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Integrating Socio-Scientific Issues, Inquiry, and Blended Learning for Scientific Literacy: a Bibliometric Foundation for the Socio-Scientific Inquiry Based on Blended Learning Conceptual Model

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ABSTRACT

Introduction. In the 21st-century information complexity era, scientific literacy is a crucial competency for students because it is closely related to critical thinking skills and evidence-based decision-making. Mastery of scientific literacy can increase students' competitiveness in the job market and the global economy, while also supporting the formation of a society capable of actively participating in discourses on important social and scientific issues. Various studies have attempted to develop scientific literacy through socio-scientific issues (SSI), inquiry-based learning, and blended learning approaches; however, these three areas are still poorly integrated, potentially resulting in ineffective learning methods. Therefore, this study uses bibliometric methodology to map the intellectual framework and global research vanguard on the convergence of these three domains and builds a theoretical foundation for the development of a Socio-Scientific Inquiry Based on Blended Learning (SSIBBL) model to improve scientific literacy.

Methods. We looked at 103 Scopus-indexed articles that were published between 2009 and 2026. We used a PRISMA-based filtering process, keyword co-occurrence mapping, thematic map analysis, co-citation analysis, and bibliographic coupling analysis with VOSviewer and Biblioshiny.

Results. Bibliometric findings indicate that SSI, argumentation, and epistemic reasoning are essential foundations of modern science education. Meanwhile, inquiry and blended learning have emerged as dominant pedagogical practices that continue to grow. Scientific literacy serves as a conceptual hub connecting SSI, inquiry, and blended learning. However, these three domains still exhibit conceptual fragmentation, and to date, there is no learning model that systematically integrates them. SSIBBL has the potential to bridge the gap between theoretical foundations and contemporary research directions, in line with recent calls for developing learning models that integrate these three domains in a coherent manner. SSIBBL enables students not only to be guided to understand socio-scientific phenomena but also to practice scientific inquiry with the support of digital technology in a blended learning environment, thus optimizing the development of scientific literacy.

Conclusion. This study generates a conceptual synthesis that serves as the foundation for developing the SSIBBL model, designed as a pedagogical framework to integrate the epistemic, socio-cultural, and technological aspects of science education. This model provides a novel approach to enhancing scientific literacy in higher education and creates avenues for empirical validation, curriculum development, and digital learning innovation in subsequent research.

KEYWORDS

scientific literacy, socio-scientific issues, inquiry, blended learning, science learning, socio-scientific inquiry based on blended learning

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INTRODUCTION

The evolution of science, technology, and societal dynamics in the 21st century has fundamentally altered the requirements for science education. Students must now not only master conceptual knowledge but also possess scientific literacy, defined as the capacity to assess socio-scientific phenomena, make evidence-based decisions, and apply scientific reasoning in practical situations [1; 2]. This shift has catalyzed a global dialogue concerning the necessity for learning models that incorporate cognitive, social, ethical, and technological dimensions, facilitating the advancement of scientific literacy in a more comprehensive and holistic fashion [3].

Socio-scientific issues (SSI) have been acknowledged as a potent educational framework for fostering scientific literacy, as they offer pertinent and stimulating learning opportunities [4; 5]. SSI presents authentic, contentious, and value-laden scenarios that compel students to evaluate scientific evidence while also considering social, ethical, and environmental perspectives [6; 7]. Subjects like climate change, food security, genetic engineering, and renewable energy not only make learning about science more relevant, but they also help students learn how to argue, make moral judgments, and become more scientifically literate overall. Nonetheless, numerous studies indicate that the efficacy of the SSI approach is maximized when integrated with a structured inquiry process, enabling students to engage in discussions while also undertaking comprehensive scientific investigations [8; 9].

Inquiry-based learning is acknowledged as a significant methodology in science education, as it involves students in scientific practices, including the formulation of questions, execution of investigations, data analysis, explanation construction, and communication of findings [10; 11]. Active participation in the inquiry process has demonstrated enhancement of students' scientific reasoning abilities, conceptual comprehension, and epistemic awareness [12; 13]. Conventional face-to-face inquiry learning frequently does not address the complexity and interdisciplinary characteristics of SSI, particularly when students need access to varied information sources, assistance with digital collaboration tools, and a more adaptable learning environment [14].

At the same time, blended learning has come about as a way to combine online and in-person learning with the help of digital technology. This method lets you use simulations, multimedia, collaborative platforms, and a wider range of learning materials. In the realm of science education, blended learning-based inquiry has been documented to enhance student engagement, fortify metacognitive regulation, and facilitate more adaptable investigative endeavors [15; 16]. Nonetheless, research into SSI, inquiry, and blended learning typically evolves in isolation, resulting in an incomplete conceptual integration of the three domains [3; 8].

The initial review showed a big problem: there wasn't a unified learning model that combined SSI, inquiry, and blended learning in a systematic way to improve scientific literacy, especially in higher education. However, each domain possesses distinct pedagogical strengths: SSI focuses on contextual relevance and moral judgment, inquiry prioritizes engagement in scientific practice, and blended learning highlights technological support and learning flexibility. There is still not much research that combines all three areas, which makes it difficult to come up with new learning designs that are both based on theory and backed up by research from around the world.

