CASE STUDY

Characteristics of the knowledge graph of scientific and technological innovation in Gansu Province

Wenhao Liu[1,2,3] · Xiaoqian Shi[4] · Junwei Zheng[2,3] · Ren Li[1,3]

Abstract
The knowledge graph based on research papers can accurately identify and present the latest developments in scientific and technological (S&T) innovation and is of great significance for supporting strategic decision-making relating to S&T innovation in undeveloped areas. Based on the international research papers produced in Gansu Province during the 13th Five-Year Plan period (2016–2020), five metrics, including the number and characteristics of papers, co-authors, main publications and their fields, major supporting institutions, and main research areas, are established herein. The results indicate that: (i) the total of 29,951 papers were published, which is about 2.89 times that in 2010–2015; (ii) Gansu Province collaborated with 149 countries/regions globally; (iii) the top 5 journals in terms of the number of papers were Medicine, Scientific Reports, RSC Advances, Science of the Total Environment, and Physical Reviews D; (iv) the funding sources were mainly from the national level; and (5) the top 5 research areas were chemistry, engineering, physics, material science, environmental science, and ecology, which accounted for 64.7% of all papers. Finally, the present study puts forward some recommendations for the decision-making process in the strategic layout of S&T innovation in Gansu Province.

✉ Junwei Zheng
Zhengjw@llas.ac.cn

Wenhao Liu
liuwh@llas.ac.cn

1 Cryosphere Research Station on the Qinghai-Tibet Plateau, State Key Laboratory of Cryospheric Science, Northwest Institute of Eco-Environment and Resources, Chinese Academy of Sciences, Lanzhou 730000, China

2 University of Chinese Academy of Sciences, Beijing 100049, China

3 Lanzhou Literature and Information Center, Northwest Institute of Eco-Environment and Resources, Chinese Academy of Sciences, Lanzhou 730000, Gansu, China

4 PetroChina Research Institute of Petroleum Exploration and Development-Northwest, Lanzhou 730020, China

1 Introduction

Science and Technology (S&T) innovation is an umbrella term for all forms of original scientific research and technological innovation. This includes the improvement of existing things, or the creation of new things, including (but not limited to) various methods, elements, paths, environments, etc., in a specific setting based on existing knowledge and substances. S&T innovation capability is often used to evaluate the comprehensive power of invention and innovation of a specific object in a certain field of science and technology, mainly including several factors such as the level of professional knowledge, knowledge structure, R&D experience, R&D experience, research equipment, economic strength, and innovation spirit of researchers (Heinzen et al., 1993; Smith et al., 2008; Edquist, 2004, 2010). This can have certain important beneficial effects, including sustainable growth, the resolution of energy, food security, and climate change issues, and the attainment of political goals. Consequently, S&T innovation plays an important role in supporting and guiding economic and social development (Jones & Williams, 1998; Steil et al., 2002; Kline & Rosenberg, 2010; Sharif, 2012; Wang et al., 2019; Kang et al., 2019; Ozkaya et al., 2021). The comprehensive and accurate evaluation of S&T innovation capacity is critical for enabling the government to make science-based decisions, and for improving the S&T innovation capacity (Crane et al., 1977; Peters et al., 2012: Dolfsma and DongBack, 2013). However, S&T innovation is a complex system involving various subject elements and non-subject elements such as social support systems, external resources, and the environment (Tödtling, 1992). Therefore, it is of great importance to gain an accurate understanding of the S&T innovation capacity in each specific region to enhance the regional innovation capacity in an all-round manner.

Gansu is an underdeveloped province in the west of China, and its S&T innovation capacity is constrained by many factors (He & Liu, 2015). Gansu has been proactive in recent years with respect to implementing national policies on making reforms in S&T, promoting the depth of reforms on the system and mechanism of S&T innovation, and actively creating an institutional environment that is conducive to S&T innovation (Ma, 2022). During the 13th Five-Year Plan (FYP) Period in particular, China vigorously implemented the strategy of innovation-driven development, with the contribution of S&T advances accounting for 55.1%. Nevertheless, such problems as the backwardness of economic development, the insufficient role of innovation principals, the severe shortage of national S&T projects, the large investment gap in S&T innovation, the poor implementation of S&T policy, and the serious outflow of S&T talent have long existed and continue to exist, thereby constraining the overall S&T innovation capacity of Gansu Province, and keeping the province low in the ranking of national S&T innovation capacity (Li et al., 2015; Shi et al., 2017; Ke et al., 2021; Wei & Shi, 2021; Yang & Ma, 2021). According to China's Regional Innovation Capacity Evaluation Report, which was issued in December 2021 (CSTDSRG, 2021), Gansu Province ranks 25th in terms of the comprehensive index of regional innovation. Therefore, it is of great value and importance for the long-term development of this underdeveloped province to evaluate and analyze its capacity in S&T innovation.

