Bibliometric Analysis of International Smart Learning Environment Research Themes Based on CiteSpace: Postprint

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Abstract

[Purpose/Significance] This study investigates the origin and development status of the international smart learning environment field, providing a reference for further improving research practices in this domain. [Method/Process] Using 402 articles collected from the Web of Science database as the data source, and employing the bibliometric tool CiteSpace software, co-occurrence and co-citation analyses were conducted on key literature, institutions, journals, and authors in the smart learning environment field. [Results/Conclusions] The findings reveal that smart learning environments originate from changes in learning environments driven by technological development; traditional learning environments can no longer meet the diverse needs of "natives" in the modern information age, necessitating the updating of learning environments to make student learning more efficient and convenient. Simultaneously, smart learning environments emphasize a student-centered approach, enhancing the intelligence of learning environments to make student learning more effective; consequently, different scholars have constructed numerous smart learning environment models. Currently, the construction of new teaching models and evaluation systems, along with intelligent cross-media learning environments, represents one of the future development trends in the smart learning environment field.

Full Text

Thematic Quantitative Analysis of International Smart Learning Environment Research Based on CiteSpace

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Abstract

[**Purpose/Significance**] This study examines the origin and development status of the international smart learning environment field, providing a reference for further improving related research and practice in this domain. [**Method/Process**] Using 402 documents collected from the Web of Science database as the data source, this paper employs the bibliometric tool CiteSpace to conduct co-occurrence and co-citation analyses of key literature, institutions, journals, and authors in the smart learning environment field. [**Result/Conclusion**] The analysis reveals that smart learning environments emerged from technological transformations of learning environments. Traditional learning environments can no longer meet the diverse needs of modern information age "digital natives," necessitating updated environments to make student learning more efficient and convenient. Smart learning environments emphasize a student-centered approach, enhancing learning effectiveness through increased environmental intelligence. Consequently, scholars have constructed numerous smart learning environment models. The development of new teaching models, evaluation systems, and intelligent cross-media learning environments represents a key future trend in this field.

Keywords: smart learning environment; hot spot; knowledge mapping; CiteSpace

Introduction

In recent years, technology has transformed various fields, and learning environments have changed accordingly within this broader social context. Smart learning environment research has become a prominent focus, emphasizing learner-centered design supported by technology. These environments provide learning resources based on learner characteristics, record and evaluate learning outcomes, and help teachers analyze student learning situations to implement targeted instructional measures. This approach facilitates enhanced communication between teachers and students while enabling personalized instruction tailored to individual learners.

The development of smart learning environments has now reached a stage where artificial intelligence imposes further requirements, and new generations of "digital natives" demand higher standards for their learning environments. Currently, few studies have systematically examined the status and developmental trajectory of the international smart learning environment field. Therefore, this paper utilizes CiteSpace to analyze the main themes and current state of international smart learning environment research, visually presenting the progress and hotspots in this area. This provides valuable references for constructing smart learning environments under artificial intelligence and for further improving research and practice in this domain.

Data Collection and Methodology

This study retrieved data in July 2021 from the Web of Science Core Collection database using the search formula: TS=(smart or intelligent AND "learning environment" or "classroom"). The search yielded 402 documents, which were exported with "full record and cited references" and analyzed using Dr. Chaomei Chen' s visualization tool CiteSpace. Node types were sequentially set as cited references, institutions, authors, keywords, etc., to examine cited literature, institutional distribution, and author distribution in international smart learning environment research through co-occurrence and co-citation analyses. Statistical diagrams with annual rings and other visual forms were used to intuitively display classic literature and evolutionary paths in the research field, revealing research hotspots and development trends.

Publication Volume Analysis

Publication volume and citation counts reflect the progress of a research field during a certain period. As shown in [Figure 1: see original paper], the first document in the smart learning environment field appeared in 1968, after which the field remained stagnant. Publication numbers only began to gradually increase at the end of the 20th century, following former U.S. Vice President Gore' s proposal of the "Digital Earth" concept, which subsequently led to the concept of digital learning environments. However, research was still in its infancy, with limited literature output.

After 2010, both publication and citation numbers grew steadily, with annual publications exceeding 10 and annual citations surpassing 50. In 2018, publications exceeded 55, and in 2019, citations exceeded 350, indicating increased attention and recognition from the academic community.

