Foreign STEAM Education Research Based on Visual Analysis

Huan Sun(✉), Min Wu, and Yan Ma

School of Computer and Information Science, Chongqing Normal University, Chongqing, China
serendipitysh@163.com

Abstract. This paper uses 3596 core papers in the WOS (Web of Science) database in the past ten years as a data source, and uses CiteSpace knowledge graph software to visually analyze foreign STEAM education. Through cluster analysis, it is found that the themes of foreign STEAM education research mainly focus on three aspects: interdisciplinary integration, thinking training, and gender-based education equity research. This article studies the current situation and hot spots of STEAM education abroad, in order to provide a reference for the development of STEAM education in China and make it more in-depth and comprehensive.

Keywords: Foreign STEAM education · Educational equity · CiteSpace software · Visual analytics

1 Introduction

The high quality of educational development is reflected in science and innovation education. Scientific and technological progress and innovation play a decisive role in enhancing comprehensive national strength. Strengthening scientific and technological innovation and educational innovation will promote the development of STEAM education, thus improving national competitiveness and solving the problem of training innovative talents. STEAM education was developed systematically after the rise of the United States. Under the dual influence of STEAM education in the United States and the pressure of global technological competition, this educational concept has been popularized worldwide [1]. In this study, CiteSpace software was used to analyze and track the relevant literature of the Web of Science core database in the field of STEAM education, in order to provide references for the development of STEAM education.

2 Data Sources and Research Methods

2.1 Sources of Data

This article uses the Social Sciences Citation Index database of the Web of Science platform published by the Institute for Scientific Data Intelligence to ensure that the data is comprehensive and reliable. The search criteria were "TS = (STEAM EDUCATION

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OR STEM EDUCATION not cell)", the time span was set to 2011, the last search date was June 2022, and the search results were 4462. In this study, the literature language was set to English, the document type was limited to Article, and the literature that did not correspond to the topic (such as medical studies, etc.) was manually removed. Finally, 3596 valid literature records were obtained.

2.2 Research Methods

CiteSpace is a visual analysis software running in the Java environment, which is a scientific knowledge graph that visually presents the structure, laws, and distribution of scientific knowledge [2]. Through the analysis of keyword co-occurrence and clustering results, the analysis of emerging words and the analysis of literature co-citation in the field of STEAM education from 2011 to 2022 to analyze the research hotspots and frontiers of foreign STEAM education.

3 Data Analysis and Results

3.1 Annual Volume Analysis

The annual volume of publications of the studied literature is shown in Fig. 1. From 2011-01-01 to 2022-06-30, a total of 3596 articles were published in the field of STEAM education, showing a year-on-year growth trend. The number of articles published in 2021 is 7 times that of 2011, reflecting the increasing emphasis on STEAM education in the international academic community. It can be speculated that after June 2022, the research on STEAM education and teaching will continue to increase.

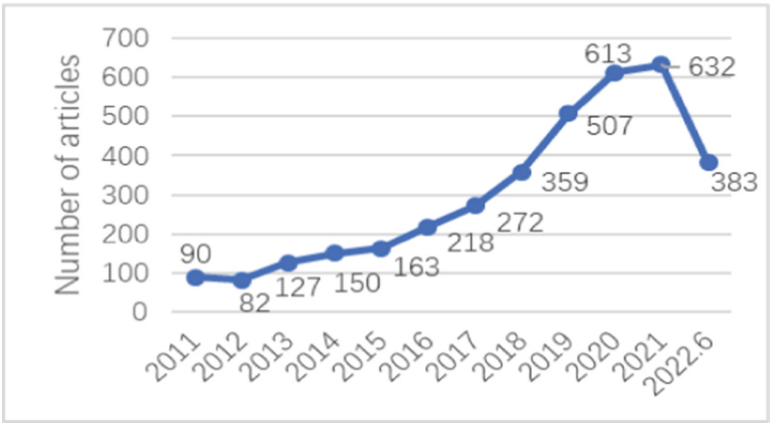

Fig. 1. Annual publications

Table 1. DISTRIBUTION OF PUBLISHERS

Rank	Institution	Number of papers	Centrality
1	Purdue university	55	0.04
2	Wisconsin	49	0.03
3	Michigan State Univ	45	0.07
4	Arizona State Univ	43	0.03
5	Univ Minnesota	43	0.08
6	Northwestern	42	0.05
7	Univ Michigan	42	0.12
8	Univ Washington	41	0.04
9	Texas A&M univ	40	0.08
10	Univ Texas Austin	39	0.08
11	Univ Colorado	33	0.10

3.2 Analysis of Issuing Institutions and Countries

An analysis of the major authors, as shown in Table 1, provides a better understanding of the most researched and authoritative institutions in the current field of STEAM education. Of the 3,596 articles in this search, the top five institutions in terms of article volume are Purdue University, the University of Wisconsin, Michigan State University, Arizona State University, and the University of Minnesota, which have strong academic strength in the field. As shown in Table 1, the University of Michigan (0.12 degree of centrality) is the most cooperative with other institutions, followed by the University of Colorado (center degree of 0.10°).

