AI-Enabled Learning Engagement Assessment for Smart Classrooms: Applications, Trends and Opportunities

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Abstract: The swift progress in Artificial Intelligence (AI) technology has significantly highlighted the role of smart classrooms in modern educational contexts. Despite this development, there remain notable challenges in the automatic assessment of students' engagement within smart classroom environments. To delve deeper into the historical context and trends regarding the evaluation of learning engagement, this study meticulously gathered and analyzed a substantial body of literature, comprising 1,281 publications indexed in the Social Sciences Citation Index (SSCI). These records, spanning from January 1, 1991, to October 1, 2023, were sourced from the Web of Science core database utilizing the search term "Evaluation of learning engagement." To visually interpret and map the findings, CiteSpace 6.2.R5 was employed to examine the volume of relevant research, the countries contributing to it, affiliated institutions, keyword correlations, temporal trends, and cited references. The analysis reveals a burgeoning interest in applying AI technologies to the evaluation of learning engagement within smart classrooms. Over the span of three decades, the evaluation of learning engagement has experienced distinct phases of evolution, categorized into three primary periods: the embryonic stage from 1991 to 2008, the steadily developing phase between 2009 and 2016, and the rapid growth period from 2017 to 2023. During this timeframe, research output has been notably higher in the United States, Australia, and Canada, contrasting with Japan, which has contributed comparatively fewer publications. Among the institutions, the University of Toronto and the University of Sydney emerged as the most frequently cited, while the journal Computers Education garnered the highest impact factor in this field. The dominant research focus within this domain primarily revolves around defining and measuring learning engagement, examining its correlation with learning outcomes, identifying influential factors, and assessing various evaluation strategies. Furthermore, the most cited works concerning "Evaluation of learning engagement" predominantly explore themes related to motivation and engagement in online learning contexts, particularly how gamification affects student motivation and engagement in Massive Open Online Courses (MOOCs).

Keywords: Artificial Intelligence; Learning Engagement Evaluation; CiteSpace

1. Introduction

In the traditional teaching model, the assessment of learning participation mainly relies on the subjective judgment of teachers and self-assessment by students. However, this assessment method has some problems, such as subjectivity, time limitations, and limitations on abilities. Therefore, how to scientifically, objectively, and quantitatively assess learning participation has become an urgent problem in education today. The intelligent classroom, as a teaching model with artificial intelligence technology at its core, achieves precise guidance for personalized learning student behavior data. It can also assess learning participation in a scientific, objective, and quantitative manner. With its characteristics of personalization, interactivity, and real-time feedback, the intelligent classroom has changed the traditional classroom education system. Assessing students' learning participation is of great significance for understanding their learning status, providing personalized teaching, and optimizing the allocation of educational resources.

In the smart classroom, AI technology can enhance the evaluation and improvement of learning engagement, providing educators with more accurate guidance and support. With the help of AI technology, it is easier to collect and analyze various types of data, which improves the application range and level of smart classroom technology. Some researchers combine students' engagement in the classroom with related data such as notes and homework records and conduct structured analysis based on AI technology to effectively evaluate student engagement. For example, Wang et al. developed an AI-based algorithm for learning engagement assessment, which evaluates student engagement by analyzing data such as student notes, classroom images, and audio [1]. AI-powered smart classroom learning engagement assessment can help teachers better understand students' learning status and performance, enabling them to make targeted adjustments and improvements more quickly, thus improving teaching quality and effectiveness. For example, Ünal et al. studied a learning engagement assessment algorithm based on student behavior, combining computer vision technology and machine learning methods to accurately assess student engagement, helping teachers to timely identify student problems and difficulties and improve teaching effectiveness [2]. AI technology not only improves the accuracy and precision of assessment but also helps educational institutions better explore the analysis and application of classroom data, promoting further development of smart education.

This paper uses CiteSpace (6.2.R5) software as a bibliometric tool to search for literature on the evaluation of AI-enhanced classroom learning participation in the SCI-E and SSCI databases. Additionally, it conducts analyses such as keyword co-occurrence, vocabulary perspective, and citation links using CiteSpace 6.2.R5 to showcase the current status and trends in related research.