Important Literature Analysis

3.2.1 Highly Cited Literature Analysis Citation analysis helps identify research hotspots during specific periods. Using CiteSpace, we conducted a co-citation analysis (Cited Reference) with a time threshold of 2011-2020 and a time slice of 1 year, generating a co-citation map shown in [Figure 2: see original paper]. In this figure, circular nodes represent documents—larger nodes indicate more citations, while smaller nodes indicate fewer citations. Nodes appear as annual rings where colors represent years and ring thickness represents citation frequency. Dark outer circles indicate high centrality, suggesting key roles in research development, while dark central fillings indicate strong burstiness, where citation volume suddenly increased during a certain period, signaling shifts in research hotspots and directions [1].

[Figure 2: see original paper] Smart Learning Environment Research Co-citation Literature

Combining node size and centrality reveals the most frequently cited documents in this field, as high citation counts indicate widely recognized research conclusions. lists the top five most cited documents.

** Highly Cited Literature in Smart Learning Environment Research**

No.	Frequency	Author	Year	Source Publication
1		Aguilar G. J.	2015	Conceptual Design of a Smart Classroom Based on Multiagent Systems, P INT C ART INT ICAI, V0, P471
2		Hwang G. J.	2014	Definition, framework and research issues of smart learning environments - a context-aware ubiquitous learning perspective, Smart Learning Environments
3		Sanchez M.	2015	A Smart Learning Environment based on Cloud Learning, International Journal of Advanced Information Science and Technology
4		Sanchez M.	2015	Basic features of a Reflective Middleware for Intelligent Learning Environment in the Cloud (IECL), 2015 Asia-Pacific Conference on Computer Aided System Engineering
5		Zhu Z. T.	2016	A research framework of smart education, Smart Learning Environments

J. Aguilar et al. [2] constructed a multiagent system for smart classrooms, describing different components and their attributes. They proposed two types of agent frameworks—one for software components and another for hardware components—and provided application examples for these frameworks in smart classroom devices and software.

G. J. Hwang et al. [3] defined smart learning environments from a context-aware ubiquitous learning perspective, viewing them as technology-supported environments that provide appropriate support at the right time based on learners' different needs. They proposed standards and a framework for smart learning environments to address design and development issues, and identified future challenges: researchers may propose new pedagogical ideas for smart learning environments, develop new frameworks using emerging technologies, and address ethical issues in educational technology applications.

M. Sanchez [4] detailed the architecture of AMICL, a reflective middleware for smart learning environments based on cloud learning. The paper discussed components enabling cloud computing management processes and provided examples of using this middleware to deliver learning analytics services in the cloud. Results showed that both student data and learning environment data were processed to optimize the learning process.

M. Sanchez et al. [5] introduced IECL (Intelligent Environment for Cloud-Learning), which combines available educational resources from cloud resources with objects in intelligent environments to adapt learning to students' learning styles. They discussed the multi-layer architecture of IECL and demonstrated its performance through applications in smart classrooms, suggesting future work should focus on implementing IECL models. The authors believe IECL will bring significant benefits to learning, as smart learning environments can determine when users access these cloud learning resources to adapt to students' learning styles.

Z. T. Zhu et al. [6] discussed the definition of smart education and proposed a four-layer framework for smart pedagogy: class-based differentiated instruction, group-based collaborative learning, individual-based personalized learning, and crowd-based generative learning. They also identified ten key functions of smart learning environments and a three-layer architecture for smart learning, enumerating benefits and challenges of smart education. They noted that interconnected learning services and experiences between smart cities and smart education systems represent future research priorities.

3.2.2 Burst Citation Analysis Burst citations refer to sudden increases or decreases in citation rates during a certain period, indicating that a topic has suddenly gained or lost popularity. Literature with strong burstiness plays an important role in reflecting changes in research hotspots.

As shown in , P. Mikulecký et al.' s literature experienced citation bursts during 2015-2016. Their article examined the latest technological developments in ubiquitous learning and context-aware domains based on existing research on smart offices and other smart workplaces, highlighting how these smart workplace research outcomes could inform the development of new technologies and smart learning environments for learning [7]. This indicates that developing smart learning environments within smart workplaces attracted attention during this period.

** Burst Citation Literature in Smart Learning Environment Research**

Start Burst	End Burst	Literature
2015	2016	P. Mikulecky, 2012, Divai 2012: 9th International Scientific Conference on Distance Learning in Applied Informatics, V0, P213
2015	2016	J. Aguilar, 2015, P INT C ART INT ICAI, V0, P471
2015	2016	M. Sanchez, 2015, INT J ADV INFORM SCI, V39, P39

During 2016-2018, J. Aguilar et al. [2] and M. Sanchez et al. [4] experienced citation bursts. The former constructed a smart classroom and proposed two types of agent frameworks, while the latter introduced the IECL concept, combining cloud resources with intelligent environment objects to adapt learning to student learning styles. This indicates that smart classroom construction, as an important research direction in smart learning environments, gained attention during this period, with scholars proposing different ideas to better promote student learning.