Using CiteSpace 5.8.R3 software to visually analyze the issuing country, as shown in Fig. 2, in the knowledge graph of the publication of documents in different countries, each node represents a country, and the size of the node is proportional to the number of articles published in the country. Each node consists of rings of different widths and colors. The different colors of the annual rings represent different times of publication, and the width of the annual rings is proportional to the amount of literature in the corresponding country's publication time. The United States is the country with the most research results in the field of STEAM education and teaching, with 1760 papers published in this field. Compared with its home countries, the United States has the largest number of literatures in this field, followed by the United Kingdom and Australia, while countries such as China and Spain are slightly inferior to the United Kingdom and Australia.

Fig. 2. Knowledge graph of different countries

4 Research Hotspots and Research Frontiers

4.1 Research Hotspot Analysis

In order to further understand the research hotspots and themes in the field of STEAM education, this paper uses the log-likelihood rate algorithm (LLR) in the CiteSpace software to cluster the keyword co-occurrence network, use quantitative calculations, summarize the similar words between the contents, find the largest value in the same cluster as the representative of the category, as the cluster name of the class, so as to divide the research field into representative subgroups of knowledge. It is possible to identify the hot spots and development trends in a certain research field. The clustering results show that the research hotspots of STEAM education mainly focus on computational thinking, educational equity, interdisciplinary research and so on.

CiteSpace provides Modularity and Silhouette indicators based on the network structure and the clarity of clustering, that is, module value (Q value) and average profile value (S value), which can be used as a basis for us to judge the effect of mapping [3]. The Q value in Fig. 3 is 0.7551, and the $Q > 0.3$ represents a significant cluster structure; An S value of 0.905 and an $S >$ of 0.7 indicate that clustering is convincing. After collation, the basic information of clustering is shown in Table 2. The STEAM education study had 10 clusters with average profile values greater than 0.7, indicating that all 10 clusters were credible.

- Gender-based research on educational equity
  The problem of gender disparities in STEAM education persists around the world, with huge gender differences in mathematics and science around the world, with the majority of men being the norm in this field. Foreign countries have conducted

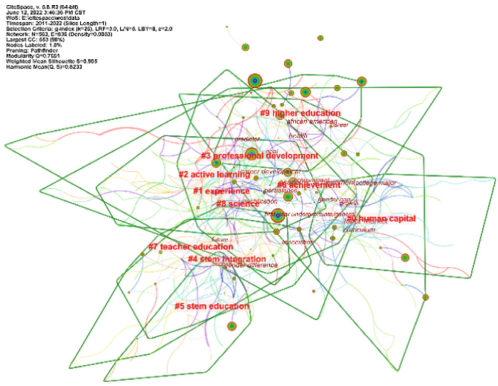

Fig. 3. Keyword clustering visualization map

Table 2. CLUSTERING BASICS

Cluster numbers and labels	Average profile value	The number of keywords	Represents keyword 1	Represents keyword 2	Represents keyword 3
#0 human capital	0.946	49	knowledge	skill	inequality
#1 experience	0.870	42	gender	motivation	persistence
#2 active learning	0.961	40	self-efficacy	children	middle school
#3 professional development	0.844	40	faculty	success	scientist
#4 stem integration	0.887	35	engineering education	implementation	first-year undergraduate
#5 stem education	0.911	34	gender difference	computational thinking	steam education
#6 achievement	0.832	34	stem	identity	college student
#7 teacher education	0.880	32	college	belief	thinking
#8 science	0.823	31	engagement	program	inquiry
#9 higher education	0.922	29	student	performance	teacher