The evaluation of S&T innovation capacity has been performed to some extent since as early as the 1990s, and the research includes a variety of protagonists, including nations, regions, industries, cities, universities, etc. (Cooke, 1992). In recent years, numerous scholars have performed much research on the quantitative evaluation of the S&T innovation capacity and related policies in Gansu Province. For example,

Zhang (2014) applied a gray comprehensive evaluation theory to assess the overall level of S&T innovation capacity based on the monitoring data of S&T progress in Gansu Province in 2011. He (2015) systematically discussed the construction of a model based on the factors affecting the regional innovation capacity and then used an entropy method to evaluate the regional innovation capacity and to suggest certain countermeasures and policies for regional capacity construction in Gansu Province. Since 2015, most studies have focused on the S&T innovation capacity of the National Agricultural Science and Technology Park in Gansu Province (Wei & Shi, 2021), industrial enterprises (Shi et al., 2017), independent scientific research institutes (Li et al., 2015), and the impact of S&T expenditure upon innovation capacities (Yang & Ma, 2021). For instance, Teng (2018) used quantitative analysis of policy text to analyze the S&T innovation policy of Gansu Province between 2011 and 2017. Meanwhile, Du (2021) used the relevant data from 2010 to 2017 to conduct an empirical study on the development of S&T innovation capacity in Gansu Province, while Zhang (2021) used the Malmquist index model to calculate the total factor productivity (TFP) of S&T resource allocation, and to analyze its decomposition value, in the field of agriculture in Gansu Province between 2011 and 2016.

Although these studies have provided a useful exploration of the data methods, a systematic evaluation of research papers as an important output of S&T innovation has yet to be performed. The scientific paper is regarded as both the most important carrier in the dissemination process of scientific research results, and as the physical output of S&T cooperation, thereby serving to clearly reflect the international cooperation in S&T research and its pathway (Kessler,1963; Price, 1965; Amaral and Neves, 2021). As such, research papers, and especially high-level research papers, are inherently sensitive to S&T innovation. Consequently, a knowledge graph based on research papers is of great strategic value and significance for supporting S&T decision-making and the layout of future development, because it can accurately depict and reflect the latest developments and trends in S&T innovation, embody the layout and direction of scientific research institutions, and clearly reveal the intensity and scope of cooperation in S&T.

The outline of the 14th FYP of Gansu Province calls for the reformation of institutions in order to improve the S&T innovation capacity. To this end, it is necessary to have a clear grasp of the research environment in which the research papers were generated, as well as the cooperation and layout of scientific research institutions, during the 13th FYP period. Consequently, given that there is no previously published research on the evaluation of the S&T innovation capability of Gansu Province by using a knowledge graph relating to the research paper output, the present authors believe this is a necessary step in the systematic research on the international research papers produced in Gansu Province during the 13th FYP period. Hence, the present paper aims to achieve the following unique and innovative research goals: (i) to perform a bibliometric analysis of international research papers produced in Gansu Province during the 13th FYP period (2016–2020), (ii) to construct five major indicators, including the number and type of papers, the characteristics of co-authored papers, the main publications and their fields, the main supporting institutions, and the major research areas, and (iii) to systematically map a knowledge graph of S&T innovation in Gansu Province during the 13th FYP period, so as to provide decision-making support for the strategic layout of S&T innovation during the 14th FYP period. The technical pathway of the present study is outlined in Fig. 1.
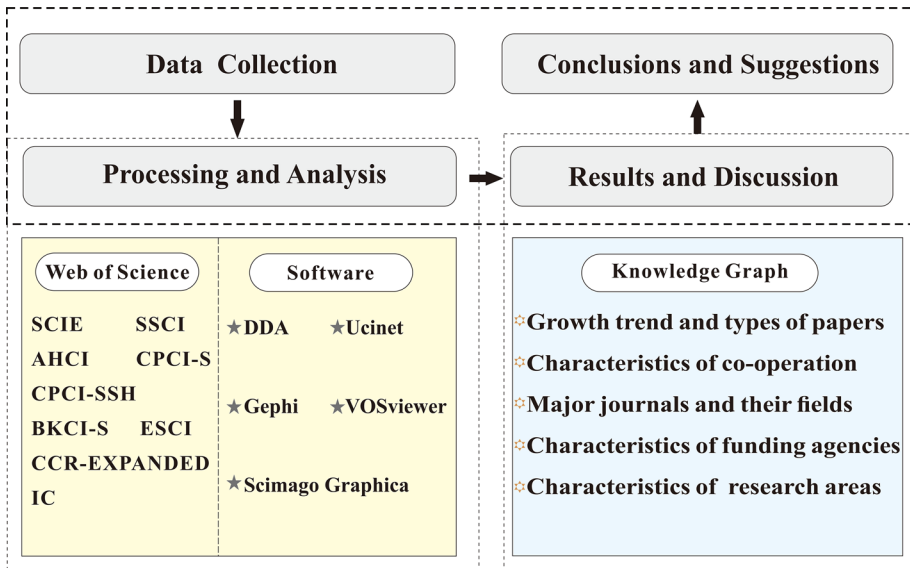
Fig. 1 The workflow of the present study