2. Materials and Methods

2.1 Data Collection

To enhance the guidance and authority of research on evaluating student engagement in smart classrooms, we selected the Web of Science (WOS) core collection database, SCI-E, and SSCI as sample data sources. The search topic was set as "Evaluation of learning engagement". The literature type browsed on WOS was set as "Article", and a total of 1281 papers were retrieved (as of October 1, 2023). According to the retrieved literature, research on the evaluation of student engagement and the empowerment of artificial intelligence in smart classrooms began in 1991 (Earl A. Alluisi, 1991). Therefore, this study chose the time range from 1991 to 2023, and each article includes information such as authors, institutions, keywords, abstracts, and publication dates.

2.2 Research Pathways

This study used CiteSpace 6.2.R5 to conduct a visual analysis of the literature data on student engagement assessment in AI-empowered smart classrooms. It adopted a mixed research method combining bibliometrics. The CiteSpace software utilizes methods such as co-citation analysis theory and pathFinder algorithm to quantify the literature in specific fields, aiming to identify the key pathways and knowledge turning points in the evolution of the disciplinary domain. Simultaneously, it creates a series of visual graphs to analyze the forefront of disciplinary development.

3. Analysis of Research Results

3.1 Annual Distribution of the Number of Studies

Through an annual analysis of the quantity of literature, it is possible to demonstrate the variation of research quantity over time in a specific field. This study proposes a polynomial regression estimation equation based on the year of publication and the number of publications:

$$y=0.1896x^2-796.5232x+667881.9 \quad (1)$$

The goodness of fit =86.42%, Based on the retrieved literature, we have created a yearly graph (Figure 1) depicting the evaluation of student engagement in an AI-empowered smart classroom. The research quantity related to the evaluation of student engagement in an AI-empowered smart classroom indicates an upward trend, indicating that this research has garnered extensive attention in the academic community.

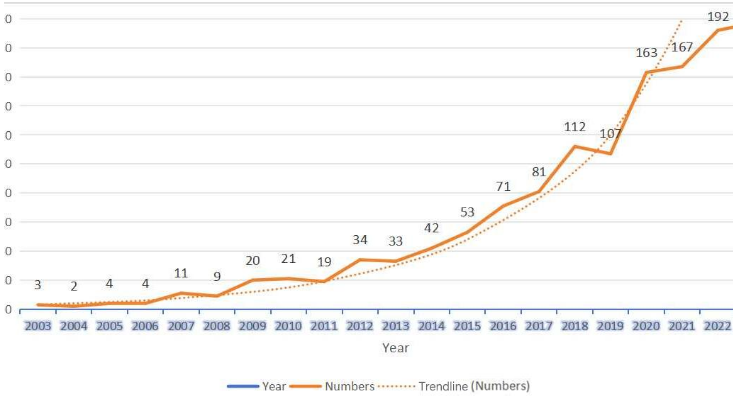

Figure 1. Research Annual Publication Count

Emerging Stage (1986-2008): From the growth trend of data. Henninger and Hurlbert proposed seven principles of undergraduate education [3]. Currently, student involvement is commonly defined as the degree of emotional reaction generated by students during specific learning activities. Chickering and Gamson proposed a method called the participation tracking approach to study student non-participation by analyzing students' performance on tests. This method models the difficulty of questions, students' response time, and the accuracy of their answers based on Item Response Theory [4]. This research indicates that modeling both students' proficiency and participation levels can better estimate their level of involvement compared to models that ignore individual proficiency differences.

Steady Development Phase (2009-2016): During this period, the research quantity steadily increased, with an average annual publication output of 36.63 articles. Researchers constructed a large number of classroom engagement sample libraries and conducted in-depth studies. They identified student engagement levels using innovative tracking techniques, primarily through facial expression recognition. To more accurately identify student engagement levels, Whitehill et al. organized and established a dataset of participant interaction behaviors [5]. Bosch et al. built a game interaction behavior database, using the BROMP observation system to observe students' emotional states during playground interactions [6]. This dataset defined four levels of labels, with each emotional state divided into extremely low, low, high, and extremely high levels. The annotation process involved crowdsourcing and then correlating the annotations with a golden standard created by psychological experts. These sample libraries provide important sources of data for educational research, aiding in the improvement of teaching and optimization of learning environments.