To address this gap, this study employs a bibliometric methodology as a systematic approach to delineate intellectual frameworks, research trajectories, and conceptual interconnections among related fields. Bibliometrics facilitates extensive analysis through keyword co-occurrence mapping, thematic map analysis, co-citation networks, and bibliographic coupling, thereby elucidating previously overlooked areas of integration [17]. These results serve as an empirical and theoretical foundation for the formulation of a more comprehensive learning model.

The aim of this research is to develop the Socio-Scientific Inquiry-Based on Blended Learning (SSIBBL) model as a pedagogical framework that integrates the SSI context, scientific inquiry methodologies, digital learning resources, and the enhancement of scientific literacy. This research specifically seeks to: (1) delineate the global research landscape concerning SSI, inquiry, blended learning, and scientific literacy via bibliometric analysis; (2) identify thematic clusters and conceptual intersections among these four domains; and (3) create a conceptual model of SSIBBL using bibliometric data. This method should lead to a teaching framework that is more relevant, complete, and flexible to the needs of science education in the digital age and the complexity of contemporary SSI.

RESEARCH METHOD

1. Research design

This research employs an exploratory bibliometric methodology to delineate the knowledge landscape and discern conceptual frameworks of SSI, inquiry, blended learning, and scientific literacy within the realm of science education. The bibliometric approach was selected due to its capacity for quantitative and visual examination of publication trends, conceptual interconnections, and the development of themes in a systematic and reproducible fashion [17].

2. Data source and search strategy

Scopus, one of the largest and most widely used scientific databases in bibliometric studies, provided all of the bibliographic data. The search was done in November 2025 with the following search string:

("socioscientific issue*" OR "socio scientific issue*" OR "socio-scientific issue*" OR "socio scientific context*") AND ("inquiry based learning" OR "scientific inquiry" OR "inquiry learning" OR "inquiry") AND ("blended learning" OR "hybrid learning" OR "online and face-to-face learning" OR "digital learning") AND ("scientific literacy" OR "science literacy") AND ("science education" OR "STEM education" OR "science teaching" OR "science learning" OR "science classroom")

3. Screening procedure

To ensure that the data were clear, traceable, and of high quality, the document selection process followed the PRISMA guidelines for systematic reviews and meta-analyses [18].

3.1. Identification

A preliminary search was executed in the Scopus database utilizing a predetermined search string. This process produced 141 documents. Thereafter, we filtered the documents by type (article and review) and language (English), which left us with 117 documents. Thereafter, all of the documents were exported as CSV files, which included bibliographic information like the title, abstract, keywords, authors, journal, and reference list.

3.2. Screening

At this point, the titles and abstracts were checked to ensure they fit with the research scope. We excluded articles that focused solely on experimental research (such as biology or chemistry topics lacking a teaching context), discussed inquiry outside of education (like data or business inquiry), applied blended learning in non-science fields, omitted scientific literacy or related competency domains, or were proceedings, editorials, or short communication articles. After this stage, 14 documents were thrown out because they didn't fit the theme. The other documents were then moved on to the eligibility stage.

3.3. Eligibility

At this point, the full text was looked at in more detail to see if the methods were sound and the context was right. Articles were excluded if they did not incorporate at least two of the four primary domains: SSI, inquiry, blended learning, and scientific literacy; utilized the search terms without addressing them within the framework of science education; lacked keywords or abstracts that aligned with the study's focus; or concentrated exclusively on medical, engineering, or social fields devoid of pedagogical significance. This step made sure that only articles that were conceptually related to the research focus were kept. No articles were removed following a comprehensive text evaluation.

3.4. Inclusion

After passing through three previous selection stages, 103 articles met all of the inclusion criteria and were found to be relevant to the study's focus on SSI, inquiry, blended learning, and scientific literacy in science education. The bibliometric analysis used these articles as its main data set.

4. Data processing

We prepared the bibliographic data by getting rid of duplicates, standardizing keywords, and getting rid of stop words and other generic terms that didn't add any information. The next step was to use two main tools, VOSviewer and Biblioshiny (R Bibliometrix), to do the analysis.

5. Reproducibility and ethical considerations

All search methods, screening, and analysis criteria are recorded to guarantee replicability. The study did not include human subjects and thus did not necessitate ethics approval; all sources are cited appropriately.

STUDY RESULTS

1. Descriptive analysis of the dataset

The bibliometric analysis commenced with an examination of the general characteristics of 103 articles acquired via the PRISMA procedure [Table 1]. The dataset includes publications from 2009 to 2026, showing that research on the link between SSI, inquiry, blended learning, and scientific literacy is a new field that has grown over the past two decades. The bibliometric method is thought to be a good way to describe the research landscape because it can be repeated, is quantitative, and can show broad intellectual patterns [17]. This dataset was put together from 58 different publication sources. This shows that the topic is not limited to one journal, but is spread out across many journals in higher education, educational technology, and science education.