2 Methodology and data

2.1 Methodology

The knowledge graph originates from Google's Knowledge Graph project (Bollacker et al., 2008). It is a structured semantic knowledge base having three "entity-relationship-entity" components, with a combination of entities and their attributes and values as its basic structure (Pujara et al., 2013; Chen et al., 2020). A knowledge graph usually has the dual properties and characteristics of both graph and genealogy, i.e., it is not only a visual knowledge graph, but also a serialized genealogy of knowledge. As such, it can fully display many implicit and complex relationships between knowledge units and knowledge groups, including network, structure, interaction, intersection, evolution, or derivation, and this complex relationship often generates new knowledge. The most outstanding advantage of the knowledge graph is that it can clearly and directly visualize the existing research situation (Pujara et al., 2013; Paulheim, 2017), and has been applied to many fields in recent years (Chen et al., 2021; Liu et al., 2021; Zhao et al., 2021; Li et al., 2022). In addition, as one of the modes of information exchange and transfer between countries, the research paper is an important tool for measuring the outputs of S&T cooperation (Liu et al., 2021, 2022). Generally speaking, the co-authorship of papers emerges as the preferred form of cooperation for scientific researchers because the institutional partners involved possess the comprehensive advantages of stable links, as well as shared instruments, equipment, and big data resources. Hence, the research presented in co-authored papers is the most intuitive and important resource for exploring scientific research cooperation. A network analysis based on co-authored papers will assist in identifying the key cooperative networks and in supporting the strategic layout of future S&T cooperation in in Gansu Province. To this end, the methods of metrology and knowledge graph visualization, including bibliometric analysis, co-authorship analysis, and literature research and analysis, are comprehensively

applied herein. The software and platforms used include VosViewer, DDA, Gephi, Ucinet, and Scimago Graphica, which have been widely used in various types of literature recording and research (Van and Waltman, 2010; 2011; Kapucu et al., 2011; Wang et al., 2022; Xu et al., 2022).

2.2 Data

To support decision-making on the strategic deployment of S&T forces in Gansu Province during the 14th FYP period, the present study focuses on the papers produced during the 13th FYP period (2016–2020) and their characteristics. To describe the overall characteristics of these research papers, the core database of the Web of Science (WOS) was used to search the world-class academic journals, books, and conference records in the fields of natural science, social sciences, and the arts and humanities. All of the following WOS core databases were selected: SCIE, SSCI, AHCI, CPCI-S, CPCI-SSH, BKCI-S, ESCI, CCR-EXPANDED, and IC. The WOS database has been used for documentation research in a number of fields (Mulet et al., 2019; Carmona et al., 2020; López et al., 2020; Liu et al., 2021; 2022). The search strategy used in the present work was to search the addresses of all the authors in the database of papers in Gansu Province by using the term (AD = "gansu") OR (PS = "gansu"), and the data retrieval period was 2011/01/01–2021/12/30. The retrieval date was May 7, 2022. After cleaning and filtering the preliminary search results, and deleting any data that were missing certain key bibliographic information, 46,013 papers were finally obtained. The analysis in the present study is based entirely on these papers and their characteristics.

