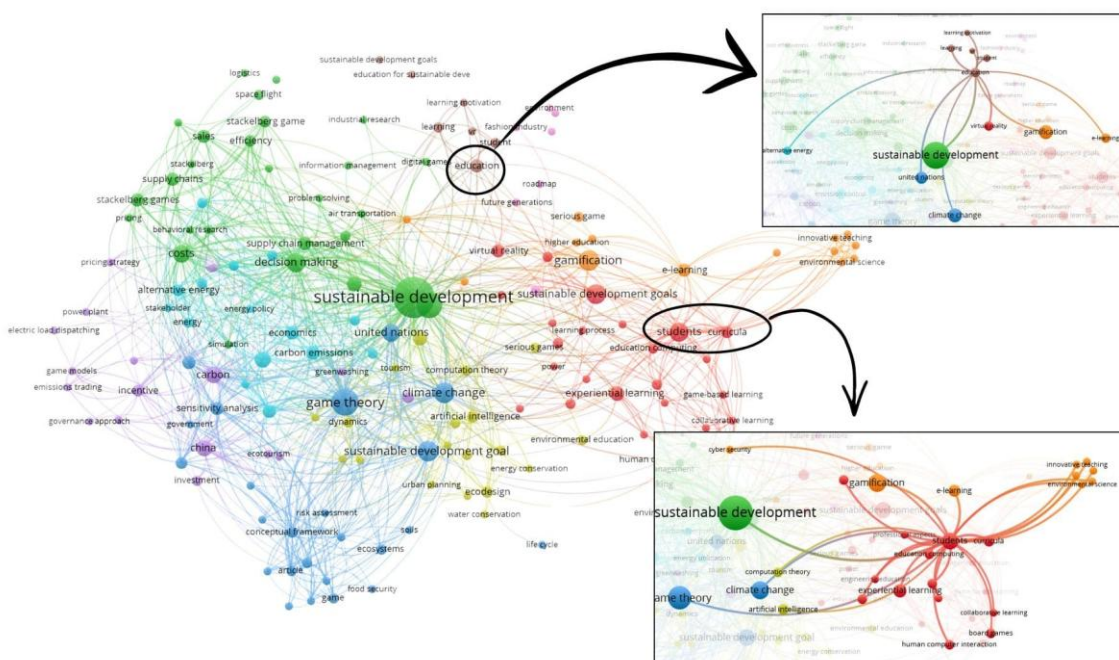


Figure 6. Traditional and Educational Games

Figure 6 highlights concepts associated with educational games and learning, including game-based learning, board games, gamification, experiential learning, students, curriculum, and collaborative learning. Traditional games did not appear as a major independent node, indicating that they remain weakly represented as a distinct indexed research theme within the analyzed corpus.

Rather than demonstrating that traditional games are already fully integrated into these clusters, the visualization identifies an adjacent educational research space in which future traditional-game studies could be positioned. The proximity of game-based learning, collaborative learning, experiential learning, curriculum, and student-related concepts is particularly relevant to the educational dimensions of SDG 4. The bibliometric evidence therefore identifies an underrepresented area at the intersection of culturally grounded traditional games and contemporary educational research, which is examined further in the Discussion.

Highly Cited Publications and Their Thematic Orientation

To address the citation-impact dimension of the study, the five highly cited and thematically relevant publications retained for focused qualitative interpretation were

examined separately from the full 114-document bibliometric corpus. Their citation counts, core findings, and relevance to the present study are summarized in Table 3.

Table 3. Top 5 Highest Cited Articles in Research

Authors (Years)	Core Findings of the Source Article	Relevance to the Present Study	Citation Count	SJR
Sadhukhan et al. (2020)	The study examined the transformation of food-waste processing systems into value-added products and the implementation of circular-economy strategies as potential “game-changing” pathways for sustainability, including responsible consumption and production, climate action, health, and clean energy.	Within the present analysis, this article illustrates how highly cited publications in the corpus are primarily oriented toward macro-sustainability challenges rather than traditional educational games. Its emphasis on sustainability transformation provides a conceptual basis for considering how educational games may subsequently communicate environmental and sustainability issues.	122	Q1 (0.75)
Hsiao, P. W., & Su, C. H. (2021)	The study reported that STEAM education supported by Virtual Reality (VR) in Education for Sustainable Development (ESD) enhanced student motivation, satisfaction, and learning outcomes through interactive and contextual learning experiences.	Among the five highly cited publications, this study provides the clearest educational connection by demonstrating how interactive technology and experiential learning can support sustainability education. Its findings are relevant to future consideration of game-based, role-playing, or culturally contextualized	107	Q1 (0.75)

Authors (Years)	Core Findings of the Source Article	Relevance to the Present Study	Citation Count	SJR
		learning approaches.		
Gautam et al. (2019)	The study examined strategic defect management within a sustainable green supply chain using a Stackelberg-based approach and supply-chain optimization.	The article represents the strategic game-theory orientation of the corpus. In the present study, its relevance lies in the concepts of strategic decision making, resource management, and actor interaction, which may inform future simulation-based sustainability learning but should not be interpreted as direct evidence concerning traditional games.	93	Q1 (2.019)
Sharma et al. (2023)	The study examined single-atom catalysts in advanced oxidation processes for water treatment and their capacity to generate selective and stable reactive species, contributing to sustainable water-treatment technologies and SDG-related environmental objectives.	This highly cited article further demonstrates the strong environmental and technological orientation of the corpus. Its connection to educational gaming is interpretive: concepts such as water purification, pollution control, and sustainable technology could provide content for future science-oriented simulations or educational games.	68	Q1 (16.918)
Hamidoğlu, A., & Weber, G. W. (2024)	The study investigated a Nash-based low-carbon implementation model in agricultural supply-chain management	The study exemplifies how game-theoretic concepts of cooperation, strategic interaction, and balance among	46	Q1 (2.019)