Table 1 Main information

Description	Results
MAIN INFORMATION ABOUT DATA	
Timespan	2009:2026
Sources	58
Documents	103
Annual Growth Rate %	0
Document Average Age	2.96
Average citations per doc	16.49
References	942
DOCUMENT CONTENTS	
Keywords Plus (ID)	84
Author's Keywords (DE)	360
AUTHORS	
Authors	315
Authors of single-authored docs	7
AUTHORS COLLABORATION	
Single-authored docs	7
Co-Authors per Doc	3.3
International co-authorships %	20.39
DOCUMENT TYPES	
article	92
review	11

The majority of the publications were research articles (92 documents), while 11 were review articles. The prevalence of empirical articles signifies that research in the domains of SSI, inquiry, and blended learning has yielded a substantial array of findings, yet has not been synthesized into a cohesive conceptual model. In this context, the creation of the SSIBBL model is pertinent as an initiative to consolidate previously distinct research trends.

According to citation analysis, the articles in the dataset have an average of 16.49 citations per document and a total of 942 cited references. This number shows that research on combining SSI, inquiry, blended learning, and scientific literacy is well-known and has a big impact on the global science education community. This citation rate also shows that research on scientific literacy, inquiry practices, and the use of technology in science learning is a popular topic of conversation.

The dataset has 360 author keywords and 84 Keywords Plus in terms of content. The variety of keywords shows that research on SSI, inquiry, blended learning, and scientific literacy is complex and includes topics like argumentation, informal reasoning, the nature of science, e-learning, digital inquiry, and technology-based assessment. This complexity is what makes thematic clusters possible. Co-occurrence analysis and thematic mapping are then used to map these clusters.

The way authors work together also shows that this field is global. 315 authors wrote 103 papers, with an average of 3.3 authors per paper. Only seven papers had a single author. Furthermore, 20.39% of the publications were the result of collaboration between people from different countries. This high level of collaboration shows that SSI, inquiry, and blended learning are not just problems in one place but also part of a conversation that goes on between countries and institutions around the world.

The average age of documents in the dataset is 2.96 years, which means that most of them are fairly new and show current research trends. The annual growth rate was 0%, but this is probably because the number of publications changes from year to year, and the data collection period was short, suggesting research is still progressing. In general, the descriptive features of the dataset show that the field of SSI – inquiry – blended learning – scientific literacy is growing and becoming more diverse. The SSIBBL model in this study provides more systematic conceptual and integrative mapping, which is necessary.

2. Keyword co-occurrence analysis

The keyword co-occurrence map produced by VOSviewer analysis illustrates a conceptual interconnectedness pattern that reflects the intellectual landscape of research concerning the integration of SSI, inquiry, blended learning, and scientific literacy [Figure 1]. After processing the data, a network visualization was made using the mapping and normalization algorithm that van Eck and Waltman came up with [19]. The mapping results reveal six interconnected clusters that collectively constitute a coherent knowledge structure. The interactions among these clusters illustrate the evolution and interrelation of pedagogical, technological, and epistemological themes within modern science education.

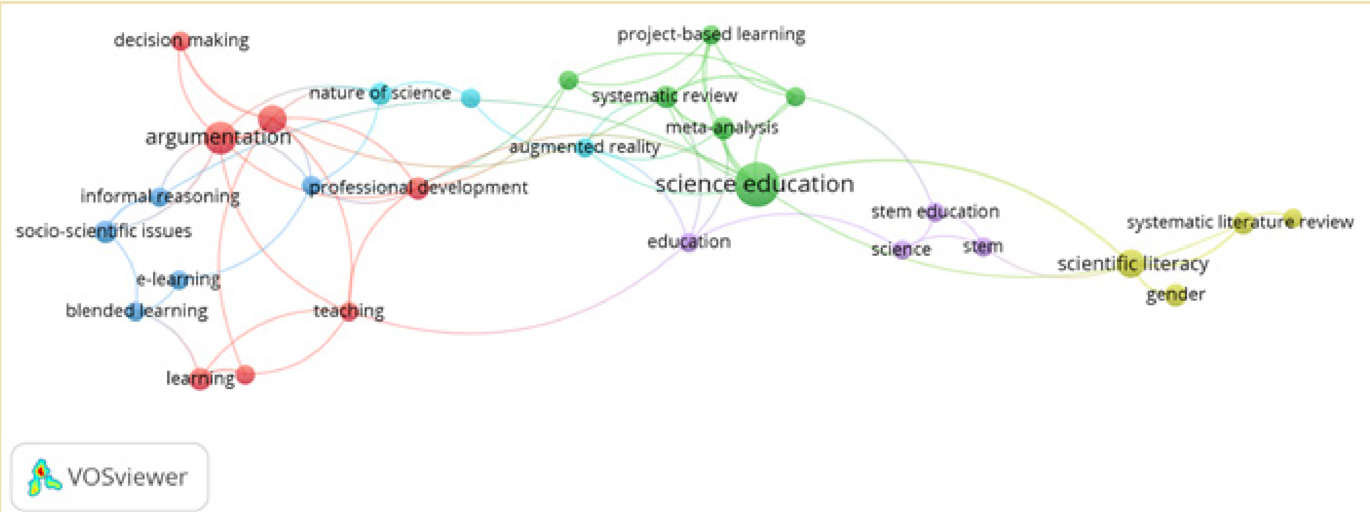

Figure 1 Keyword co-occurrence maps

The red cluster, which focuses on argumentation, decision-making, socio-scientific issues, and education for sustainable development, shows that the SSI domain is mostly about complex reasoning, evaluating evidence, and making decisions based on arguments. These keywords make it clear that SSI is not just a place to learn but also a place to improve higher-order thinking skills. Its close ties to teaching and professional development show that a teacher's ability to facilitate argumentative interactions in the classroom is very important.