3.2.3 High Betweenness Centrality Citation Analysis Literature nodes with high betweenness centrality can connect different clusters, enabling researchers to more clearly identify distinct clusters [8]. As shown in , G. J. Hwang et al. [3] have the highest betweenness centrality (0.18), introducing the definition and standards of intelligent learning environments from a context-aware ubiquitous learning perspective and proposing a framework to integrate various emerging technologies with smart learning environments. P. Mikulecký et al. [7] examined the latest technological status in ubiquitous learning and context-aware domains based on smart workplace research, highlighting possibilities for developing new technologies and smart learning environments for learning. J. Aguilar et al. [9] reviewed agent-based industrial automation research, surveys, results, and theoretical foundations, proposing three agent-based computational models responsible for control, supervision, and planning in industrial automation processes, and subsequently three "multi-agent systems." Y. L. Kim et al. [10] proposed an intelligent classroom system composed of emotion sensing, deep learning-based emotion recognition, and real-time mobile cloud computing components that can make real-time adjustments or corrections based on non-verbal behaviors (e.g., gestures) to provide real-time suggestions to teachers. However, challenges remain: integrating these technologies into overall system design, ensuring algorithm adaptability for real-time execution, and quantifying effective educational variables for algorithms. R. Koper et al. [11] proposed the Human Learning Interface (HLI) concept—a set of interaction mechanisms related to learning through which humans contact the external world—to meet the requirement of "better and faster learning." HLI can be used to control, stimulate, and facilitate learning processes, and analyzing HLI can help develop effective smart learning environment systems.

** High Betweenness Centrality Literature in Smart Learning Environment Research**

Rank	Betweenness Centrality	Literature
1	0.18	G. J. Hwang, Definition, framework and research issues of smart learning environments - a context-aware ubiquitous learning perspective, Smart Learning Environments
2	0.17	P. Mikulecký, Smart Environments for Smart Learning, Divai
3	0.14	J. Aguilar, Sistemas MultiAgentes y sus Aplicaciones en Automatizacion Industrial, Universidad de Los Andes
4	0.13	Y. L. Kim, Towards Emotionally Aware AI Smart Classroom: Current Issues and Directions for Engineering and Education, IEEE Access

Rank	Betweenness Centrality	Literature
5	0.12	R. Koper, Conditions for effective smart learning environments, Smart Learning Environments

Through important literature co-citation analysis, this study identifies influential English literature, representative research, literature indicating shifts in research hotspots, and literature serving as connecting nodes in the smart learning environment field, thereby revealing the origin, development trajectory, and important research areas. Smart learning environments originated from changes in learning environments driven by technological development. Traditional learning environments could no longer meet the diverse needs of modern "digital natives," requiring updated environments to make student learning more efficient and convenient. In the early stages of research, G. J. Hwang, R. Koper, and other scholars focused on defining smart learning environments and their characteristics from macro perspectives, proposing various framework design ideas. However, with the development of information technology and society, scholars began shifting toward physical environment intelligence applications—integrating emerging technologies into learning environments to promote their improvement and development. J. Aguilar, M. Sanchez, Z. T. Zhu, Y. L. Kim, and others have combined emerging technologies to propose new concepts for updating smart learning environments while conducting construction and empirical research on new smart classroom components. In the future, as learning analytics and artificial intelligence gradually integrate with smart learning environments, new conceptions and models of smart learning environments will become research hotspots.

Important Institution Analysis

Examining institutional collaboration reveals the research strength and distribution in the international smart learning environment field. Using CiteSpace to analyze research institutions, [Figure 3: see original paper] shows that universities are the main research forces, though their research is relatively dispersed. The five most frequent institutions are Central China Normal University, University of Los Andes, Foundation for Research and Technology-Hellas (FORTH), Universidad Técnica Particular de Loja, and University of Hradec Králové, indicating these institutions have the greatest influence. The five institutions with the highest burst rates are University of Hradec Králové, University of Los Andes, Universidad Técnica Particular de Loja, SUNY College at Oswego, and Central China Normal University, suggesting these institutions' research findings have received widespread attention in recent years.