Authors (Years)	Core Findings of the Source Article	Relevance to the Present Study	Citation Count	SJR
	involving interactions among farmers, companies, and consumers to support environmentally responsible practices.	stakeholders are applied to sustainability. These principles offer conceptual parallels with cooperation and collective strategy in traditional games, although the source article itself does not directly investigate traditional games.		

As summarized in Table 3, none of the five highly cited publications directly investigated traditional games. Instead, the most influential publications were primarily concerned with circular economy and waste management, sustainable supply chains, water-treatment technologies, low-carbon systems, and technology-supported sustainability education (Hamidoğlu & Weber, 2024; Sadhukhan et al., 2020). This pattern reinforces the broader network finding that the game-SDG literature is strongly oriented toward environmental, technological, and strategic sustainability problems.

At the same time, the five studies demonstrate several conceptual pathways that are relevant to the educational interpretation developed in this study. Strategic decision making and supply-chain optimization are evident in the sustainability-oriented studies, while interactive and technology-supported learning is represented by the STEAM-VR study (Gautam et al., 2019; Hsiao & Su, 2021; Sharma et al., 2023). These findings do not demonstrate the effectiveness of traditional games themselves; rather, they show that the current high-impact literature provides conceptual foundations involving cooperation, strategic interaction, sustainability literacy, experiential learning, and environmental problem solving. The limited direct representation of traditional games among the most highly cited publications therefore constitutes an important gap to be interpreted in relation to SDG 4 in the this article.

Discussion

Growth and Intellectual Structure of Game-SDG Research

The bibliometric findings indicate a clear expansion of game-related research associated with the Sustainable Development Goals (SDGs), particularly during 2022–2025. Rather than representing a single educational research stream, however, the mapped literature encompasses multiple disciplinary orientations, including industrial sustainability, environmental decision making, mathematical game theory, and educational applications of games. This multidisciplinary structure is reflected in the central position of “sustainable development” and the strong network position of “game theory,” which recorded a total link strength of 158. Similar developments have been observed in previous reviews showing the growing use of simulations and

serious games to address sustainability-related learning and decision-making problems (Stanitsas et al., 2019; Hallinger et al., 2020).

The prominence of sustainability-related themes is also consistent with the highly cited publications identified in the present corpus. Several influential studies apply strategic or game-theoretic approaches to supply-chain management, low-carbon systems, environmental technologies, and interactions among economic actors. For example, Hamidoğlu and Weber (2024) employ a Nash-based framework to examine low-carbon agricultural supply-chain interactions. Such studies demonstrate the broad analytical relevance of games within sustainable development, but their concept of “game” differs fundamentally from games used as educational or recreational activities. Therefore, the increasing volume of game-SDG literature should not be interpreted as equivalent growth in research specifically addressing traditional games or children’s game-based learning.

Distinguishing Game Theory from Educational Game Research

One of the most important interpretations emerging from the bibliometric network is the need to distinguish mathematical game theory from game-based learning, gamification, serious games, and traditional games. In the present network, game theory is primarily associated with strategic decision making, climate change, investment, supply chains, and other sustainability-oriented systems. By contrast, educational concepts—including students, curriculum, experiential learning, collaborative learning, game-based learning, and gamification—form a more distinct educational region of the network. This distinction explains why the high total link strength of “game theory” cannot be treated as direct bibliometric evidence for the educational effectiveness or prevalence of traditional games.

At the same time, the existence of educational clusters demonstrates that games are increasingly being considered as environments for active and experiential learning. Reviews of game-based learning have identified its potential contribution to problem solving, collaboration, communication, and other twenty-first-century competencies, although outcomes depend considerably on game design, learner characteristics, and instructional context (Qian & Clark, 2016). More recent meta-analytic evidence similarly indicates that digital games can support critical thinking, communication, collaboration, and creativity, but with different magnitudes of effect across these competencies (Cheng & Weatherly, 2025). Consequently, the present bibliometric findings should be interpreted as identifying a conceptual bridge between established educational game research and the still-underrepresented field of traditional games, rather than demonstrating that these domains are interchangeable.

Traditional Games as an Underrepresented Pathway for SDG 4

The limited visibility of “traditional games” as an independent node represents one of the most important findings of this study. Rather than indicating that traditional games lack educational relevance, their weak bibliometric representation reveals a gap between a rapidly expanding game-SDG literature and the comparatively limited international indexing of culturally grounded forms of play. This interpretation is consistent with the network structure, in which educational concepts such as game-based learning, experiential learning, collaborative learning, curriculum, and gamification are visible, whereas traditional games do not form a comparable dominant cluster.