The green cluster, which includes inquiry-based learning, problem-based learning, project-based learning, and systematic review, stresses how important the inquiry approach is to science education. The way different types of research work together shows that inquiry isn't just one thing, but a range of scientific inquiry activities. The fact that "science education" is a central node in this cluster shows that inquiry is a key way to teach science.

The blue cluster shows that blended learning, e-learning, and informal reasoning are all very similar. This diagram shows that digital learning is very important for improving students' reasoning skills, especially in the case of SSI, which needs flexibility, easy access to information, and time for personal reflection. The fact that the word "students" is connected in this group shows that digital inquiry is an important part of how today's students learn.

The yellow cluster, which includes scientific literacy, science learning, and systematic literature reviews, shows that the main goal of the research is to improve scientific literacy. The inclusion of the term "gender" in this cluster signifies a focus on social determinants affecting literacy outcomes, suggesting that scientific literacy is regarded as a multifaceted skill responsive to socio-cultural contexts.

The purple cluster shows the bigger picture of science education by using words like education, science, STEM, and STEM education. This group puts research on SSI, inquiry, and blended learning into the larger context of new ideas in curriculum and education. STEM's presence shows that combining these four areas is important in more than one field.

The light blue cluster, which includes augmented reality, the nature of science, and online learning, shows how immersive technology and online learning are becoming more common as tools for inquiry-based learning. This group shows a new way that research is being done, where the epistemological dimension (the nature of science) is combined with digital technology to make learning more captivating.

The keyword co-occurrence map shows that research on SSI, inquiry, blended learning, and scientific literacy grows in different groups, but there are strong conceptual connections between them. This structure suggests unexploited opportunities for integration, especially at the convergence of argumentation in socio-scientific inquiry, investigative methodologies in inquiry-based learning, and the adaptability of digital education. These results give us a strong empirical foundation for developing SSIBBL as an integrative learning model that strikes a balance between the socio-scientific context, scientific inquiry methods, and technological support to improve scientific literacy.

3. Thematic map analysis

Biblioshiny's thematic map analysis categorizes keywords into four quadrants, determined by their centrality and density [Figure 2]. The procedure is based on the classic method created by Callon et al. [20]. This map shows the themes that are mature, developing, or fading. The findings demonstrate varied yet synergistic thematic advancements in the research pertaining to SSI, inquiry, blended learning, and scientific literacy.

The themes in the motor themes quadrant show that they are both very relevant and growing. Scientific literacy is at the center of the picture, which means that it is not only the main focus of research but also the most consistently studied outcome in modern science education. The incorporation of blended learning in this thematic cluster underscores the growing importance of digital pedagogical methods in enhancing contemporary educational practices. The emergence of systematic reviews and meta-analyses represents a significant progression in empirical literature, enabling a comprehensive synthesis of evidence. The inclusion of professional development and education for sustainable development within the same cluster substantiates that the enhancement of educator capacity and a sustainability perspective are essential components of the scientific literacy discourse. In theory, this position means that the SSIBBL model needs to make scientific literacy one of its main goals by using blended learning as its main teaching method.

