Curriculum and Teaching Methodology (2023)
Clausius Scientific Press, Canada
DOI: 10.23977/curtm.2023.061505
ISSN 2616-2261 Vol. 6 Num. 15

Research on Hotspots and Trends of Chemistry Teaching Informatization in China over the Past Ten Years: Visual Analysis Based on CiteSpace

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Keywords: Education Informatization; Chemistry Teaching; CiteSpace; Visualization

Abstract: With the implementation of the Action Plan of Education Informatization 2.0, the process of education informatization has achieved great success, and digital technology has had a significant impact on education management and participants at all levels. This paper uses the Chinese Journal Full-text Database (CJFD) as the data source to conduct statistics, and uses CiteSpace to statistically analyze the research on chemistry teaching informatization in China from 2013 to 2022. Based on the results of visual analysis, relevant research hotspots in China were summarized, which mainly focus on three frontier areas: digital experimentation with hand-held technology, quadruple representation teaching model, and teaching strategies and applications in the context of informatization. This paper will provide suggestions and references for Chinese teachers and educational researchers.

1. Introduction

With the continuous progress of science and technology, education informatization is developing rapidly, and intelligent technology is deeply integrated into the whole process of education teaching, which helps to improve students' information literacy and teaching effectiveness. In the development of information technology in education, chemistry, as a basic subject, involves not only complex mathematical calculations but also the concept of visualization of spatial elements and the understanding of matter at the microscopic level, and the description of matter in symbolic form [1]. To find out the development status and research hotspots of chemistry teaching informatization in China, and to discover the future research directions for the deep integration of information technology and chemistry teaching, our study conducted a bibliometric analysis of Chinese research on information technology in chemistry teaching in the past ten years with the help of Citespace visual analysis software. This paper aims to provide support for front-line teachers and researchers who are focusing on informatization and to give reference to future teaching practices.

2. Data Sources and Research Methodology

2.1. Search Strategies and Data Collection

In this paper, the China Journal Full Text Database (CJFD) was selected as a representative data source in China. To ensure the quality of the selected articles, the source categories of the journals were selected as "Beida Core", "Chinese Social Science Citation Index (CSSCI)" and "China Science Citation Database (CSCD)". We selected the publication year as "2013-2022". 327 articles were retrieved totally, and 91 high-quality articles were included after screening one by one, which were exported in the form of a title list as a data set for domestic research for data analysis.

2.2. Research Method

This study uses CiteSpace (5.3.R4) for bibliometric analysis. The results of bibliometrics include the statistics of the number of articles in the CJFD and keyword analysis, which are used to explore the research frontiers of chemistry teaching information in China. The co-occurrence network is based on the frequency of two entities (e.g., keywords) appearing in the same article [2]. CiteSpace measures the co-occurrence network by a variety of metrics, including mediated centrality, clustering modularity index (Q), and silhouette coefficient index (S). In our study, the likelihood ratio test (LLR) was used to extract cluster labels from keywords related to the articles ($p < 0.001$). We checked each cluster carefully and the final cluster labels were optimized according to the judgment of experts and ourselves.

3. Data Analysis and Results

3.1. Analysis of Annual Postings

From Figure 1, it can be seen that the annual number of papers on related topics included in CJFD from 2013 to 2022 generally showed a trend of increasing and then decreasing, with a basic upward trend from 2014 to 2019, a decrease in the number of papers after 2019, and a rebound in 2022, with a relatively small number of high-quality literature and studies on average each year. This may be due to the fact that some educators are currently skeptical about the effectiveness of information technology in improving chemistry teaching and learning, and there are certain implementation dilemmas in conducting practical research on the application of information technology to chemistry teaching, and the uneven information literacy of teachers and students, which leads to a lack of abundance of relevant high-quality research. Therefore, in future educational teaching work, teachers and other related researchers need to continue to explore the effectiveness of new technology-assisted chemistry teaching, based on the actual school teaching, integrate information technology with educational theory and teaching practice, and promote the transformation, which will facilitate the development of information-based teaching.

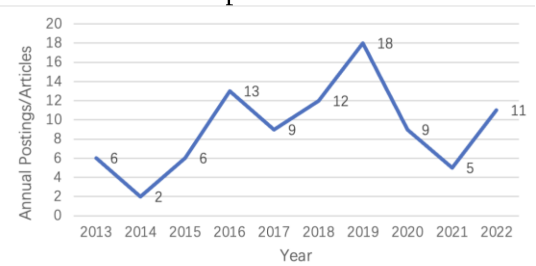

Figure 1: Annual scientific production on related topics in CJFD from 2013 to 2022.