3 Analysis and discussion

3.1 Number of papers

For comparison with earlier years, the yearly numbers of papers in Gansu Province during the 12th (2011–2015) and 13th (2016–2020) FYP periods are presented in Fig. 2. Here, the number of papers increases rapidly between 2011 and 2021, reaching 9221 papers in 2019. However, there are significant differences between the 12th FYP period, when a total of 10,380 papers were published, and the 13th FYP period, when 29,951 papers were published, representing a 2.89 times increase. During the 12th FYP period, the annual average number of papers was 2076, while that during the 13th FYP period was 5990, demonstrating an obvious growth rate.

3.2 Characteristics of the co-authored papers during the 13th FYP period

3.2.1 Cooperation among countries and regions

The results indicate that the partners who have cooperated with Gansu Province on research papers are distributed across 149 countries/regions globally. The top 50 countries/regions are the USA, Germany, the UK, Australia, Japan, Canada, Russia, Pakistan, Italy, France, the Netherlands, South Korea, India, Sweden, Switzerland, Taiwan (China), Poland, Spain, Brazil, New Zealand, Turkey, Singapore, the Czech Republic,
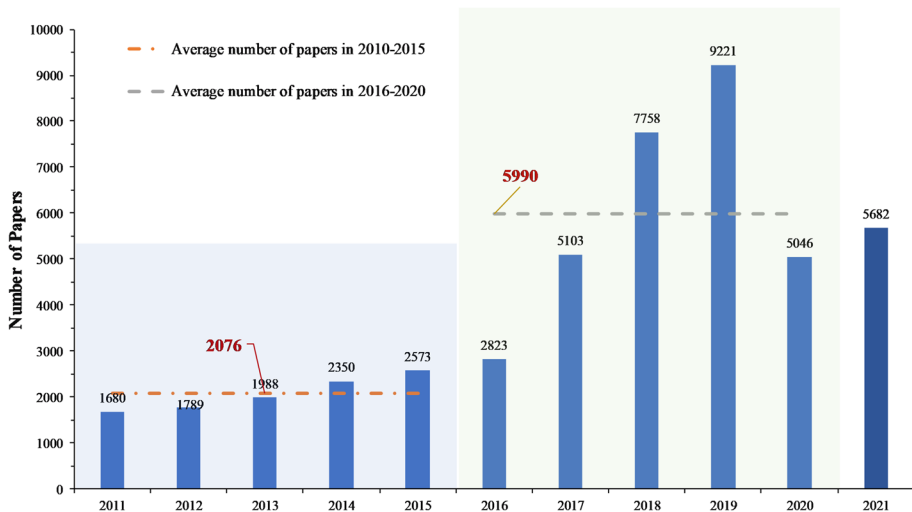
Fig. 2 The yearly numbers of research papers in Gansu Province between 2011 and 2021

Saudi Arabia, Mongolia, Egypt, Israel, Finland, Hungary, Vietnam, Romania, Ireland, Portugal, Ukraine, Denmark, Norway, Belgium, Ghana, Colombia, Philippines, Thailand, Austria, Malaysia, Algeria, Iran, Nepal, Chile, South Africa, Peru, and Kazakhstan. The total number of co-authored papers involving these countries was 10,979, accounting for 36.7% of the overall 29,951 papers. This indicates that while Gansu Province has good performance in terms of co-authored international papers, there remains much room for improvement. This is mainly manifested in the existence of a certain bias toward cooperation with major scientific and technological countries. In addition, while the numerous countries involved demonstrate the breadth of participation of Gansu Province in internationally co-authored papers, the intensity of this cooperation is quantitatively insufficient.

As an important part of the Belt and Road (B&R) initiative, Gansu has a broad space for promoting the development of the Silk Road, and for deepening the level of cooperation in various fields. The province is expected to become the backbone and an important support for the building of a prosperous, cultural, green, and harmonious B&R. Cooperation at the scientific and technological level is key to achieving these supporting tasks. In this respect, Gansu has cooperated with countries along the B&R route at the research paper level. Thus, the top 50 countries that have co-authored research papers with Gansu Province include 22 countries taking part in the B&R initiative. The number of co-authored papers between Gansu Province and these 22 countries is 2600, accounting for 23.68% of the total number of co-authored papers (i.e., 10,979).

In addition, while Gansu Province and those countries taking part in the B&R initiative clearly have a good basis for cooperating on research papers, there remains room for improvement in terms of the intensity of cooperation. Moreover, among the top 50 cooperating countries/regions, those involved in the B&R initiative account for only 34.4% of all countries that are involved that initiative. Hence, the development of strategies for further promoting cooperation between Gansu Province and countries taking part in the B&R initiative in multiple fields, with S&T as a starting point, requires further attention and effort.