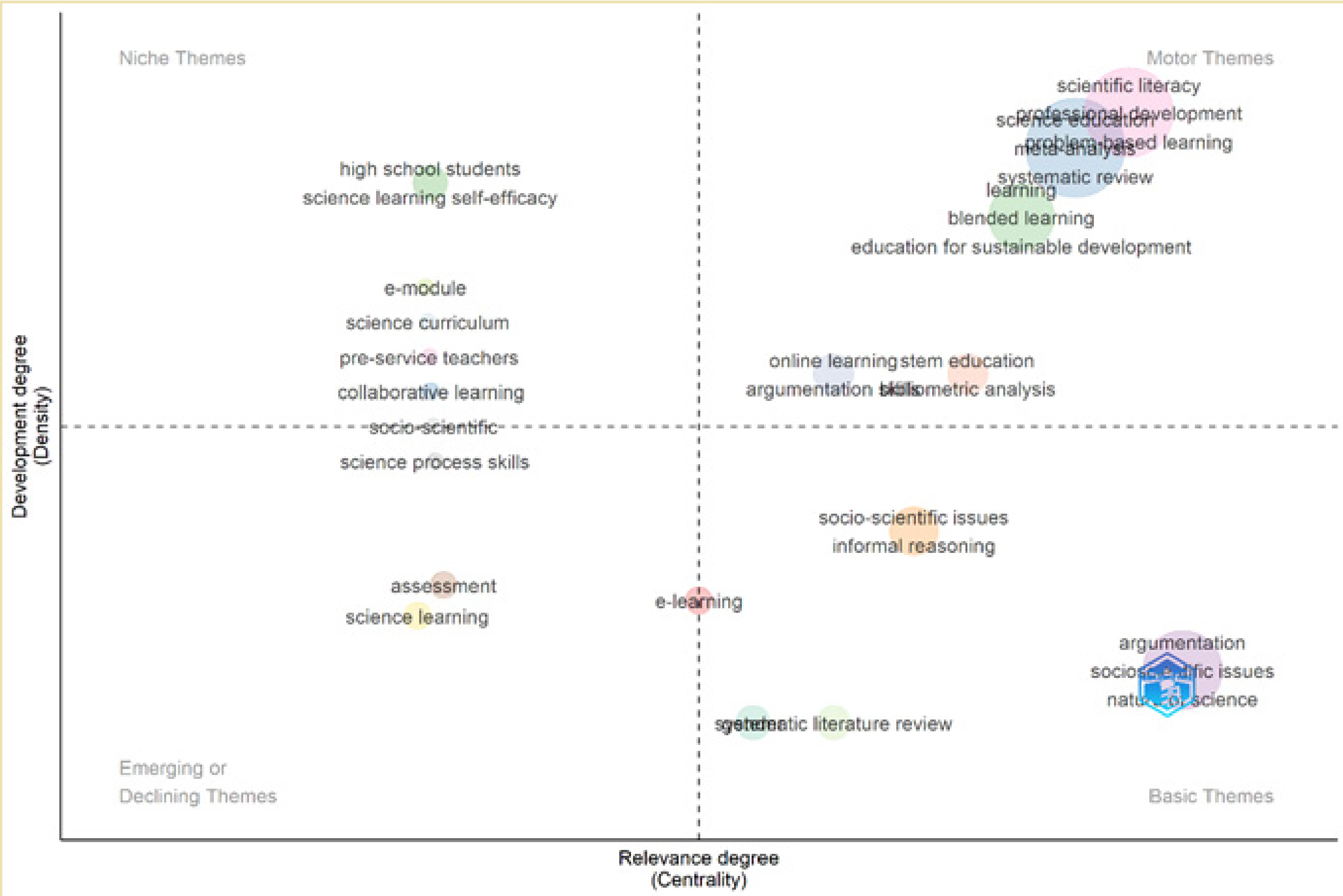

Figure 2 Thematic maps

Niche themes are those that have grown considerably but don't affect the core body of knowledge. Terms like "science learning self-efficacy", "e-module", and "collaborative learning" show that there are certain pedagogical studies that improve ways of learning, but they are not the main focus of global research. The themes of pre-service teachers and science curriculum are also present, showing that researchers are interested in teacher education and curriculum development, but their impact is still not obvious. These themes offer significant contributions to SSIBBL, especially regarding the provision of digital support materials, online collaboration, and the enhancement of affective dimensions, such as self-efficacy in science education.

The emerging or declining themes quadrant has keywords that aren't very relevant or developed, which indicates that themes are in a transitional phase right now. Assessment and science learning are still important, but they aren't changing much. E-learning's place in this quadrant shows that research is moving away from traditional online learning and toward more complicated blended approaches. This quadrant has systematic literature reviews, which means that evidence synthesis is still being used, but it is no longer the main topic of conversation. This quadrant is a chance for SSIBBL to become a new way to learn about science by combining SSI and inquiry into the digital ecosystem that is constantly changing.

Basic themes are important but not very useful for teaching. Argumentation and socioscientific issues are identified as essential conceptual foundations that necessitate further enhancement and integration. The existence of informal reasoning and the characteristics of science within this group underscore that the epistemological dimension constitutes the foundational basis for research in this domain, despite the absence of a fully realized and structured learning model. The online learning theme, which is on the edge of the quadrant, shows that we are moving toward a blended learning approach, which is consistent with the results of other cluster analyses.

The thematic map results indicate that scientific literacy and blended learning are now important and well-established themes. However, key themes like argumentation, socioscientific issues, informal reasoning, and the nature of science still need to be better integrated into a complete teaching framework. At the same time, supporting themes like self-efficacy, collaborative learning, and e-modules point to possible ways to grow, while new themes create chances for new ideas in digital learning. This thematic structure shows that there is still no integrated model that combines SSI, inquiry, and blended learning to improve scientific literacy. Consequently, the findings from this mapping unequivocally underscore the necessity of establishing SSIBBL as an innovative pedagogical framework that integrates diverse conceptual and technological dimensions that have historically evolved in isolation.

4. Co-citation network and bibliographic coupling analysis

We used co-citation and bibliographic coupling analyses to obtain a full picture of the intellectual structure and direction of research in SSI, inquiry, blended learning, and scientific literacy. Co-citations show the theoretical bases that make up the field's conceptual foundation, while bibliographic coupling shows how close contemporary research is to each other, and how the field is changing and growing. Combining the two analyses allows us to understand the relationship between past intellectual traditions and current research directions. This combination is what makes the SSIBBL learning model necessary.