3.2. Keyword Analysis

3.2.1. Keyword Cluster Analysis

To obtain the hotspots and trends of chemistry teaching informatization in China, we used the word frequency analysis method. In CiteSpace, keywords were selected as node types for keyword co-occurrence analysis, and the keyword clustering profile shown in Figure 2 was obtained, based on which the keyword co-occurrence network clustering table in Table 1 was further manipulated. Figure 2 exhibited significant modularity and contour indices, which indicated that the network and clustering were highly plausible (Q = 0.8049, S = 0.7065).

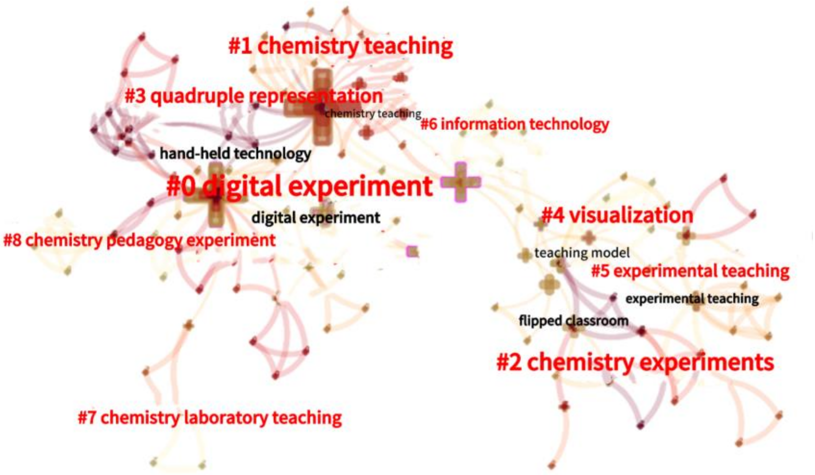

Figure 2: Co-occurrence network of keywords (2013 – 2022).

Table 1 shows the top three keywords in the clustering labels based on the LLR algorithm, which mostly revolve around the core terms of "digital experimentation", "hand-held technology", "chemistry Experimentation", "virtual laboratory" and other Keywords. In addition, the keywords were ranked according to their frequency, as shown in Table 2. Excluding "chemistry", "education", "technology" and other search terms, we can find that the main high-frequency keywords are "hand-held technology ", "information technology", "digital experiment", etc.

Table 1: Main keywords under clustering label based on LLR algorithm in research.

Cluster label	Number of nodes	Year	Main keywords under LLR algorithm
#0 Digital Experiment	26	2017	Digital experiments; Experimental design; Hand-held technology
#1 Chemistry Teaching	21	2016	Chemistry Teaching; Chemistry Subjects; Science and Technology
#2 Chemistry experiments	14	2015	Chemistry experiments; Multimedia technology; Virtual labs
#3 Quadruple Representation	14	2013	Quadruple Representation; Symbolic Representation; Curve Representation
#4 Visualization	11	2019	Visualization; Teaching models; Web-based information
#5 Experimental teaching	11	2017	Experimental teaching; Biochemistry; Chemical reagents
#6 Information Technology	10	2019	Information Technology; Cloud Classes; Hybrid Teaching
#7 Chemistry Laboratory Teaching	5	2018	Chemistry experiment teaching; Experimental demonstration; Virtual experiment technology
#8 Chemistry Pedagogy Experiment	5	2017	Chemistry pedagogy experiment; Chemistry simulation experiment platform; Micro-video

Table 2: Top 10 keywords in domestic research.

No	Frequency	Keyword	Intermediary Centrality
1	15	Chemistry Teaching	0.39
2	14	Hand-held Technology	0.34
3	8	Information Technology	0.42
4	5	Digital Lab	0.18
5	4	Flipped Classroom	0.08
6	4	Quadruple Representation	0.08
7	4	Experimental Teaching	0.12
8	4	Teaching Model	0.09
9	3	Visualization	0.03
10	3	Multimedia Technology	0.04

3.2.2. Burst Detection of Keywords

We extracted the top 20 cited keywords and sorted them by the start time of the burst (Table 3). It can be seen that the research areas with explosive trends in the last two years are "analytical chemistry experiments", "digital experiments", "visualization" and "Information technology".

Table 3: Top 20 keywords in domestic research.