Important Journal Analysis

Co-citation analysis of journals reveals knowledge sources in the smart learning environment field. The five most frequently cited journals are Computers & Education (Freq=73), Lecture Notes in Computer Science (Freq=59), Educational Technology & Society (Freq=47), Computers in Human Behavior (Freq=41), and Thesis (Freq=33). The five journals with highest betweenness centrality are Lecture Notes in Computer Science (Centrality=0.21), Educational Technology & Society (Centrality=0.17), Computers & Education (Centrality=0.14), Thesis (Centrality=0.14), and Computers in Human Behavior (Centrality=0.13). The most recent trending journals include International Journal on Artificial Intelligence Tools (Burst=3.19), Knowledge-based Intelligent Information and Engineering Systems (Burst=3.14), Cognitive Science (Burst=3.05), User Model User-adap (Burst=3.08), and Educational Technology & Society (Burst=2.91), as shown in [Figure 4: see original paper].

Important Author Analysis

Core authors in a field possess certain academic influence. Using CiteSpace for co-citation analysis of authors in the smart learning environment field, the five most frequently cited authors are J. Aguilar (Freq=9), A. Leonidis (Freq=5), H. H. Yang (Freq=4), J. Cordero (Freq=4), and B. Klimova (Freq=3). J. Aguilar, J. Cordero, and A. Leonidis are important researchers in smart classrooms within the smart learning environment field, describing software and hardware components and proposing different systems and frameworks to update and improve smart classrooms from various aspects, enabling them to better promote student learning. H. H. Yang and B. Klimova primarily develop and research smart learning environment tools, conducting quantitative and qualitative analyses of relationships between smart learning environments and teachers' and students' self-efficacy. The five authors with strongest burstiness are M. Antona (Burst=1.53), B. Klimova (Burst=1.49), J. Cordero (Burst=1.34), J. Aguilar (Burst=3.09), and H. H. Yang (Burst=1.80), indicating they play important roles in knowledge dissemination in the smart learning environment field, as shown in [Figure 5: see original paper].

Origin and Development of Smart Learning Environments

Through co-occurrence and co-citation analyses of collected literature using CiteSpace, important literature nodes reveal not only the origin and development of smart learning environments but also outline research hotspots and future trends.

Origin of Smart Learning Environments

For many years, learning environments consisted solely of blackboards and chalk, limiting many teaching activities. However, since the 1990s, rapid information technology development has swept through all aspects of society, with various elements of learning environments interacting with technology to different degrees. The evolution of the times has shifted modern educational goals from passive student learning to active learning with critical thinking skills. Consequently, new generations of "digital native" learners, who have been exposed to various electronic devices from childhood, possess different thinking patterns and stronger innovation capabilities than their parents. To cultivate students' inquiry-based active learning habits and enable them to reach their full potential in learning environments, changing learning environments and constructing smart learning environments has become imperative. Thus, smart learning environments emerged as an advanced form of digital learning environment.

Different scholars have explored and developed the concept of smart learning environments in depth. K. W. Chin et al. [12] early proposed that smart learning environments are learner-centered environments based on information and communication technology applications. G. J. Hwang et al. [13] further developed this concept, viewing smart learning environments not only as technology-supported environments but also as systems that can determine learning effectiveness by analyzing learners' performance and their online and physical environments. Later, Huang et al. [14] argued that smart learning environments are advanced digital environments that enable context awareness, recognize learner characteristics, provide adaptive learning resources and convenient interaction tools, automatically record learning processes, and evaluate learning results. The concept of smart learning environments has gradually become enriched.

As shown in [Figure 6: see original paper] and [Figure 7: see original paper], during 1994-2007, keywords such as intelligent tutoring systems, systems, digital learning, and learning environment emerged, with strong co-citation phenomena in the intelligent tutoring systems cluster. The emergence of intelligent tutoring systems and digital learning changed students' learning environments, enabling learning anytime and anywhere beyond traditional classrooms and libraries. Information technology integration into society also diversified learning methods, marking the beginning of learning environment transformation.

Development Trajectory

In recent years, smart learning environments have become a key research focus, attracting scholars worldwide. The co-occurrence map for 2008-2014 in [Figure 6: see original paper] shows that keywords such as education, smart learning environment, smart classroom, and technology received attention, with the most bursty keywords including internet, smart classroom, and smart learning environment. [Figure 7: see original paper] reveals that from 2008-2015, clusters including education, learning technology, smart classroom, and evaluation showed active co-citation, indicating that concepts, characteristics, and software/hardware facilities of smart classrooms and smart learning environments attracted academic discussion. Initially, learning environments merely added some interactive whiteboards, but today, the rich development of multiple technologies has diversified and specialized equipment in smart learning environments. During this transformation, works by D. M. Xu et al. [15], J. Dooley et al. [16], C. C. Hsu et al. [17], F. Yang et al. [18], N. Gligoric et al. [19], and K. Maria et al. [20] served as critical connecting points, as researchers began considering how to conduct better education in these new environments, proposing many ideas and perspectives.