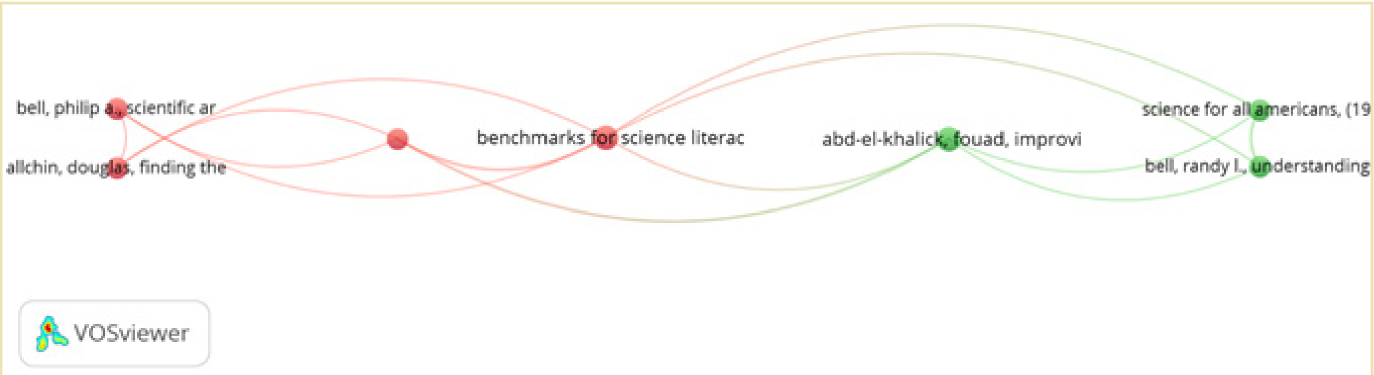

Figure 3 Co-citation network

Small [21] and Marshakova [22] came up with the idea of "shared calling," which is used in co-citation analysis to identify connections between documents. The analysis identifies two primary theoretical clusters that underpin research pertaining to SSI, inquiry, and scientific literacy [Figure 3]. The first group is mostly made up of books about argumentation, epistemic reasoning, and socio-scientific reasoning. Some examples are Bell, Allchin, and Benchmarks for Science Literacy (AAAS). The main ideas in this group are how to make arguments based on evidence, how to use informal reasoning in social and scientific issues, and how scientific discussion can help people understand things better. The second cluster is about scientific literacy and the nature of science (NOS). It is based on important works like Science for All Americans and the works of Bell, Lederman, and Abd-El-Khalick. The ideas in this group focus on what science is, how scientific knowledge is organized, and how important the inquiry process is for developing scientific literacy. Transitional documents like the Benchmarks for Science Literacy make it easy to see how the two clusters are related. They connect argumentation, epistemic reasoning, and scientific literacy within a single epistemological framework. In this way, the co-citation network shows that scientific literacy isn't just about knowing facts; it also depends a lot on practicing argumentation, scientific reasoning, and understanding the NOS – three areas that are crucial to the growth of SSIBBL.

Simultaneously, bibliographic coupling was examined through the lens of reference list similarity as articulated by Kessler [23]. The analysis results indicate that the current research configuration emphasizes technology-driven science education and digital inquiry methodologies [Figure 4]. The first group of papers, which includes work by Chi, Wang, and Liu, talks about how technology can improve the inquiry process. This set of studies includes things like multimedia, online learning environments, and digital scaffolding for argumentation. This group of studies indicates that blended learning is an important part of supporting scientific inquiry. The second cluster, which is heavily based on Khishfe's work, is about socio-scientific reasoning, how to use NOS in SSI, and how to judge evidence when making decisions. This group makes the case stronger that epistemic practices should be the main way that people learn in SSI-based models. The third cluster focuses on studies of online inquiry and self-regulated learning. Wu and Tsai's work shows how self-regulation, metacognition, and cognitive engagement work in digital settings. The fourth cluster talks about technology-based science learning and digital assessment. It stresses that technological support, like assessments that take place on online platforms, is an important part of modern learning design.

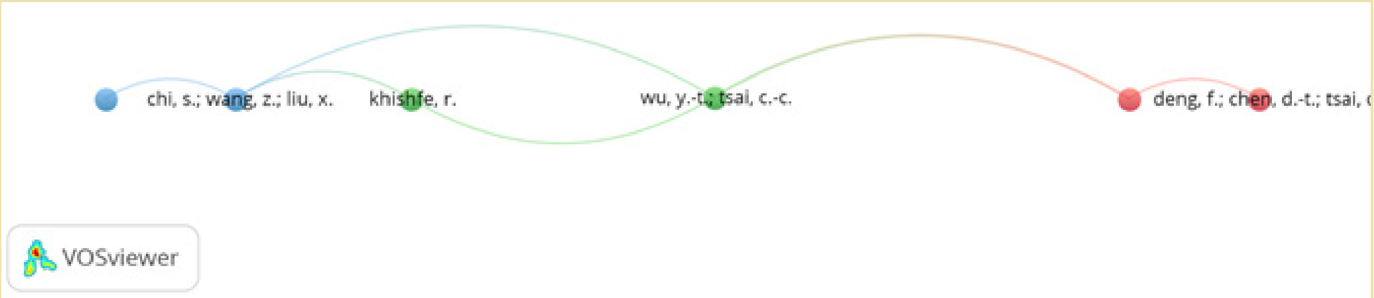

Figure 4 Bibliographic coupling

When these two analyses are combined, it becomes evident that the theoretical framework of the field is robust, yet the trajectory of current research remains disjointed. There are two different paths for research on SSI and epistemic reasoning, as well as research on digital inquiry and blended learning. Bibliographic coupling, on the other hand, shows the start of a conceptual chain that connects the two: SSI → epistemic reasoning → inquiry → digital inquiry → blended learning. This pattern indicates a propensity for convergence; however, no pedagogical model comprehensively incorporates all these dimensions. This fragmentation underscores a notable pedagogical deficiency in the literature: the absence of a cohesive learning framework that amalgamates the socio-scientific context, scientific inquiry methodologies, epistemic dimensions, and technological facilitation of blended learning to fully attain scientific literacy.