This gap is important for SDG 4 because traditional games combine dimensions that are simultaneously educational, social, and cultural. Traditional games frequently involve cooperation, collective strategy, communication, rule following, bodily interaction, sportsmanship, and culturally embedded practices (Dugas & Ben Ali, 2023). Empirical evidence further indicates that participation in traditional children's games can be associated with social skills and culturally situated interaction (Ayaz-Alkaya & Akca, 2025), while recent studies in early childhood contexts have highlighted their relevance to cooperation, communication, sharing, conflict resolution, and empathy (Lathifah et al., 2025; Özcan & Sakız, 2025). Their culturally grounded structure also provides a basis for character-oriented learning linked to local wisdom (Hanifa & Aryanti, 2025). These characteristics provide a stronger educational rationale for positioning traditional games within the quality-education agenda than would be obtained by simply treating them as another form of game theory.

The relationship with sustainable development can also extend beyond learning outcomes. Traditional games are embedded within local practices and may transmit cultural knowledge across generations, thereby connecting educational innovation with cultural continuity. Research on traditional sporting games has shown that culturally rooted games can provide contextualized opportunities for learning about physical and social dimensions of sustainability and emotional well-being (Luchoro-Parrilla et al., 2024). Similarly, the integration of traditional sports and games into sustainable-development contexts has been identified as a promising direction for cultural preservation and sustainable learning (Prabucki & Rozmiarek, 2025). Therefore, the present study positions traditional games not as a bibliometrically dominant educational intervention, but as an underdeveloped research pathway connecting local culture, social participation, and SDG 4.

Social Interaction and Twenty-First-Century Skills

A further implication concerns the potential relationship between traditional games and twenty-first-century competencies. The 6C framework emphasizes critical thinking, creativity, collaboration, communication, citizenship, and character, and it has been used in contemporary educational discussions to frame the competencies expected of learners (Bulkis et al., 2025). Traditional games are conceptually relevant to several of these competencies because participation commonly requires children to communicate with peers, negotiate rules, cooperate toward shared objectives, respond strategically to changing situations, and regulate their behavior within a social group. The relevance of these competencies is also consistent with broader research on game-based learning and twenty-first-century skills (Qian & Clark, 2016; Cheng & Weatherly, 2025).

Nevertheless, this relationship requires careful interpretation. The present bibliometric study did not directly measure changes in children's 6C skills; therefore, these competencies should be regarded as a theoretically supported direction for future empirical investigation rather than as outcomes demonstrated by the present dataset. This distinction is particularly important for early childhood education, where communication and social participation constitute foundational components of development (Hoff, 2021). From a social-learning perspective, interaction with peers provides opportunities for children to observe, respond, negotiate, and construct behaviors in social contexts (Firmansyah & Saepuloh, 2022). Traditional games

potentially provide such contexts because their rules and goals are enacted through direct social participation rather than through one-way instruction.

This interpretation is supported by emerging empirical evidence. Ayaz-Alkaya and Akca (2025), for example, found an association between participation in traditional games and children's social skills, while Lathifah et al. (2025) reported that culturally grounded traditional games facilitated cooperation, communication, empathy, sharing, and conflict resolution in early childhood settings. These findings complement the social dimensions identified by Dugas and Ben Ali (2023). However, stronger experimental and longitudinal studies are still required before causal claims can be made regarding specific developmental outcomes.

The distinction between traditional and digital games is also relevant. Digital game-based research provides substantial evidence concerning critical thinking, communication, collaboration, and creativity (Cheng & Weatherly, 2025), whereas traditional games may provide additional forms of face-to-face interaction, bodily participation, culturally contextualized rules, and collective experience. These modalities should therefore be investigated as complementary rather than competing educational approaches. Game-based environments can also be designed to structure interactive learning while managing cognitive demands, as illustrated by research using role-playing game environments (Zhong, 2022). Future comparative studies could consequently examine which combinations of traditional, physical, and digitally supported game experiences are most appropriate for particular age groups and learning objectives.

Traditional Games as a Culturally Grounded Form of Joyful Learning

Joyful learning provides an important pedagogical framework for interpreting the educational potential identified in the bibliometric network. Joyful learning emphasizes learning experiences that are meaningful, engaging, emotionally supportive, and participatory rather than positioning enjoyment as separate from academic learning (Andayanie et al., 2025). Traditional games are particularly relevant to this framework because they can combine enjoyment, challenge, physical activity, social interaction, cooperation, and experiential learning within a single activity.

This interpretation is consistent with the educational region of the bibliometric network, where gamification, experiential learning, collaborative learning, students, curriculum, innovative teaching, and game-based learning appear in interconnected clusters. The network itself does not demonstrate that traditional games produce joyful learning outcomes; rather, it identifies an existing educational research space into which traditional games can be theoretically positioned. Evidence from technology-supported ESD also demonstrates that interactive and contextual learning experiences, including STEAM learning supported by Virtual Reality, can strengthen learner motivation and engagement with sustainability-oriented content (Hsiao & Su, 2021). Similarly, broader evidence on gamification indicates that learning benefits depend on the alignment between game elements and pedagogical design rather than on the presence of game elements alone (Sailer & Homner, 2020).

This distinction has practical implications. Traditional games should not simply be introduced into classrooms because they are enjoyable or culturally familiar. Their educational value depends on how educators connect particular game characteristics—such as cooperation, strategy, communication, environmental interaction, or cultural narratives—to specific learning objectives. For SDG 4, such

integration could involve social-emotional learning, cultural literacy, sustainability literacy, communication, collaboration, and meaningful participation. Traditional games may therefore function as culturally grounded forms of joyful learning when their rules, social interactions, and cultural meanings are intentionally aligned with educational purposes.