Rapid Development Phase (2017-2023): During this stage, the number of literature greatly increased, with an average annual publication volume of 145.57 articles, four times higher than the previous phase [7]. These two sets of features were combined with heart rate data to establish a machine-learning model for predicting learning engagement. The experimental results showed that among different feature inputs, the facial action unit features performed the best, and combining different features resulted in optimal performance. Yun et al. proposed to use deep learning for feature extraction and classification of image data [8]. They also overcame the problem of insufficient training data. Additionally, they introduced a new spatiotemporal dynamic modeling layer. During the COVID-19 pandemic, various universities have adopted online teaching methods. However, long hours of online learning inevitably become monotonous, causing students to lose interest and become anxious, which in turn affects their learning performance. Therefore, evaluating students' engagement in online learning has become an urgent matter. Hayashi et al. introduced a Bidirectional Long-term Recurrent Convolutional Network to identify online learning engagement in videos [9]. In conclusion, extracting features through deep learning methods can provide a more objective and accurate assessment of engagement, as well as deeper insights and guidance for educational research and teaching practice.

3.2 Analysis of Important Publications

Quantitative statistics show that 1281 papers related to the evaluation of participation in AI-enabled intelligent classroom learning have been published in over 700 journals. The top ten journals include Computers Education Academic Medicine, PLOS ONE, Medical Education, Medical Teacher, JAMA-J AM MED ASSOC, Lancet, Comput Hum Behav, Bmj-Brit Med J, and Bmc Med Educ. Among them, 144 articles were published in the top-tier journal JAMA-J AM MED ASSOC, with an impact factor of 120 or higher. From this, it can be seen that the academic community is very enthusiastic about research in this field.

3.3 Analysis of Publications Countries and Institutions in the Field of Evaluation Study of Learning Engagement in AI-Enabled Smart Classrooms

3.3.1 Country Analysis

We extracted the countries that have research literature on assessing student engagement in AI-enabled smart classrooms and filtered out the countries with more than 100 publications by using CiteSpace 6.2.R5. The United States has the highest number of publications, reaching 880 articles, accounting for 68.75% of the total. China has published a total of 100 articles, ranking high overall and leading research in this field. Scholars from both domestic and international institutions have conducted productive explorations and research on the automatic assessment (or recognition) of classroom engagement. Among them, the use of emotional data such as facial expressions, body postures, and actions, based on computer vision technology and machine learning methods, has gradually become the mainstream technological approach in this field. The University of Science and Technology of China have made valuable explorations and research in the direction of intelligent assessment of learning engagement based on facial expressions, body postures, and actions.

To investigate the collaborative dynamics among various nations, we employed CiteSpace 6.2.R5 for a comprehensive national analysis of published academic papers and subsequently produced a graph, as illustrated in Figure 2. In this graph, the nodes, totaling 122, depict individual countries, while the connections between these nodes, amounting to 552 edges, represent the cooperative relationships that exist among them. The dimensions of the nodes serve a dual purpose; they not only reflect the volume of published papers from each country but also signify their interconnections with other nations in terms of academic collaboration.Upon examining the graph, it is apparent that the United States leads in the publication of academic papers, boasting a total of 880 contributions. This is significantly higher than the following countries, which include the United Kingdom with 251 papers, Australia with 227, Canada with 156, and China with 100. Notably, the United Kingdom stands out due to its exceptional centrality score of 7.81. This score suggests that the UK plays a crucial role in guiding and influencing research related to the evaluation of student engagement in AI-enabled smart classrooms. Such findings underscore the United Kingdom's prominence in this field and highlight its strategic position within the international academic community.

Figure 2. National Collaborative Network Mapping for Student Engagement Assessment Research in AI-Enabled Smart Classrooms

3.3.2 Institutional Analysis

The distribution of research from different institutions was analyzed to identify the top nine research institutions that have published over 20 papers on student engagement evaluation in AI-empowered smart classrooms from 1991 to 2023 by using CiteSpace 6.2.R5. The University of Toronto in Canada has the highest number of publications, with a total of 33 papers. Among these nine institutions, six universities are from the United States, which is also the country with the highest number of publications. These universities are the University of Colorado Boulder, the University of Michigan, Harvard Medical School, Johns Hopkins University, the University of North Carolina, and the University of California, Los Angeles. Therefore, it can be said that American schools show a strong interest in research in this field.