3.2.2 Cooperating institutions

For the institutions that have conducted cooperation with Gansu Province, 130 co-authored papers were taken as the threshold, and the top 50 domestic (i.e., Gansu Province) institutions involved in co-authored research papers were identified and plotted on a cluster map by using integrated software such as VosViewer, Gephi, Ucinet, and Scimago Graphica. As shown in Fig. 3; Table 1, the cluster map can be divided into 6 clusters. It should be noted that while these institutions are clustered according to their networks of co-authored papers, there are many links between different clusters. This relationship is indicated by the colored lines, and the thickness of each line represents the intensity of the partnership.

The results in Fig. 3; Table 1 reveal obvious attribute similarities among the institutions that have co-authored papers with Gansu Province. For example, there are 19 institutions in the first cluster, which contains Lanzhou University, Gansu Provincial Medical University, and the hospital system as the main actors. These bring together numerous medical colleges and universities, along with well-known universities and disciplines that are included in China's "double world-class project." Meanwhile, the second cluster contains 11 institutions and is dominated by 9 universities and research institutions in Gansu Province. In the third cluster, there are eight institutions, including institutions under the Chinese Academy of Sciences, and institutions and universities in the field of atmospheric science. The fourth cluster is mainly composed of agricultural and forestry institutions, and colleges and universities involved in agriculture,
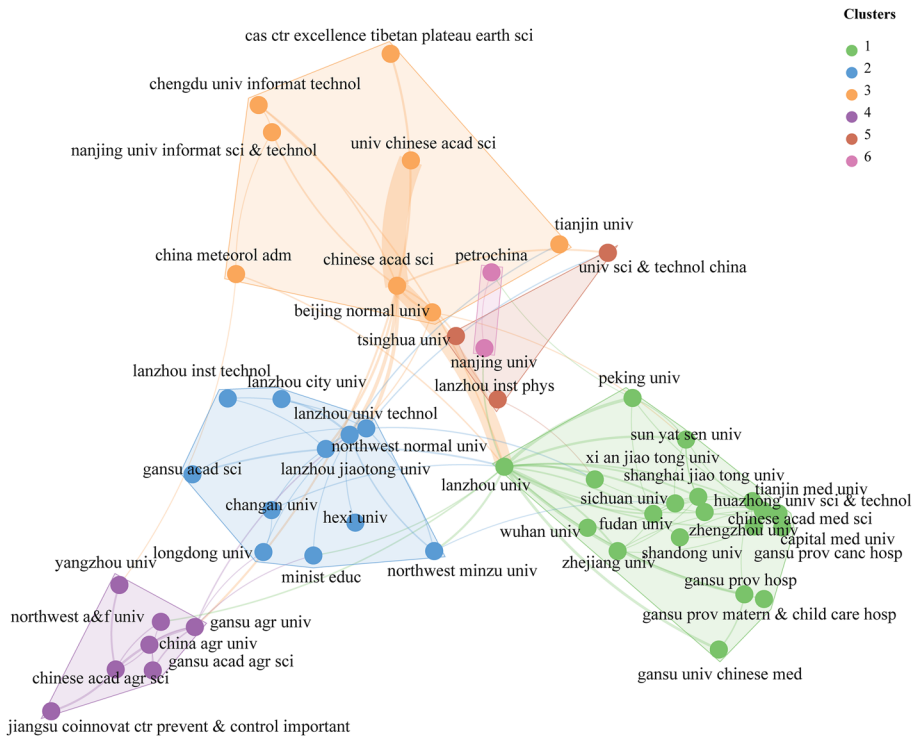