Implications and Future Research Directions

Taken together, the bibliometric findings reveal a research landscape in which game-related SDG scholarship has grown substantially but remains dominated by macro-sustainability, technological, and strategic applications. The weak representation of traditional games therefore constitutes a meaningful research gap. Importantly, this gap should not be addressed by assuming that traditional games automatically produce sustainability or twenty-first-century learning outcomes. Instead, future research should empirically test the mechanisms through which particular traditional games may contribute to social interaction, communication, collaboration, cultural learning, joyful engagement, and sustainability literacy.

Several directions follow from this interpretation. First, experimental and quasi-experimental studies are needed to examine the effects of clearly specified traditional-game interventions on children's social interaction, receptive language, communication, collaboration, and other developmental indicators. Second, studies should investigate how culturally specific game characteristics—such as rules, local narratives, materials, group structures, and forms of cooperation—relate to learning outcomes. Third, research could examine traditional games within broader SDG 4 and ESD frameworks, particularly their contributions to inclusive participation, cultural continuity, sustainability literacy, and meaningful learning. Fourth, longitudinal research would help determine whether learning and social outcomes persist beyond short-term interventions.

Finally, digital technologies do not necessarily need to replace traditional forms of play. Future instructional models could explore carefully designed combinations of traditional games with gamification, interactive media, augmented or Virtual Reality environments, or digital documentation. Such integration may provide opportunities to preserve local cultural meanings while extending accessibility and pedagogical flexibility. However, technology should remain supportive of, rather than substitute for, the social and cultural characteristics that give traditional games their distinctive educational value. This direction is consistent with social-learning approaches that emphasize meaningful interaction (Firmansyah & Saepuloh, 2022) and with sustainability-oriented educational innovations that employ interactive technologies to support contextual learning (Hsiao & Su, 2021). Accordingly, the principal contribution of the present bibliometric study is not to demonstrate the effectiveness of traditional games, but to identify their limited visibility within the current game-SDG landscape and to establish an evidence-informed agenda for investigating them as culturally grounded pathways toward joyful learning, social interaction, and SDG 4.

CONCLUSIONS

This study mapped the development and intellectual structure of game-related research associated with the Sustainable Development Goals (SDGs) using 114 Scopus-indexed documents published from 2016 to May 2026. The findings show a clear increase in publication output and accumulated citations during the study

period, with the strongest growth occurring between 2022 and 2025. The most prominent keywords were “sustainable development,” “game theory,” and “gamification,” indicating that the research landscape is shaped by both macro-sustainability applications and educational game-related approaches.

A key finding is that traditional games did not emerge as a dominant independent node in the bibliometric network. Instead, the broader educational region of the network included concepts such as game-based learning, collaborative learning, experiential learning, curriculum, students, and gamification. This pattern indicates that traditional games remain weakly represented within the indexed game-SDG literature, even though adjacent educational themes provide a relevant conceptual space for their future development.

The prominence of “game theory” should also be interpreted carefully because, within the analyzed corpus, it primarily reflects mathematical and strategic applications in sustainability, including decision making, supply-chain systems, and environmental management, rather than traditional or educational games. Therefore, the contribution of this study lies not in demonstrating the effectiveness of traditional games, but in identifying their limited bibliometric visibility and positioning them as an underexplored educational research pathway within SDG 4.

Supported by the reviewed literature, traditional games have characteristics such as cooperation, communication, social interaction, sportsmanship, strategic thinking, and culturally embedded values that may be relevant to joyful learning and quality education. These characteristics suggest that traditional games warrant further empirical investigation as culturally grounded learning resources that may contribute to social interaction, communication, twenty-first-century competencies, cultural continuity, and meaningful educational experiences.

Overall, this study contributes to the literature by clarifying the position of traditional games within the broader game-SDG research landscape and by identifying a research gap at the intersection of local cultural practices, joyful learning, social interaction, and SDG 4. Traditional games should therefore be viewed as a promising future research agenda rather than as an educational approach whose effectiveness has already been established by the present bibliometric evidence.

RECOMMENDATIONS

This study has several limitations that should guide future research. First, the bibliometric analysis was based exclusively on the Scopus database; consequently, relevant publications indexed in other databases or published in sources not covered by Scopus may not have been captured. Second, the analysis relied on bibliographic metadata and did not include direct empirical observations of children, teachers, or classroom practices. Third, the term “traditional games” did not emerge as a dominant node in the bibliometric visualization, which may reflect variations in terminology, indexing practices, keyword selection, and the use of broader labels such as game-based learning, educational games, traditional sports, or culturally grounded play.

Future studies should therefore extend the evidence base in several directions. Empirical research, including experimental, quasi-experimental, mixed-methods, and longitudinal designs, is needed to examine how specific traditional games influence children’s social interaction, receptive language, communication, collaboration, creativity, critical thinking, character, and other dimensions of the 6C framework. These studies should clearly specify the type of traditional game, participant

characteristics, intervention duration, learning objectives, and validated outcome measures.

Further research should also investigate how traditional games can be intentionally integrated into SDG 4-oriented curricula and Education for Sustainable Development. Particular attention should be given to the mechanisms through which local rules, cultural narratives, cooperation, physical interaction, environmental context, and community values contribute to meaningful and joyful learning experiences. Comparative studies could examine differences among traditional games, digital games, gamification, and blended game-based approaches to determine which formats are most appropriate for particular developmental stages and educational objectives.