A graph (Figure 3) illustrating and analyzing the publication output of various institutions was constructed by using CiteSpace 6.2.R5. The graph reveals that there are 439 nodes(N), with 544(E) connections between them, resulting in a network density (D) of 0.0057. The node representing the University of Michigan is the largest, having published 28 articles. However, this is due to the University of Michigan's close collaboration with other institutions, which accounts for its larger node size.

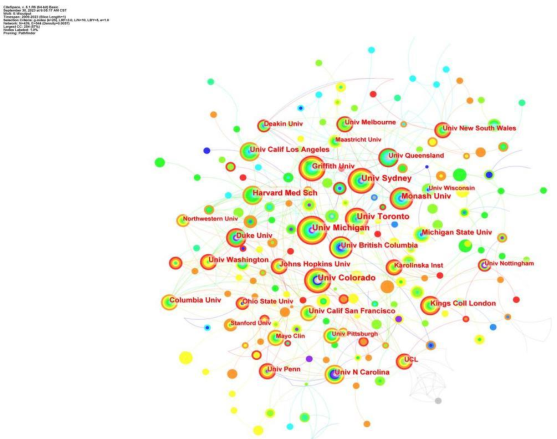

Figure 3. Mapping Institutional Collaboration Networks for Student Engagement Assessment Research in AI-Enabled Smart Classrooms

3.4 Keyword Network Graph Analysis

Keywords can help us understand the research focus and areas of interest in a particular field quickly. A keyword co-occurrence map (Figure 4) was generated by using CiteSpace 6.2.R5. The size of the nodes is proportional to the frequency of keyword occurrence, reflecting the research focus. In the research on evaluating student engagement in AI-enabled smart classrooms, keywords with frequencies exceeding 100 include education, engagement, student, impact, and performance. Additionally, keywords such as engagement, deep learning, and interactive learning showed a burst growth index of 4 or above, indicating a significant increase in research on these keywords in a certain period.

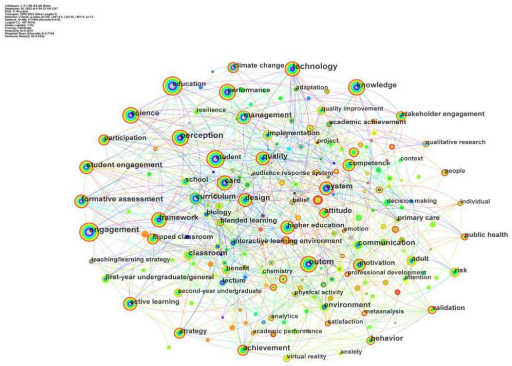

Figure 4. Keyword Co-occurrence Mapping for Student Engagement Assessment Research in AI-enabled Smart Classrooms

In the research on keyword co-occurrence, engagement and outcome measure are concepts that appeared relatively early. Before 2008, research on assessing student engagement in AI-empowered smart classrooms was still in its early stages. During this period, researchers began to pay attention to student participation in learning and developed more teaching strategies that involved student interaction, representing the initial exploration of student classroom engagement research. From 2009 to 2016, topics such as blended learning [10], interactive learning [11], and distance learning [12] emerged, indicating that research was becoming more in-depth and the field of student classroom engagement was expanding. Researchers began to introduce interactive learning, blended teaching, and other methods, which have improved student classroom participation and learning efficiency. In recent years, keywords such as artificial intelligence, deep learning, student-centered learning, learning engagement, smart classroom, educational technology, and big data have been appearing more frequently, indicating a shift in focus in teaching from teacher-centered to student-centered, greatly enhancing classroom interaction with students. The deep learning-based engagement identification methods proposed by scholars both domestically and abroad have demonstrated significant performance in representing the visual patterns of engagement behavior.