The integration of co-citation and bibliographic coupling offers robust empirical and theoretical validation for the advancement of SSIBBL. Theoretical foundations underscore the significance of argumentation, NOS, and epistemic reasoning in the cultivation of scientific literacy. Concurrently, recent research highlights the necessity of digital learning and inquiry technologies in contemporary science education practices. Therefore, SSIBBL can be seen as a model that is based on well-known intellectual traditions, is open to new research, and can meet the needs of modern teaching. This model could bring together the epistemic, cognitive, and digital parts of science learning in a way that is more flexible, useful, and relevant to the problems of the 21st century.

DISCUSSION

1. Synthesis of findings

The bibliometric analysis reveals that research on SSI, inquiry, blended learning, and scientific literacy evolves as four interconnected yet not fully integrated domains. This finding aligns with recent reviews indicating that SSI is extensively examined to enhance scientific literacy and critical reasoning, yet is frequently regarded as a distinct methodology from the formulation of integrated learning models [24]. The keyword co-occurrence in this study indicates a thematic distinction between the emphasis on argumentation and informal reasoning in SSI-based learning, inquiry practices in science education, and the utilization of technology to facilitate the learning process, which is similarly evidenced in research trends concerning argumentation and SSI across diverse contexts [25; 26]. The thematic map illustrates that scientific literacy and blended learning are the principal themes, signifying that both are the focal points of current research, in alignment with the growing volume of systematic reviews and meta-analyses regarding the efficacy of blended learning and scientific literacy in higher education [27; 28]. At the same time, socio-scientific issues, argumentation, and the nature of science have become key themes with a strategic role, but they have not yet become a fully developed teaching model, even though they have been recognized for a long time as important parts of literacy-based science education [29; 30].

Co-citation networks exhibit a robust theoretical framework grounded in epistemic reasoning, argumentation, and the essence of science. Foundational texts like Science for All Americans and the AAAS Benchmarks for Science Literacy underscore that scientific literacy should be developed through epistemological comprehension and scientific ways of thinking, rather than mere content mastery [31]. The research conducted by Bell, Allchin, Abd-El-Khalick, and their associates illustrates that argumentation and the NOS are essential epistemic practices that empower learners to assess scientific assertions and make informed decisions in SSI contexts [32; 33]. Conversely, bibliographic coupling indicates contemporary research trajectories that progressively amalgamate digital inquiry, online education, self-regulated learning, and technology-driven assessment in the domain of science education [34; 35].

When these findings are synthesized, a general pattern emerges indicating that SSI, inquiry, blended learning, and scientific literacy are interconnected domains, yet fragmented by varying methodologies. Recent systematic and bibliometric reviews corroborate that, although the conceptual interconnections among these domains are evident, their conceptual and pedagogical integration is still constrained [36; 37]. In other words, there isn't a teaching framework that systematically and operationally brings the four areas together. This pattern indicates a strategic opportunity to create a new learning model that can connect the epistemic, pedagogical, and digital aspects to improve scientific literacy. This is what the SSIBBL model is based on.

2. Identification of research gaps

Bibliometric analysis also uncovered multiple research deficiencies that underscore the necessity for the SSIBBL model. First, while SSI has been extensively examined as an effective learning environment for fostering scientific literacy, critical thinking, and decision-making [38], it is often disconnected from formal inquiry frameworks, thereby underutilizing its integrative capabilities. Second, research on blended learning is rapidly expanding and has demonstrated enhancements in learning engagement, self-regulation, and academic performance [27; 39]; however, there is a paucity of studies that explicitly connect it to socio-scientific reasoning or epistemic practices within the context of SSI. Third, scientific literacy is predominantly regarded as an outcome—illustrated by the PISA framework and SSI-oriented scientific literacy research—rather than as an integral component of a cohesive learning process that explicitly links SSI, inquiry, blended learning, and scientific epistemology [38; 40]. Fourth, few models currently integrate digital inquiry, argumentation, and SSI into a single framework. However, recent studies have shown how important self-regulated inquiry and digital interaction are in science learning modules [41].

Furthermore, bibliographic coupling shows that research on digital inquiry and research on epistemic reasoning grow at the same time, without directly affecting each other. This pattern corresponds with the results of other bibliometric reviews that demonstrate a distinction between research on learning technology and the discourses of NOS and SSI [42; 43]. This necessitates the creation of pedagogical frameworks that integrate advancements in learning technology with the epistemological underpinnings of science education. All of these results lead to one conclusion: even though there is a lot of positive theory behind it, there isn't yet an integrative model that brings together SSI, inquiry, epistemic understanding, and blended learning in a way that makes sense.

3. Conceptual implications toward the SSIBBL model

Bibliometric results show that the SSIBBL model needs to be made. Cluster analysis reveals that SSI, argumentation, and informal reasoning are significant foundations in science education [44; 45], whereas inquiry and blended learning are prominent and expanding pedagogical practices [46]. However, these two groups have not yet been integrated into a unified framework. Thematic evolution indicates a transition in research from concentrated topics, such as argumentation or NOS, to the incorporation of digital technologies and contexts; however, this integration remains incomplete and fails to establish a holistic learning framework [47].