The integration of digital technologies also represents a promising direction. Future learning models may combine traditional games with gamification, interactive media, augmented or Virtual Reality, and other digital tools while preserving the social and cultural characteristics that distinguish traditional forms of play. Such technology should complement rather than replace face-to-face interaction, cultural meaning, and community participation.

Finally, future bibliometric research should consider broader search strategies and multiple databases to capture variations in terminology and improve the visibility of culturally grounded game research. Expanding search terms to include concepts such as “indigenous games,” “traditional sports,” “folk games,” “local games,” and “cultural play” may provide a more comprehensive understanding of how traditional forms of play are positioned within quality education, sustainability, and SDG-related research.

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The authors declare no conflict of interest.

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Not applicable.

Data Availability

The bibliographic data analyzed in this study were retrieved from the Scopus database and are subject to Scopus access and licensing conditions.

Author Contributions Statement

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Laily Masrurin Nisa	✓		✓	✓					✓		✓		✓	
M Agustin Ningrum									✓	✓		✓	✓	
Sri Setyowati	✓		✓	✓										
Ruqoyyah Fitri		✓	✓							✓				

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
M Syahidul Haq		✓								✓				
Nurul Istiqfaroh	✓									✓				

C : Conceptualization

I : Investigation

Vi : Visualization

M : Methodology

R : Resources

Su : Supervision

So : Software

D : Data Curation

P : Project administration

Va : Validation

O : Writing - Original Draft

Fu : Funding acquisition

Fo : Formal analysis

E : Writing - Review & Editing

REFERENCES

- Alfi, B. R., Paidi, P., & Pratama, A. T. (2024). Validating instrument to assess science literacy and independent learning skills in high school. *JPBI (Jurnal Pendidikan Biologi Indonesia)*, 10(3), 979-988. <https://doi.org/10.22219/jpbi.v10i3.34770>
- Anayanti, D. K., & Zainuddin, A. (2025). The influence of parenting style and teacher's teaching style on student learning independence. *Scaffolding: Jurnal Pendidikan Islam dan Multikulturalisme*, 7(1), 164-183. <https://doi.org/10.37680/scaffolding.v7i1.6901>
- Arjaya, I. B. A., Suastra, I. W., Redhana, I. W., & Sudiatmika, A. A. I. A. R. (2024). Global trends in local wisdom integration in education: A comprehensive bibliometric mapping analysis from 2020 to 2024. *International Journal of Learning, Teaching and Educational Research*, 23(7), 120-140. <https://doi.org/10.26803/ijlter.23.7>
- Ayu, G. N., Putri, C. A., Riyanto, A. R., & Koto, I. (2025). The scientific literacy competence of students in Indonesia and Mexico based on PISA 2022: An international comparative study. *The Future of Education Journal*, 4(5), 1033-1038. <https://doi.org/10.61445/tofedu.v4i5.525>
- Bahi, N., & Aloysius, S. (2025). How can the development of e-modules PBL improve students critical thinking skills and independent in biology learning? *JPBI (Jurnal Pendidikan Biologi Indonesia)*, 11(3), 983-998. <https://doi.org/10.22219/jpbi.v11i3.42399>
- Berliana, G. Y., Sugiyanto, S., & Fardhani, I. (2023). Student's learning outcomes and scientific literacy improvement through the implementation of reading to learn and discovery learning models. *Jurnal Penelitian Pendidikan IPA*, 9(5), 2563-2572. <https://doi.org/10.29303/jppipa.v9i5.2573>
- Branch, R. M. (2010). *Instructional design: The ADDIE approach*. Springer. <https://doi.org/10.1007/978-0-387-09506-6>
- Bórquez-Sánchez, E. (2025). Scientific literacy in biology and attitudes towards science in the Chilean education system. *Research in Science & Technological Education*, 43(2), 589-613. <https://doi.org/10.1080/02635143.2024.2320104>
- Budiastuti, R., & Mercuriani, I. S. (2025). Development of innovative technology electronic modules based on orchid potential in Nglanggeran forest through project-based learning on biotechnology material to enhance science literacy and learning interest of high school students. *Jurnal Penelitian Pendidikan IPA*, 11(1), 1057-1065. <https://doi.org/10.29303/jppipa.v11i1.9410>
- Creswell, J. W., & Plano Clark, V. L. (2007). *Designing and conducting mixed methods research*. SAGE Publications.
- Damopolii, I., Nunaki, J. H., Jeni, J., Rampheri, M. B., & Ambusaidi, A. K. (2024). An integration of local wisdom into a problem-based student book to empower