3.5 Analysis of Important Authors

An analysis of the authors involved in the assessment research of student engagement in AI-enabled smart classrooms was conducted using CiteSpace 6.2.R5, and the top eight authors with a higher number of publications were selected (Table 1). The results indicate that there is relatively little variation in the publication volume among the authors, involving over 500 authors. Among them, Haidet, P is the scholar with the highest number of published articles, with a total of 10 papers, while the remaining authors have generally published around 5 to 8 papers, which is comparatively fewer.

Table 1. Top 8 Authors in Terms of Publications

Authors	Number of Articles
Haidet, P	10
Palermo, Claire	8
Rees, Charlotte E	7
Nguyen, Van N B	7
Sharma, Kshitij	7
Virvou, Maria	6
Griffith, Krystal	5
Richards, B	5

To visually analyze the collaborative relationships among authors, we utilized the CiteSpace 6.2.R5 visualization tool to generate a network graph illustrating author collaborations (Figure 5). The time range was set from 1991 to 2023, with a time slice of 1 year. By employing this software, we successfully generated an author collaboration network graph to evaluate student engagement in AI-enabled smart classrooms. Remarkably, the graph comprises 534 nodes, exhibiting a connectivity coefficient of 440 and a density of 0.0031. It is evident from the graph that the nodes are relatively dispersed, with only a few forming clusters. This observation suggests limited collaboration among the authors and the absence of a central team. In future studies, authors should strive to enhance their collaboration to obtain mutual benefits.

3.6 Analysis of Highly Cited Literature

The highly cited references in this study cover comprehensive research themes in multiple disciplinary fields, such as student motivation, engagement, and classroom environment.

(1) Student learning motivation and engagement: This field of articles has the highest AI-enabled smarter citation counts, covering aspects such as student autonomous learning, learning interest, cognition, emotions, and behavior.

(2) Classroom environment and learning engagement: This field of articles primarily focuses on the impact of classroom environmental factors, such as classroom teaching atmosphere, classroom technology, and design of classroom activities, on student engagement.

(3) The influence of learning assessment and feedback on engagement: This field of articles examines the impact of evaluations and feedback that students receive on their learning engagement.

(4) Special factors in subject domains: This field of articles addresses topics related to specific academic subjects, including mathematics learning, language learning, and more.

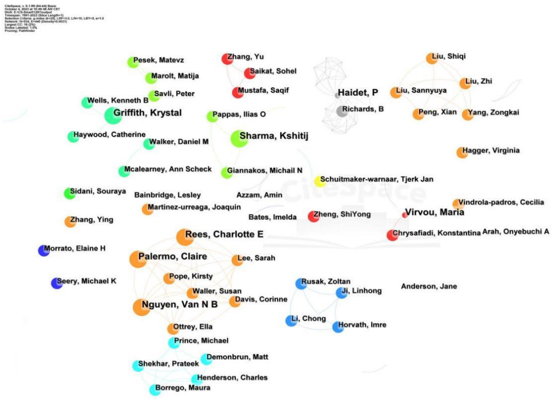

Figure 5. Author Collaboration Network Mapping

3.7 Co-Citation Analysis of Authors

The research paper on student engagement assessment, co-authored by Mark H. Rose and Brian R. Belland, has been cited 900 times according to the Web of Science database. Mark H. Rose's other academic papers have been cited over 6,500 times, and Brian R. Belland's other academic papers have been cited over 4,000 times.

The author co-citation network (Figure 6) was generated using CiteSpace 6.2.R5. There are 798 nodes and 1397 edges in the network, with a density of 0.0044. The size of nodes represents the frequency of citations and their connection with other authors.

3.8 Keywords Cluster Analysis

Cluster analysis is used to discover thematic groups in knowledge graphs, where nodes with similar themes are grouped. This helps us understand the structure and organization of knowledge better, and identify intersections and commonalities between different knowledge domains, guiding knowledge integration and application. CiteSpace 6.2.R5 is utilized to perform cluster analysis on keywords (Figure 7). After pruning, the clustered graph retains 443 nodes and 1280 connections. The density is 0.0131. The modularity Q is 0.5635, which is higher than 0.3, indicating relatively ideal clustering results. Ten major clusters are obtained using the log-likelihood LSI algorithm. The larger the cluster, the more research it represents, and the clustering effect weakens as the cluster number increases. The Weighted Mean Silhouette S is 0.8289, indicating good clustering performance.