Keywords	Year	Strength	Begin	End	2013 - 2022
Quadruple Representation	2013	1.3813	2013	2016	
Chemistry Pedagogy	2013	0.7379	2015	2017	
Inspiration	2013	1.1129	2016	2016	
Multimedia Teaching	2013	1.1129	2016	2016	
Development Trends	2013	1.1129	2016	2016	
Science and Technology	2013	1.1129	2016	2016	
Chemistry Teaching	2013	3.1786	2016	2018	
Chemistry Subjects	2013	1.1129	2016	2016	
Intermolecular forces	2013	0.8394	2018	2019	
Experimental teaching	2013	1.2706	2018	2020	
Microlearning	2013	1.066	2019	2019	
Biochemistry	2013	0.903	2019	2019	
Teaching Model	2013	0.7381	2019	2019	
Teaching Reform	2013	1.066	2019	2019	
Flipped Classroom	2013	0.7381	2019	2019	
Analytical Chemistry Experiment	2013	0.8063	2019	2022	
Teaching Chemistry in Secondary Schools	2013	1.066	2019	2019	
Digital Experiment	2013	2.1734	2019	2020	
Visualization	2013	1.6079	2019	2019	
Information Technology	2013	0.7578	2019	2022	

3.3. Analysis of the Frontier Areas of Research in China

Combined with the cluster mapping and cluster table, it can be summarized that the research hotspots on chemistry teaching informatization in China at the emergence stage can be roughly divided into the following three areas: (1) digital experimentation with hand-held technology; (2) quadruple representation teaching model; (3) teaching strategies and application research in the context of informatization.

3.3.1. Hand-held Technology Digital Experiment

Hand-held technology, also known as hand-held lab, is an information technology system consisting of sensors, data collectors, and a computer with supporting software for collecting and processing experimental data [3]. The system can quantitatively measure various types of scientific data in the educational process and present visualized image information through the computer to show the process of experimental changes in real-time. Digital experiments with hand-held technology have the advantages of being quantitative, intuitive, and accurate [4]. Exploratory learning through hand-held technology not only reflects the ideas and concepts of basic education reform but also fits the cognitive rules of students' learning [5, 6]. In 2003, Qian Yangyi et al. were the first to introduce hand-held technology into the domestic chemistry teaching process with the topic of triple flame temperature determination of alcohol lamps [7]. Subsequently, the deep integration of digital experiments with hand-held technology and chemistry teaching flourished, and a series of chemistry teaching case applications and micro-level cognitive model construction studies emerged.

Chen Boyin et al. [8] introduced hand-held technology for experimental design to investigate the corrosion rate of metal at the anode of the electrolytic cell and the anode of the primary cell, and the pressure change represented the present metal corrosion rate and then constructed the pressure-time curve to analyze the experiment in depth through four-fold characterization. Based on hand-held technology and cognitive-constructivist learning theory, Wang Lixin et al. [9] proposed the Transformation, Quantitative Perception, Visual Perception, and Comparison (TQVC) conceptual cognitive model and applied it to teaching practice, which was found to be helpful for teachers to understand the cognitive patterns of students' conceptual learning in the hand-held technology environment from a psychological perspective. Wang Xiaofang et al. [10] conducted a bibliometric analysis of nearly 20 years of research in China based on digital experiments with hand-held technology and suggested increasing the case development of digital experiments in elective courses, conducting empirical research on hand-held technology in basic education, and integrating STEM education models in digital experiments, which pointed out the shortcomings of existing research in China and guided potential research directions for chemistry educators.

However, it is still difficult to widely use hand-held technology for digital experiments in secondary school chemistry teaching. Zhu et al. investigated the attitudes of chemistry teachers toward the application of digital experiments with hand-held technology and found that "experimental resources and support" were the primary factors limiting the practical application of hand-held technology in teaching [3]. It is undeniable that hand-held technology experiments have more visual presentation effect and experimental informatization function, but due to the differences in the level of hand-held technology experimental equipment and resources in different regions, as well as the inconsistent attitudes of different types of teachers, the feasibility of large-scale application of hand-held technology still needs more research to be confirmed. A series of empirical studies on teaching should be designed in the future to evaluate hand-held technology comprehensively and comprehensively with actual feedback from teachers and students and teaching effects.

3.3.2. Quadruple Representation Teaching Model

Based on the technical background of digital experiments to collect data instantly and generate curves automatically, Qian Yangyi first proposed the quantitative analysis method of "curve characterization" in 2009 and built a teaching model of "four-fold characterization" in chemistry, namely, macroscopic characterization, microscopic characterization, symbolic characterization and curve characterization [11]. Curve representation is to take the curves obtained from digital experiments as the template for analysis, and learners should relate the starting point, ending point, inflection point, and other special points of the curve, the trend of curve changes, and different line segments to experimental phenomena, particle changes, and reaction equations [12], and finally reflect the relationship between the dependent variable and the time variable in the experiment in the form of coordinate curves in their minds, thus helping students to establish a quantitative and visualized learning effect. That can help them understand the chemical reaction process better.