- students' conservation attitudes. *Participatory Educational Research*, 11(1), 158-177. <https://doi.org/10.17275/per.24.10.11.1>
- Fajeriadi, H., Azzam, M. N., & Azzahra, F. G. (2025). The effect of local potential-based biology learning resources on students' competencies: An in-depth analysis. *Biosfer*, 18(2), 315-326. <https://doi.org/10.21009/biosferjpb.54745>
- Fitrianawati, M., & Noerazizah, A. S. (2025). The impact of renewable energy learning media based on local wisdom on critical thinking skills. *International Journal of Learning Reformation in Elementary Education*, 4(1), 18-26. <https://doi.org/10.56741/ijlree.v4i01.763>
- Ge, J., Cheng, J., Liang, X., & Zhang, J. (2026). Place-based learning in K-12 science education: A systematic review. *Educational Research Review*, 52, 100826. <https://doi.org/10.1016/j.edurev.2026.100826>
- Graham, A., Powell, M. A., Anderson, D., Fitzgerald, R., & Taylor, N. (2013). *Ethical research involving children*. UNICEF Office of Research-Innocenti.
- Hariyanto, H., Hikamah, S. R., Maghfiroh, N. H., & Priawasana, E. (2023). The potential of the discovery learning model integrated the reading, questioning, and answering model on cross-cultural high school students' problem-solving skills. *Journal of Education and Learning*, 17(1), 58-66. <https://doi.org/10.11591/edulearn.v17i1.20599>
- Hidayat, A. E., Wisanti, W., & Isnawati, I. (2024). Biological literacy skills of senior high school student using local potential-based biodiversity question sets. *JPBI (Jurnal Pendidikan Biologi Indonesia)*, 10(3), 724-734. <https://doi.org/10.22219/jpbi.v10i3.35571>
- Homsombat, P. (2025). Integrating local wisdom and modern education: A holistic approach to curriculum development. *Journal of Exploration in Interdisciplinary Methodologies*, 2(3), 66-83. <https://so19.tci-thaijo.org/index.php/JEIM>
- Hopipah, R., Sofyan, H., & Haryanto, E. (2025). The influence of the discovery learning model on enhancing motivation and learning outcomes in natural and social sciences (IPAS) among students. *Jurnal Penelitian Pendidikan IPA*, 11(3), 230-236. <https://doi.org/10.29303/jppipa.v11i3.9750>
- Juandi, D., Kusumah, Y. S., Tamur, M., Perbowo, K. S., Siagian, M. D., Sulastri, R., & Negara, H. R. P. (2021). The effectiveness of dynamic geometry software applications in learning mathematics: A meta-analysis study. *International Journal of Interactive Mobile Technologies*, 15(2), 18-37. <https://doi.org/10.3991/ijim.v15i02.18853>
- Judijanto, L., Yudha Santoso, R., Megah Retta, L., & Sarkawi, S. (2024). Strategy of integration of local wisdom in the curriculum of higher education. *International Journal of Teaching and Learning*, 2(6), 1537-1546. <https://injetel.org/index.php/12/article/view/181>
- Kaya, M., Güvercin Seçkin, G., & Arslan, Z. (2026). The effects of self-directed learning-oriented interventions on student learning outcomes: A second-order meta-analysis. *International Journal of Educational Research*, 103071. <https://doi.org/10.1016/j.ijer.2026.103071>
- Khairani, R. N., & Prodjosantoso, A. K. (2023). Application of discovery learning model based on blended learning to activities and learning outcomes. *Jurnal Penelitian Pendidikan IPA*, 9(10), 8974-8981. <https://doi.org/10.29303/jppipa.v9i10.4402>

- Khairunisa, K., Violita, V., Arsih, F., Chatrri, M., Anhar, A., & Fransisca, R. (2025). Development of biology module based on discovery learning and ethnoscience to improve students' science literacy. *JPBI (Jurnal Pendidikan Biologi Indonesia)*, 11(3), 895-907. <https://doi.org/10.22219/jpbi.v11i3.41861>
- Lakens, D. (2013). Calculating and reporting effect sizes to facilitate cumulative science: A practical primer for t-tests and ANOVAs. *Frontiers in Psychology*, 4, 863. <https://doi.org/10.3389/fpsyg.2013.00863>
- Maghfiroh, S., Wilujeng, I., Jumadi, J., & Masyitha, D. (2023). Development of physics e-module based on discovery learning to improve students' scientific literacy. *Jurnal Penelitian Pendidikan IPA*, 9(2), 452-458. <https://doi.org/10.29303/jppipa.v9i2.1733>
- Mahdi, M., Raharjo, T. J., & Widiasih, W. (2023). Analysis of problem solving ability in natural sciences and life skills through guided discovery learning in the view of student learning independence in the subject matter of changes in energy forms. *Jurnal Penelitian Pendidikan IPA*, 9(12), 11093-11100. <https://doi.org/10.29303/jppipa.v9i12.5289>
- Manurung, A. S., & Pappachan, P. (2025). The role of discovery learning in efforts to develop students' critical thinking abilities. *Journal of Education and Learning*, 19(1), 46-53. <https://doi.org/10.11591/edulearn.v19i1.21788>
- Mashami, R. A., Ahmadi, A., & Pahriah, P. (2025). Green chemistry and cultural wisdom: A pathway to improving scientific literacy among high school students. *Social Sciences & Humanities Open*, 11, 101653. <https://doi.org/10.1016/j.ssaho.2025.101653>
- Niate, M., & Paidi, P. (2025). Development of SETS e-module on endocrine system material to improve scientific literacy and learning independence of high school students. *BIO-INOVED: Jurnal Biologi-Inovasi Pendidikan*, 7(2), 308. <https://doi.org/10.20527/bino.v7i2.21357>
- Ningsih, H., Rokhman, F., Pramono, S. E., & Raharjo, T. J. (2026). Kelayakan bahan ajar interaktif sistem pernapasan manusia pada keterampilan berpikir kritis siswa kelas V SD. *Pendas: Jurnal Ilmiah Pendidikan Dasar*, 11(1). <https://doi.org/10.23969/jp.v11i01.40045>
- Novalia, R., Marini, A., Bintoro, T., & Muawanah, U. (2025). Project-based learning: For higher education students' learning independence. *Social Sciences & Humanities Open*, 11, 101530. <https://doi.org/10.1016/j.ssaho.2025.101530>
- Nurhayati, N., Jaenudin, D., & Sukmanasa, E. (2025). Development of e-modules based on local wisdom on ecosystem material to increase scientific literacy. *AL-ISHLAH: Jurnal Pendidikan*, 17(1). <https://doi.org/10.35445/alishlah.v17i1.6224>
- Nurohman, S., & Fikri, I. (2025). Science e-book integrated with local potential of petis making based on problem based learning-ESD to improve science literacy skills of junior high school students. *Jurnal Penelitian Pendidikan IPA*, 11(1), 1039-1048. <https://doi.org/10.29303/jppipa.v11i2.7956>
- OECD. (2023). *PISA 2022 results (Volume I): The state of learning and equity in education*. OECD Publishing. <https://doi.org/10.1787/53f23881-en>
- Pamungkas, J., Harun, H., & Manaf, A. (2023). A systematic review and meta-analysis group contrasts: Learning model based on local cultural wisdom and student learning outcomes. *International Journal of Instruction*, 16(2), 53-70. <https://doi.org/10.29333/iji.2023.1624a>