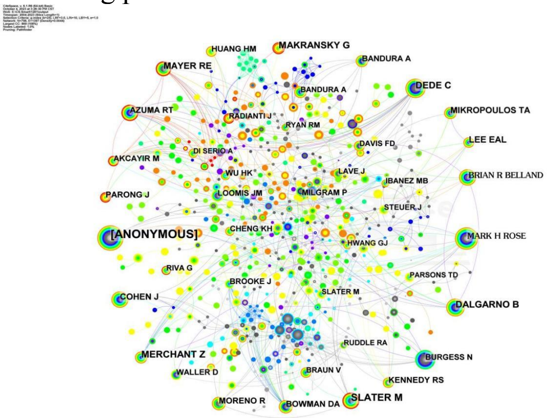

Figure 6. Author co-citation mapping

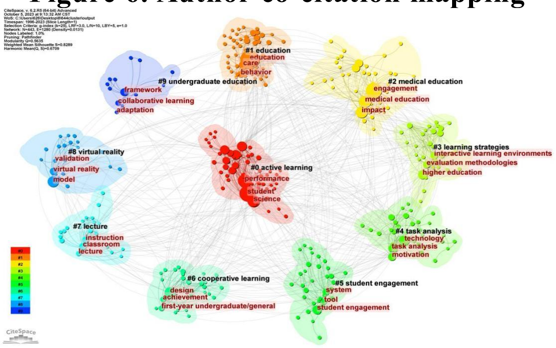

Figure 7. Keyword-cluster knowledge map

Cluster #0-Active Learning: This cluster includes keywords such as active learning, digital systems, and logic functions. The theme of this cluster focuses on utilizing digital systems and logic functions to implement active learning scenarios, as well as exploring methods to improve the learning experience using artificial intelligence technology. The results indicated that these systems significantly improved student participation and investment in the classroom, leading to enhanced learning outcomes. The authors believe that these technologies can provide personalized and interactive learning experiences.

Cluster #1-education: This group of keywords includes education, health promotion, and clinical experience. This category reflects the application of AI technology in the field of education, which will help promote students' health and improve their clinical skills.

Cluster #2 - medical education: This group of keywords includes medical education; laboratory instruction; and learning strategies. This category highlights the importance of innovation in medical education and reflects the potential of artificial intelligence technology to change the way students learn and prepare for future careers.

Cluster #3-learning strategies: This group of keywords includes learning strategies; improving classroom teaching; and collaborative learning. This category emphasizes the importance of learning strategies in improving classroom teaching and enhancing student engagement.

Cluster #4-task analysis: This group of keywords includes task analysis; adaptation models; and adaptive learning. The study emphasizes the importance of understanding the key elements of the task for designing effective learning strategies, as well as the potential of artificial intelligence in promoting personalized and adaptive learning experiences.

Cluster #5-student engagement: This group of keywords includes augmented reality; educational technology; and natural language processing. Cluster #6-cooperative learning: This group of keywords includes first-year undergraduate/general; collaborative.

Cluster #7-lecture: This group of keywords includes lecture; performance; and instruction.

Cluster #8-active learning: This group of keywords includes virtual reality; structural equation modeling; and immersive technology.

Cluster #9-undergraduate education: This group of keywords includes undergraduate education; experimental subjects; and experimental design learning.

3.9 Timeline Analysis

The Timeline graph displays the distribution of literature in a specific field over the years on a timeline, with time represented on the horizontal axis. The relevance and impact of the literature are represented on the vertical axis, while the darkness of the color indicates the publication year. According to the CiteSpace6.2.R5-generated Timeline graph, the research hotspots in this field are concentrated in areas such as "engagement," "student," "education," "medical education," and "performance" (Figure 8). Initially, research focused on core topics of AI-enabled technology and key issues in educational reform, such as "science," "engagement," "design," and "instruction". These areas are crucial for researchers and decision-makers to consider when conducting related work. In recent years, research has increasingly focused on topics such as "smart classroom," "computer vision," "cognitive intervention," and "internet of things,".