Fig. 3 The domestic institutions and their co-authorship clusters

Table 1 The clusters of domestic institutions with international co-authorships

Cluster/Number	Institutions
1 (19)	*Capital Med Univ; Chinese Acad Med Sci; Fudan Univ; Gansu Prov Canc Hosp; Gansu Prov Hosp; Gansu Prov Matern & Child Care Hosp; Gansu Univ Chinese Med; Huazhong Univ Sci & Technol; Lanzhou Univ; Peking Univ; Shandong Univ; Shanghai Jiao Tong Univ; Sichuan Univ; Sun Yat Sen Univ; Tianjin Med Univ; Wuhan Univ; Xi'an Jiao Tong Univ; Zhejiang Univ; Zhengzhou Univ;*
2 (11)	*Changan Univ; Gansu Acad Sci; Hexi Univ; Lanzhou City Univ; Lanzhou Inst Technol; Lanzhou Jiaotong Univ; Lanzhou Univ Technol; Longdong Univ; Minist Educ; Northwest Minzu Univ; Northwest Normal Univ*
3 (8)	*Beijing Normal Univ; Cas Ctr Excellence Tibetan Plateau Earth Sci; Chengdu Univ Informat Technol; China Meteorol Adm; Chinese Acad Sci; Nanjing Univ Informat Sci & Technol; Tianjin Univ; Univ Chinese Acad SciBeijing Normal Univ; Cas Ctr Excellence Tibetan Plateau Earth Sci; Chengdu Univ Informat Technol; China Meteorol Adm; Chinese Acad Sci; Nanjing Univ Informat Sci & Technol; Tianjin Univ; Univ Chinese Acad Sci*
4 (7)	*China Agr Univ; Chinese Acad Agr Sci; Gansu Acad Agr Sci; Gansu Agr Univ; Jiangsu Coinnovat Ctr Prevent & Control Important; Northwest A&F Univ; Yangzhou Univ*
5 (3)	*Lanzhou Inst Phys; Tsinghua Univ; Univ Sci & Technol China;*
6 (2)	*Nanjing Univ; Petrochina*

biology, animal husbandry, and other related fields. In the fifth cluster, there are 3 institutions, including the Lanzhou Institute of Physics, Tsinghua University, and the University of Science and Technology of China. The sixth cluster includes 2 institutions, namely Nanjing University and Petro China.

The above analysis indicates that Gansu Province maintains good co-authorship relationships with well-known universities, research institutions, and ministries in China, where the province has established obvious cooperative networks with well-known professional research institutions in many fields, including medicine, engineering science, atmospheric science, agricultural and forestry science, space science, and energy resources. This situation will assist Gansu Province in continuing to actively engage in the development of such disciplines in the future.

3.3 Journals and their research areas

As shown in Fig. 4, the top 15 journals in terms of the number of papers published include Medicine, Scientific Reports, RSC Advances, Science of the Total Environment, Physical Reviews D, Sciences in Cold and Arid Regions, Organic Letters, Chemical Communications, New Journal of Chemistry, PLOS One, Physical Reviews C, Applied Surface Science, Journal of Alloys and Compounds, ACS Applied Materials and Interfaces, and IEEE Access. These journals encompass the following nine research areas: chemistry, engineering, physics, materials science, environmental sciences and ecology, other topics in science and technology, computer science, physical geography, and general and internal medicine (Fig. 5).
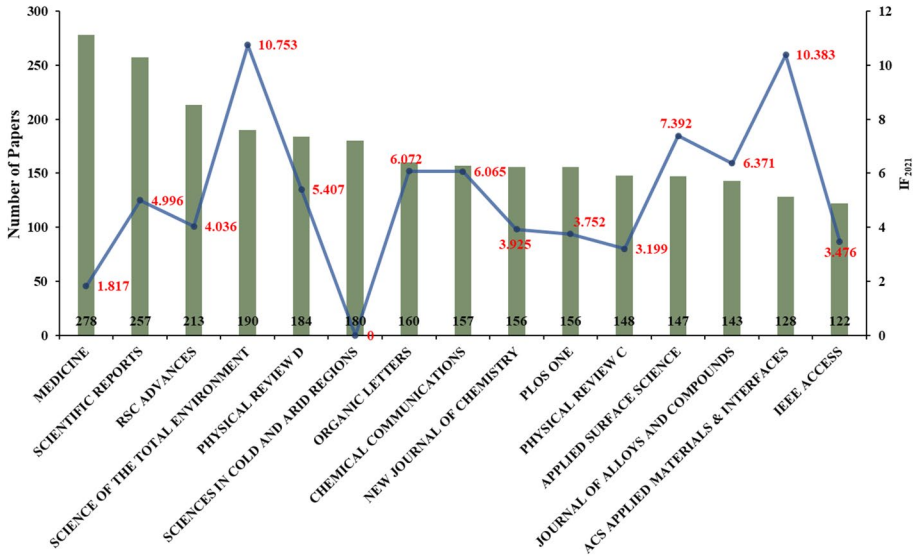
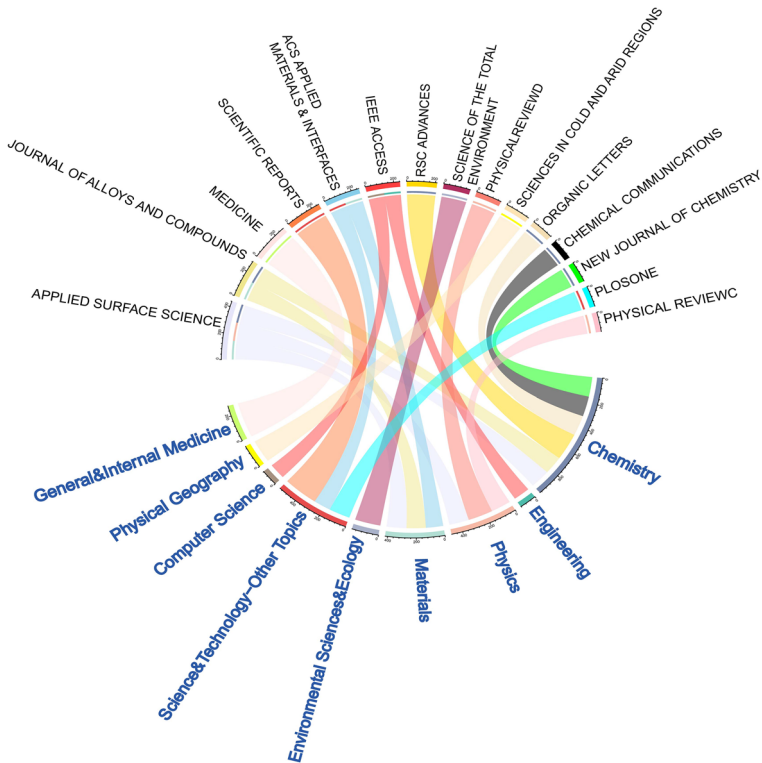**Fig. 4** The major journals with the most published papers in Gansu Province