The quadruple representation teaching model has a double meaning for both teachers and students. From the perspective of teachers' teaching and students' knowledge learning, teachers teach students' specialized knowledge in chemistry through experimental phenomena, microscopic configurations, chemical symbols, and coordinate curves. The meaning of teaching is not only to teach them knowledge, but also to develop their ability to describe and explain chemical experimental phenomena, three-dimensional spatial conceptualization, and logical thinking through the teaching of quadruple representations. The acquisition of knowledge is the end we seek, but the process of acquiring knowledge is also essential.

The quadruple representation teaching mode is mostly used in the teaching of chemical experiments, and Wei Xinping [13] designed a case reference of quadruple representation teaching with the experiment of "the effect of concentration on chemical equilibrium" as the teaching content and suggested establishing the inner connection between the quadruple representation and highlight the logical way of thinking in chemistry through the quadruple representation teaching mode to facilitate students' construction of basic concepts of chemistry. Liu Jianxiang [14] used "chemical reaction rate" as the content of the quadruple representation teaching design, evaluated the teaching effect by questionnaire, and found that the experimental course based on the quadruple representation could improve students' ability to analyze problems. Gao Miaotian [15] investigated the quadruple representation teaching mode for an "acid-base titration experiment" and evaluated the learning effect of students through a paper-and-pencil test, which also verified the effectiveness of the quadruple representation teaching mode. However, these two empirical studies were conducted with a small number of students in one class, which was not convincing; and both studies did not set up a reasonable control group and did not consider other variables adequately, so the conclusions reached are subject to verification.

In brief, although the teaching model of quadruple representation has been widely studied by chemistry educators, it is mainly based on this idea to optimize the teaching process of chemical experiments, and the number of empirical studies is relatively small. Moreover, due to the limited sample size of relevant research, the method of verifying teaching effectiveness is also not convincing. Therefore, well-designed randomized controlled trials should be conducted in the future to teach different groups in different ways, fully consider the various biases that may occur in the design and implementation of the trials, adjusting for potential confounding factors through a reasonable statistical approach, and then compare the differences in teaching effectiveness.

3.3.3. Teaching Strategies and Application Research in the Context of Informatization

The Ministry of Education's "Thirteenth Five-Year Plan for Education Informatization" demands further promotion of education informatization in order to achieve deep integration of information technology and subject teaching [16]. In recent years, a variety of information technologies have been gradually applied to chemistry teaching and integrated with chemistry teaching theory, making information-based teaching and learning integrated with traditional classroom teaching, and popular among teachers and students. Ni Shengjun [17] constructed an instructional design based on the cloud classroom platform for junior high school chemistry teaching as an example and conducted a validation and comparison study to affirm the promotional effect of hybrid instructional design on teaching effectiveness. Guan Ling et al. [18] proposed the establishment of a micro-class, recording system, and online testing system for organic chemistry experimental teaching in the information era. Another study on analytical chemistry laboratory teaching [19] concluded that chemistry teachers should make full use of information-based laboratory teaching resources, use multimedia to assist laboratory teaching and realize hybrid laboratory teaching through small-scale restricted online courses (SPOC).

Therefore, in the context of educational informatization, the research, and application of chemistry teaching strategies should keep pace with the development of information technology. It requires chemistry educators to change their inherent teaching concepts, develop scientific teaching plans in combination with educational theories, create teaching situations conducive to scientific inquiry using reasonable digital means, give full play to the vividness and interest of the chemistry classroom, and promote the application of information technology in chemistry teaching.

4. Conclusion

In the context of the rapid development of intelligent education nowadays, the application of information-based teaching in chemistry has certain development prospects. In this paper, we visualized and analyzed the literature related to information-based teaching of chemistry in China mainly in terms of the number of publications and keywords with the help of CiteSpace software, and came to the following conclusions: the research on chemistry informatization teaching in China is relatively limited, and the high-quality research published in core journals is not abundant; the research hotspots on chemistry informatization teaching in China are mainly summarized in three aspects: digital experiments with hand-held technology, quadruple representation teaching model, and teaching strategies and applications in the context of informatization. The overall research content tends to be diversified, which provides theoretical basis and practical foundation for the design of chemistry teaching integrating information technology and improving the teaching effect of chemistry subjects.

However, this study still has certain limitations. Information technology itself cannot improve teaching efficiency. Only by combining the characteristics of the subject with scientific teaching design, and by organically combining technology with various teaching modes, can we better reflect its educational value. In the future, education informatization will be more deeply integrated into front-line teaching, which requires the joint efforts of technology researchers and educators to follow the trend of smart education and design teaching models and environments based on information technology, so that education informatization can truly serve teachers and students, and thus promote deeper changes in education teaching.

Acknowledgement

Fund project: This work is funded by the following projects: Postgraduate Research & Practice Innovation Program of Jiangsu Province (KYCX23_2535); Humanities and Social Science Research Project of Chinese Ministry of Education (21YJA740037).

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