extensive research on this phenomenon, including the causes of gender differences in STEAM education, measures to solve this problem, and advocating women to enter the STEAM field. Japan is one of the largest economies in the world, but it is one of the lowest ranked countries in terms of gender equality. To address this problem, Kijima Rie and Sun Kathy Liu stimulated their interest in five areas of science, technology, engineering, art, and math, namely steam, by applying design thinking, and the findings showed that middle school girls were interested in STEAM Demonstrate greater interest and a higher level of creativity [4]. It can be seen that the use of design thinking can bring possibilities and opportunities for women's development in the STEAM field, and is of great significance and reference value for achieving educational equity. In addition, a large number of studies have confirmed the role of poor mathematical self-efficacy or perception in women's poor mathematical performance [5]. For example, women's ability in language may be superior to men's, which may give women more flexibility in career choices than men, so there are more opportunities to consider STEAM and non-STEAM fields. Expectations for success vary from subject area to subject area, and individuals are more likely to choose activities that have higher expectations for success.

In addition to women, the objects of attention of STEAM education abroad are ethnic minorities and special groups. In STEM: A Vision for Innovation in STEM Education 2026, released by the U.S. Department of Education's Joint Research Institute, STEM education promotes multicultural integration, promotes inclusion, and reduces bias, especially against gender and minorities [6]. Griffiths Amy Jane et al. developed and tested a comprehensive evaluation model for STEM education for children with learning differences, arguing that some students with autism disorder and other learning differences have higher attention and logical thinking skills in science, technology, engineering, and mathematics [7]. This plays an important role in the success of this area.

In order to achieve educational fairness in STEAM education and reduce gender bias, it is necessary to set different teaching goals for different types of groups, adopt diversified teaching methods and means, formulate appropriate teaching content, and teach according to talents to explore the advantages of vulnerable groups in STEAM.

- Interdisciplinary integrated research

The emergence of STEAM in the research and practice of science, technology, engineering, art, and mathematics education is now an internationally questionable fact. Although STEAM education has received international attention, the lack of a comprehensive approach to teaching STEAM interdisciplinarity may hinder the strong theoretical foundation and new contributions of STEAM education.

In recent years, the International Association for Technology and Engineering Education in the United States has developed a STEM integrated education model (I-STEM model) for the K-12 stage, which includes curriculum, teaching and evaluation, combined with real-world scenarios. It realizes the integration of scientific inquiry and engineering design and has reference value for relevant researchers and teachers [8]. Globally, interdisciplinary and interdisciplinary learning in schools has become an increasingly popular and increasingly interesting area of educational reform, prompting discussions about science, technology, engineering, and mathematics (STEM) to shift toward artistic integration in STEAM education. When an art course becomes

an interdisciplinary approach to achieve a basic understanding of the content of other fields, students' transferability and thinking skills are likely to improve. Wilson Hope E et al. have demonstrated through research that STEAM courses can effectively improve students' critical and creative thinking [9]. In addition, STEAM subject integration is increasingly being advocated as a way for students to be more connected and relevant to their learning. The methods of achieving disciplinary integration are diverse, involving multidisciplinary, interdisciplinary, etc. In the integrated STEAM educational environment, teachers and students need to explore and analyze the learning content on their own, pay attention to the core concepts of the discipline and the big concept between disciplines in the content, focus on cultivating students' high-level thinking ability in design, and use a variety of means and adopt specific strategies to solve problems in real situations.

- Research on student academic performance and thinking cultivation
  The goal of STEAM education is to develop creative thinkers, including computational thinking, to solve problems through integrated learning after STEAM education, thereby improving student achievement. In her work, Jeannette Wing emphasizes the importance of cultivating this mindset in children for effective learning in STEM education. Through empirical research on this topic, scholars have shown that most studies have adopted a general definition of computational thinking, and some definitions of specific areas of computational thinking have been proposed in STEAM education [10]. Problem-based teaching is currently the most popular teaching model, and computational modeling, game design, and robotics are current research hotspots. However, Grover and Pea highlight the confusion in the definition of the term. That said, computational thinking has many perspectives and evolving definitions, as well as a variety of different environments and tools that are believed to facilitate the above way of thinking in the field of education. Data-driven thinking is closely related to computational thinking because operations on data are expected to have computational significance. Data-driven thinking is an emerging trend in STEM education due to the increasing use of data-driven processes in our society.