- Pantiwati, Y., Aminudin, A., Waluyo, L., Permana, F. H., Sari, T. N. I., & Nurrohman, E. (2025). E-module based on LI-PRO-GP learning model to improve students' conceptual understanding and problem-solving abilities in science learning. *International Journal of Information and Education Technology*, 15(3), 549-564. <https://doi.org/10.18178/ijiet.2025.15.3.2265>
- Pratama, A., Sari, T. N. I., Istiqomah, N., Widiyanti, E. R., & Kusniati, Y. (2024). Improving critical thinking and metacognitive skills through the discovery learning model assisted by practicum for high school students. *Biosfer*, 17(1), 102-112. <https://doi.org/10.21009/biosferjpb.34481>
- Prihatiningtyas, S., Shofiyah, N., Yunus, S. R., Ma'arif, I. B., & Putra, I. A. (2025). Enhancing science literacy through flipbook-based STEM Qur'an e-modules: A case study in Islamic boarding schools. *Humanities and Social Sciences Communications*, 12(1). <https://doi.org/10.1057/s41599-025-05054-w>
- Puspita, H., Firdaus, F. M., & Kawuryan, S. P. (2024). Self-directed learning model based on local wisdom values on student learning outcomes. *Journal of Innovation in Educational and Cultural Research*, 5(1), 22-28. <https://doi.org/10.46843/jiecr.v5i1.839>
- Rediani, N. N., Kaize, B. R., Hanifah, S., Nainggolan, H. T., Dharma Sanjaya, P. M., & Hallatu, T. G. R. (2023). Developing environmental care attitudes and scientific literacy through Sasi local wisdom-based e-modules. *Jurnal Pedagogi dan Pembelajaran*, 6(2), 238-246. <https://doi.org/10.23887/jp2.v6i2.64518>
- Richardson, J. T. E. (2011). Eta squared and partial eta squared as measures of effect size in educational research. *Educational Research Review*, 6(2), 135-147. <https://doi.org/10.1016/j.edurev.2010.12.001>
- Salim Putra, M. D. F., Subali, B., & Marwoto, P. (2025). Development of STEM based physics e-module with virtual lab to improve learning outcomes. *Physics Communication*, 9(1), 63-70. <https://doi.org/10.15294/pc.v9i1.8343>
- Saputra, R. S., & Octavia, B. (2024). E-module assisted by augmented reality with a discovery learning model on virus material to increase scientific literacy and learning independence for class X high school students. *Jurnal Penelitian Pendidikan IPA*, 10(11), 8507-8518. <https://doi.org/10.29303/jppipa.v10i11.8795>
- Sari, T. N. I., Pantiwati, Y., & Fauzi, A. (2024). Development of four-tier multiple-choice diagnostic instrument to identify middle school students' misconceptions about biology material. *Biosfer: Jurnal Pendidikan Biologi*, 17(1), 257-273. <https://doi.org/10.21009/biosferjpb.35289>
- Sari, T. N. I., Rakhmawati, A., & Rahmawati, H. R. (2025). Effectiveness of PjBL worksheet based on local potential to improve critical and creative thinking skills of Phase E high school students. *Journal of Innovation in Educational and Cultural Research*, 6(2), 242-252. <https://doi.org/10.46843/jiecr.v6i1.1836>
- Sayangan, Y. V. (2024). A qualitative study on the impact of local wisdom-based discovery learning in teaching concept geometry. *Al-Jabar: Jurnal Pendidikan Matematika*, 15(1). <http://ejournal.radenintan.ac.id/index.php/al-jabar/index>
- Sele, Y., Sila, V. U. R., Oetpah, F., & Kabnani, Y. (2023). Students' learning independence from different specialization classes: A comparative study. *Jurnal Pembelajaran dan Biologi Nukleus*, 9(1), 57-65. <https://doi.org/10.36987/jpbn.v9i1.3925>
- Setyaningsih, A., Kholik, N., Azis, A. A., Yusnanto, T., & Sadikin, A. (2023). The effect of learning environment and students independent learning on students