Key research directions in the smart learning environment field have emerged from the literature. First, different scholars have introduced various emerging technologies into smart learning environments. C. C. Hsu et al. [21] integrated sensor technology to develop a reading concentration monitoring system for use with e-books in intelligent classrooms, detecting student learning behaviors by capturing various physiological signals to help teachers understand student reading concentration in classroom settings. Y. Kim et al. [10] used real-time sensing and machine intelligence to make real-time adjustments or corrections based on students' non-verbal behaviors (e.g., gestures) to provide real-time suggestions to teachers. Pan et al. [22] introduced speech processing technology, using suspended microphones to achieve zero-intervention classroom data collection, designing sound wave recognition and speech recognition algorithms to identify speakers and record classroom discussion processes, with real-time feedback to students and teachers.

Second, different scholars have designed various smart learning environment models. Y. Kim et al. [23] designed a cloud computing-based intelligent learning environment model providing context-aware systems that collect and analyze learner behaviors to deliver personalized learning services. Q. H. Zhang et al. [24] created an intelligent learning environment model through context awareness and data mining methods that can predict learners' potential learning needs, collect and analyze real-time learning data, understand learner needs, and customize resources accordingly.

Future Development Trends

Artificial intelligence is developing rapidly and now plays an important role in smart learning environments. In recent years, keywords such as learning analytics, Internet of Things, models, and flipped classroom show prominent co-occurrence, with flipped classroom, learning analytics, technology, and Internet of Things among the top 10 bursty keywords. After 2015, clusters including smart learning environment, models, and problem-solving models have shown active co-citation. The cluster analysis timeline ([Figure 8: see original paper]) reveals dense co-citation phenomena in smart classroom, smart learning environment, and learning technology clusters, indicating influential and critical nodes in these clusters that have been extensively studied. In summary, as technology continues to develop, the integration between technology and smart learning environments deepens, with learning analytics, big data, and the Internet of Things connecting with smart learning environments, and diverse interaction technologies and data processing technologies supporting smart learning environment construction from multiple dimensions.

Teaching models, models, and intelligent cross-media learning environment construction in smart learning environments under AI influence have become important research directions. As AI technology continues to develop, learning environments will be continuously reconstructed, with elements in smart learning environments constantly updated. Building new smart learning environments and improving them comprehensively represents a major trend in current development.

(1) Strong Technical Support for Teaching and Learning
Future development will prioritize intelligent cross-media environment construction. In recent years, scholars have dedicated themselves to making learning environments smarter, applying various new cross-media technologies to build smart learning environments, enriching human interaction with cross-media content, helping teachers and students interact in real time, and obtaining open educational resources promptly. In the future, with the rapid development of the information age, diverse learning tools will continue to be applied in smart learning environments with greater specificity and personalization. For example, visual analysis of data collected through online education platforms and intelligent education assistants can deeply mine learner information, providing teaching references for teachers and learning suggestions for learners. Wearable devices can help learners expand their interaction channels. Through interconnection among multiple devices and platforms, various technologies can fully play their roles in smart learning environments, injecting new vitality into them [25] and aligning better with contemporary educational development visions.

(2) Real-World Problems Driving Teaching Models
As environmental construction deepens, teaching models in smart learning environments have become another research trend. The emergence of increasingly practical problems (e.g., teaching activity implementation) indicates a shift toward micro-level research in smart learning environments. Continuously accumulating evaluation systems and teaching models in practice lays foundations and provides reference directions for future related research.

Conclusion

This study used CiteSpace software to conduct co-occurrence and co-citation analyses of smart learning environment literature collected from the Web of Science Core Collection, clearly revealing the origin, development trajectory, and trends in this field. The study found that smart learning environments originated from technological transformations of learning environments. Traditional learning environments could no longer meet the diverse needs of "digital natives," necessitating updated environments for more efficient and convenient student learning. The concept and characteristics of smart learning environments have undergone multiple refinements, but new elements continue to emerge with the times. Different technologies in different periods update smart learning environments and smart classrooms, generating a series of smart learning environment models. In recent years, rapid AI development has profoundly impacted smart learning environments, making research on new smart learning environment teaching models and evaluation systems, as well as intelligent cross-media learning environment construction, future development trends.

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Author Contributions

Xu Xinfei: Conducted literature search, data analysis, and paper writing.
Deng Guomin: Revised the manuscript and provided improvement suggestions.

Note: Figure translations are in progress. See original paper for figures.