This study summarizes three research characteristics in this field through knowledge graph analysis:

(1) Interdisciplinary Integration: Research on student engagement in AI-enabled smart classrooms necessitates interdisciplinary integration across disciplines such as artificial intelligence, education, and psychology. Integrating and cross-applying knowledge from different fields is necessary to enhance the feasibility and practicality of research outcomes. This necessitates thorough research and the utilization of theories and methods from various disciplinary domains.

(2) Data-Driven Approach: This type of research extensively relies on substantial amounts of student data. Therefore, conducting comprehensive research and practical implementation are essential in data collection, processing, storage, and protection.

(3) Integration with Educational Practices: This research focuses on enhancing student engagement and teaching effectiveness by integrating research findings with educational practices to facilitate their practical application and validation.

Figure 8. Keyword time zone map analysis

The article cites a high number of 16.22. It systematically reviews the definitions, dimensions, sources, and influencing factors of student engagement in domestic and international research ecology, making it of significant reference value for enhancing student engagement. The author introduces the concept of engagement, including three aspects: cognition, behavior, and emotion, as well as specific indicators and measurement tools for each aspect. In addition, the article emphasizes the significant impact of student engagement on academic performance, transformation, and adaptation, providing direction and framework for further research in this field. In recent years, The authors used various data sources, including student's voice, facial expressions, gestures, and interactive behaviors. Their proposed deep learning model can effectively identify student engagement and provide real-time feedback and guidance for teachers. This article demonstrates the potential of machine learning in assessing student engagement and provides practical insights on how to utilize this data. These well-known references provide an important theoretical foundation and practical tools for assessing student engagement. They explore the multidimensional concept, motivational basis, and influencing factors of engagement, and measure them through various reliable methods and tools. These references are of significant reference value for educators to understand and promote student engagement in practice (Figure 9).

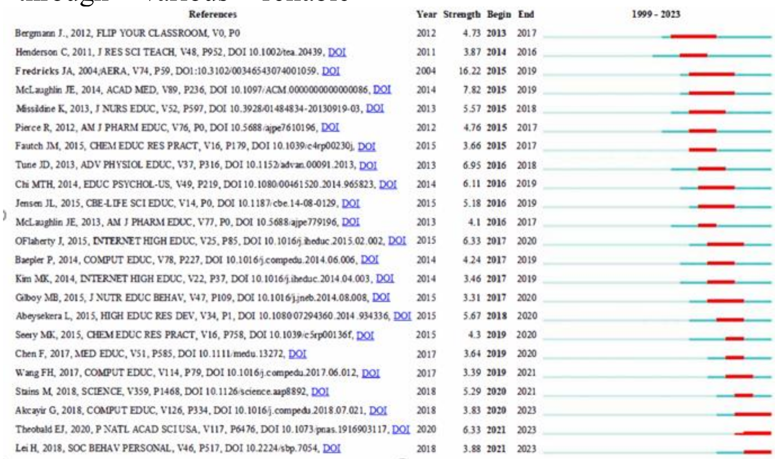

Figure 9. Top 23 References with the Strongest Citation Bursts

4. Discussion

In this paper, we use CreateSpace (6.2.R5) to visually analyze 1,420 papers related to the evaluation of learning engagement, which helps us to systematically understand the status of the evaluation of the learning engagement research field. This method can, to a certain extent, better overcome the limitations of literature analysis and reduce the subjectivity and difficulty of manual screening. In this study.

The paper utilizes CiteSpace 6.2.R5 software to analyze relevant literature. It presents an overview of the research status, hotspots, and future development trends. First, it examines the fundamental aspects of assessing the impact of AI on student engagement in smart classrooms, encompassing figures such as the annual publication count, authors, countries, and research institutions. Second, it employs keyword co-occurrence and keyword burst mapping analysis to identify the main domains, basic content, and research hotspots of this study. Finally, by exploring citation clusters and the breakout of high-frequency keywords, it showcases the research frontier and emerging trends. The specific research areas primarily focus on techniques for collecting and analyzing learning data, measures and evaluation methods for gauging student engagement, and prediction and feedback techniques to enhance student participation. The research methods predominantly employ machine learning algorithms, data mining, and model construction. Future research directions encompass multi-modal data fusion and evaluation of student engagement empowered by AI, prediction of student engagement based on deep learning, and exploration of optimization and enhancement of models calculating student engagement.

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