- learning outcomes. *Jurnal Manajemen Pendidikan*, 5(1), 142-147. <https://doi.org/10.55352/mudir>
- Setyorini, L., Haryani, S., & Susilaningih, E. (2022). Development of e-module based on local wisdom to improve science literacy and reading literacy. *Jurnal Pendidikan Kimia*, 14(1), 28-38. <https://doi.org/10.24114/jpkim.v14i1.32948>
- Shaydulloyevich, B. Q. (2025). Improving lesson effectiveness through engineering students' independent learning. *Current Research Journal of Pedagogics*, 6(12), 23-26. <https://doi.org/10.37547/pedagogics-crjp-06-12-06>
- Sidauruk, S., Ni'mah, F., Meiliawati, R., Analita, R. N., Rahmadani, A., Budi, F. S., & Adhani, A. (2025). Scientific literacy on peatland across various study programs, genders, and current domicile of university students in Borneo. *Journal of Education and Learning*, 19(1), 449-459. <https://doi.org/10.11591/edulearn.v19i1.21794>
- Sidauruk, T., Delita, F., Berutu, N., Elfayetti, E., & Rohani, R. (2025). E-modules to improve learning independence, motivation and learning outcomes. *Jurnal Penelitian dan Pengembangan Pendidikan*, 9(1), 171-180. <https://doi.org/10.23887/jppp.v9i1.74404>
- Sjöström, J. (2025). Vision III of scientific literacy and science education: An alternative vision for science education emphasising the ethico-socio-political and relational-existential. *Studies in Science Education*, 61(2), 239-274. <https://doi.org/10.1080/03057267.2024.2405229>
- Susilawati, S., Mulyani, G., Halim, A., Saputri, M., Farhan, A., & Widia, S. (2025). Enhancing scientific literacy through an interactive e-module enriched with Acehese local wisdom. *Journal of Physics: Conference Series*, 3148(1), 012008. <https://doi.org/10.1088/1742-6596/3148/1/012008>
- Syahira, H. Q., Pursitasari, I. D., Retnowati, R., & Syarpin, S. (2025). E-module of the human digestive system with self-directed learning readiness framework to improve students' science literacy. *Jurnal IPA dan Pembelajaran IPA*, 9(4), 1070-1085. <https://doi.org/10.24815/jipi.v9i4.48969>
- Tias, D. E. Y., Atmaja, I. W. W., Emyus, A. Z., & Priawasana, E. (2026). Discovery learning combined with the RQA strategy to strengthen science literacy and basic thinking skills in elementary school students. *Jurnal Penelitian Pendidikan IPA*, 12(1), 210-224. <https://doi.org/10.29303/jppipa.v12i1.13876>
- Utama, N., & Zulyusri, Z. (2022). Meta-analisis praktikalitas penggunaan e-modul oleh guru dan peserta didik dalam pembelajaran. *Jurnal Biologi dan Pembelajarannya*, 9, 27-33. <https://ojs.unpkediri.ac.id/index.php/biologi>
- Utaminingsih, S., Fathurrahman, I., & Zuliyanti, N. (2022). E-module with discovery learning model based on educational games. *KnE Social Sciences*, 532-544. <https://doi.org/10.18502/kss.v7i14.12006>
- van Breukelen, G. J. P. (2013). ANCOVA versus CHANGE from baseline in nonrandomized studies: The difference. *Multivariate Behavioral Research*, 48(6), 895-922. <https://doi.org/10.1080/00273171.2013.831743>
- Wardhani, D. F., Arisanty, D., Nugroho, A., & Utami, U. B. L. (2023). The local wisdom of the Paramasan Dayak tribe in environmental management. *Environment and Ecology Research*, 11(5), 859-872. <https://doi.org/10.13189/eer.2023.110514>
- Wege, K., Harso, A., & Wolo, D. (2022). Analysis of student learning independence during the pandemic. *Journal of Research in Instructional*, 2(1), 87-96. <https://doi.org/10.30862/jri.v2i1.34>

- Widyaningrum, R., & Prihastari, E. B. (2023). Implementing local wisdom-integrated project-based learning model to instill students' learning independence. *SHS Web of Conferences*, 173, 01011. <https://doi.org/10.1051/shsconf/202317301011>
- Wisdayana, N., Achyani, A., & Aththibby, A. R. (2025). Teaching materials based on socio scientific issues: An effective strategy to improve science literacy and critical thinking skills. *Jurnal Penelitian Pendidikan IPA*, 11(4), 346-354. <https://doi.org/10.29303/jppipa.v11i4.10786>
- Yerimadesi, Y., Warlinda, Y. A., Rosanna, D. L., Sakinah, M., Putri, E. J., Guspatni, G., & Andromeda, A. (2023). Guided discovery learning-based chemistry e-module and its effect on students' higher-order thinking skills. *Jurnal Pendidikan IPA Indonesia*, 12(1), 168-177. <https://doi.org/10.15294/jpii.v12i1.42130>
- Zahara, L., Santosa, M. H., & Widiana, I. W. (2025). A study of physics scientific literacy and students' learning independence in three subdistricts of East Lombok. *Jurnal Penelitian Pendidikan IPA*, 11(12), 308-315. <https://doi.org/10.29303/jppipa.v11i12.13243>