4.2 Research Frontier Analysis

1) *Emergent word analysis*
   Emerging keywords can reflect emerging research hotspots in the field over a certain period of time. The highlight words in this part are produced by CiteSpace5.8 software, and the threshold selects TOP25 to generate a prominent word map in the field of STEAM education, as shown in Fig. 4. The emergence word includes two important properties, namely the sudden intensity and the continuous-time of the sudden state, which is an important reference index for observing the research prospects in this field. From Fig. 5, several keywords with high prominence intensity can be found in STEAM education research, mainly reflected in meta-analysis, validation, retention, participation and so on. The keywords validation, early childhood, and engineering student, which have lasted for nearly two years, suggest that these keywords are currently exerting influence on the STEAM education field and are also a research hotspot.

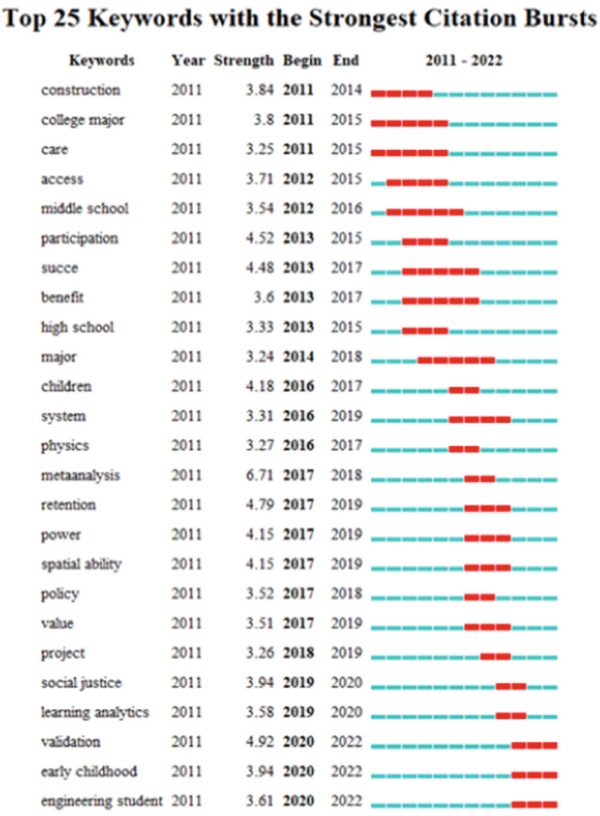

Fig. 4. Emergent word analysis

2) *The literature was cited for analysis*
The frequency of citation of papers is an important indicator of measuring the social impact of academic papers in bibliometrics. Through the co-citation analysis of the literature, the STEAM education research literature co-citation map was drawn using Citespace software, 734 network nodes, and 3494 connections were generated, and the density of the topological network was 0.013. According to the frequency of citations, the centrality of literature mediation, and the intensity of literature prominence, the key literature in this field is analyzed one by one. As shown in Fig. 5, the larger the node in the CiteSpace visualization, the higher the number of citations of the article, indicating that the document has a greater influence on the STEAM education field. Freeman S et al. argue in a 2014 article that active learning can improve test averages, with the failure rate of traditional teaching being 55% higher than that of active learning, and the analysis supports the theory that calls for an increase in the number of STEM degree students can be echoed by abandoning traditional teaching in favor of active learning [11].

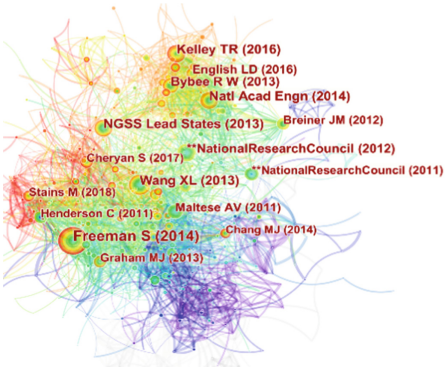

Fig. 5. The literature is cited for analysis

5 Conclusions

Through the statistical analysis of the relevant literature in the field of STEAM education, it is found that the research in this field has entered a stage of prosperity, and its related research results have also exploded. This study uses CiteSpace software to visually analyze the STEAM education samples from 2011 to 2022, and obtains the following conclusions and implications:

a) At present, the United States has a high influence in STEAM education research, its system is relatively mature, and the main research institutions are concentrated in universities, which has a certain reference effect on other countries. However, STEAM education in China is still in its infancy, and it is necessary to strengthen cooperation and exchanges between international and research institutions while engaging in research in this field.
b) Foreign STEAM education research hotspots mainly focus on student thinking cultivation, interdisciplinary integration, gender-based education equity research, student participation and academic performance. Additionally, it shows the development trend of multidisciplinary and interdisciplinary integration, which is conducive to researchers to more clearly understand the future development of STEAM education.

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