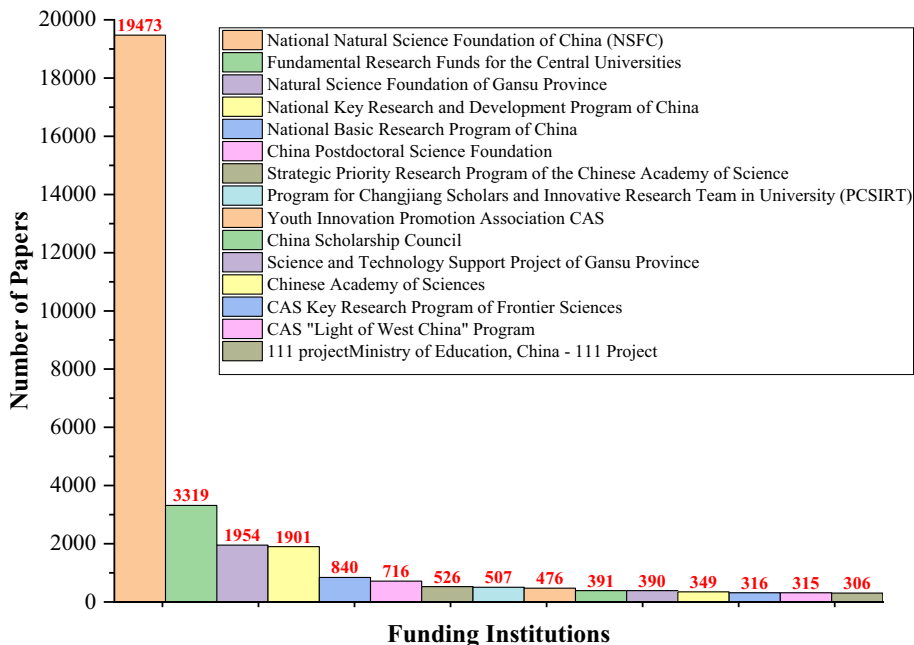**Fig. 5** The research areas represented by the major journals

Fig. 6 The main funding institutions for research papers in Gansu Province during the 13th FYP period

3.4 Funding institutions

As shown in Fig. 6, the top 15 funding institutions include the National Natural Science Foundation of China (NSFC), Fundamental Research Funds for the Central Universities, the Natural Science Foundation of Gansu Province, the National Key Research and Development Program of China, the National Basic Research Program of China, the China Postdoctoral Science Foundation, the Strategic Priority Research Program of the Chinese Academy of Science (CAS), the Program for Changjiang Scholars and Innovative Research Team in University (PCSIRT), the Youth Innovation Promotion Association (CAS), the China Scholarship Council, the Science and Technology Support Project of Gansu Province, the Chinese Academy of Sciences, the CAS Key Research Program of Frontier Sciences, the CAS "Light of West China" Program, and the 111 project of the Ministry of Education (China-111 Project).