The keyword map indicates that scientific literacy serves as a vital link among SSI, inquiry, and blended learning, consistent with numerous studies that identify SSI as a framework for fostering scientific literacy and scientific citizenship [48]. Nonetheless, no model has effectively enabled this connection. SSIBBL was created because there was a need to bring together these different areas of study into a teaching framework that lets students not only learn about socio-scientific phenomena but also do scientific research with the help of digital technology and a mix of different types of learning environments. SSIBBL bridges the divide between theoretical foundations (co-citation) and current research trajectories (bibliographic coupling), aligning with recent initiatives to create learning models that amalgamate epistemic practices, social science inquiry, and digital technology within a cohesive framework [3; 49].

4. Proposed conceptual model: SSIBBL

The SSIBBL model is an all-in-one teaching framework that links socio-scientific contexts, scientific inquiry processes, epistemic practices, and digital learning tools to help students become scientifically literate [Figure 5]. This method aligns with the perspective that pertinent scientific education in the 21st century should empower students to participate in genuine scientific practices, construct arguments grounded in evidence, and critically engage with digital learning environments [50; 51].

Figure 5 SSIBBL conceptual model

This model has four main parts in its basic idea:

• SSI engagement

Students start learning by looking into a real-world SSI that makes them curious, makes them argue, and makes them contemplate the evidence.

• Inquiry process

Learning advances through the stages of inquiry – formulating questions, gathering data, analyzing evidence, and drawing conclusions – focusing on epistemic practices like argumentation, modeling, and reasoning.

• Blended learning supports

Digital tools like an LMS, multimedia, virtual labs, and online discussion boards help the inquiry cycle by making it easier for students to manage their learning, work together, and do technology-based formative assessments.

• Scientific literacy outcome

Learning outcomes include not only conceptual knowledge but also epistemological understanding, argumentative skill, and the ability to make decisions based on evidence.

The SSIBBL model employs theoretical clusters (argumentation–NOS–literacy) and innovative pedagogical clusters (inquiry–digital learning) to establish a more holistic and cohesive framework than prior methodologies.

5. Practical implications

There are many practical effects of putting SSIBBL into action. This model provides teachers a way to teach that lets them consistently include current issues, technology, and real scientific practices, which is in line with current advice on how to use technology-based SSI in science learning [52]. For curriculum developers, SSIBBL can be a guide for creating a competency-based curriculum that combines scientific literacy, scientific reasoning, and skills for the 21st century. This model enables researchers to evaluate the efficacy of SSI–inquiry–blended learning integration in higher education settings, particularly regarding its influence on scientific literacy, critical thinking, and socio-scientific reasoning. This model also provides institutions with a way to make technology-based learning and blended learning more useful and meaningful.

6. Limitations and future research directions

This bibliometric analysis employs a comprehensive dataset from Scopus; however, it possesses several limitations. First, the data only includes English-language publications, so there may be relevant literature in other languages that hasn't been mapped. This is a common problem in bibliometric studies [17]. Second, machine learning and visualization tools like VOSviewer and Biblioshiny are used to understand thematic relationships. This means that more theoretical review and content analysis are needed to look at the more profound meaning behind the network patterns [53]. Third, the bibliometric study cannot empirically assess the efficacy of the SSIBBL model; thus, experimental and design-oriented research remains necessary to validate and enhance the model.

Future research avenues include (1) the development of tools to measure the impact of SSIBBL on scientific literacy and epistemic practices; (2) classroom experiments to evaluate the model's effectiveness in improving scientific literacy, critical thinking, and socioscientific reasoning; (3) the integration of artificial intelligence (AI) in digital inquiry and learning analytics; (4) the creation of digital data-driven assessments to monitor argumentation and inquiry processes; and (5) comparative studies between SSIBBL and other learning models, such as PBL or hybrid inquiry, across various educational contexts and levels.

CONCLUSION

A bibliometric analysis of 103 articles indicates that research on SSI, inquiry, blended learning, and scientific literacy evolves as four interconnected domains but has yet to be incorporated into a cohesive pedagogical framework. Co-citation networks validate that the literature on science education is grounded in the epistemological principles of argumentation, informal reasoning, and the essence of science, all of which facilitate the advancement of scientific literacy. At the same time, bibliographic coupling shows that new research is moving toward digital inquiry, self-regulated learning, and tests that use technology. These findings collectively reveal an epistemic and pedagogical disparity between the theoretical underpinnings of the field and the trajectory of contemporary research advancements.

This study proposes the SSIBBL model as an integrative framework that unites the SSI context, scientific inquiry processes, epistemic practices, and technology-based pedagogical support to enhance the attainment of scientific literacy. This model addresses the fragmentation in research by offering a structured learning pathway that begins with initial engagement in socio-scientific topics, progresses through the application of inquiry, incorporates blended learning as a digital framework, and culminates in the attainment of scientific literacy as the ultimate goal. SSIBBL not only makes theoretical contributions to the creation of issue-based learning models, but it also points the way for how to combine science and technology epistemology in higher education.

Subsequent research ought to investigate the efficacy of SSIBBL via empirical studies in diverse contexts, create tools to evaluate epistemic practices and scientific literacy in blended settings, and examine the function of AI in augmenting digital inquiry processes. This model has the potential to enhance academic research and offer practical contributions to innovative learning designs that address the requirements of 21st-century education.

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