The results in Fig. 6 indicate that the National Natural Science Foundation of China funded 19,473 papers, accounting for 65% of all papers. Meanwhile, 3319 papers were supported by the Fundamental Research Funds for the Central Universities, accounting for 11.1%. The Natural Science Foundation of Gansu Province ranks in third place, having funded a total of 1954 papers, accounting for 6.5% of the overall total. Out of the top 15 funding institutions, 5 are under the umbrella of the Chinese Academy of Sciences (CAS), which has supported 1982 papers, accounting for 6.6% of the overall total. In particular, the Provincial Natural Science Fund and Provincial Science and Technology Project have played important roles in the output of research papers in Gansu Province during the 13th FYP period. However, the efforts have been limited and need to be strengthened.

3.5 Research areas

In the Web of Science (WOS) database, each paper is classified according to the research area. A discussion of this index will assist in clearly grasping the priorities and advantages of research papers in Gansu Province. Therefore, to support the strategic planning of S&T strength during the 14th FYP period, the present study focuses on the overall characteristics of each research area during the 13th FYP period in terms of the number of papers, the layout and changes therein year by year, and the influence of the papers in various other areas. It should be noted that the same paper is sometimes associated with multiple fields and, as a result, the number of papers in the statistics is higher than the actual total number of papers. However, this does not prevent an unbiased reflection of the research intensity in various fields.

3.5.1 The number of papers in various research areas

The top 20 research areas are shown in Fig. 7. Here, the research areas with more scientific and technological outputs encompass the 4 disciplines of science, engineering, agricultural science, and medicine, within which chemistry, engineering, physics, material science, and the environmental sciences and ecology are the top five in terms of the numbers of papers published. The average number of papers is 3873, and the total number of papers is 19,367, which accounts for 64.7% of the overall total (29,951).
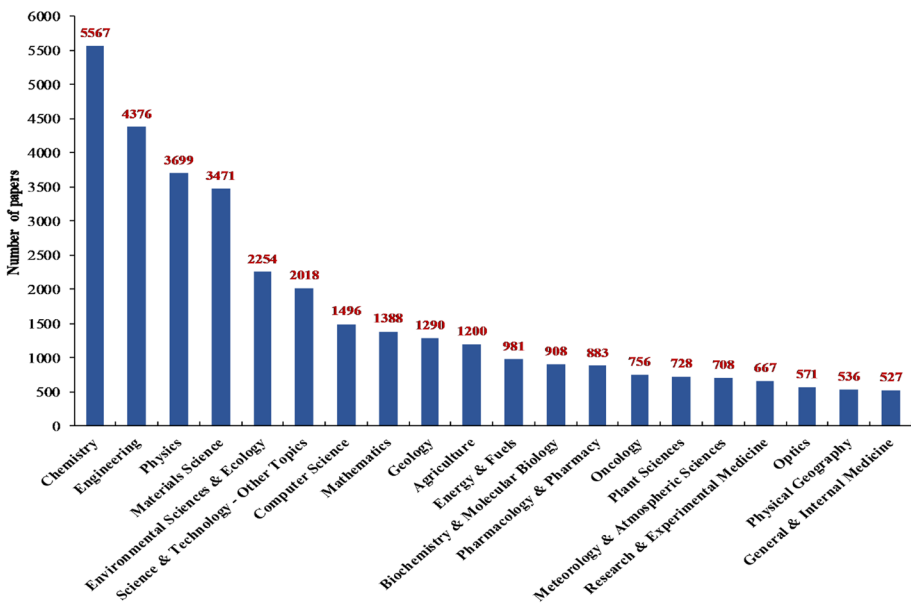

Fig. 7 The top 20 research areas of papers in Gansu Province during the 13th FYP period

3.5.2 Year-by-year changes in the characteristics of papers in the various fields

The results in Fig. 8 indicate that while the characteristics of papers in the various research areas have changed in various ways during the 13th FYP period, the total number of papers in each discipline remained consistent with the overall trend for papers within that area in the same year.

For example, the field of chemistry produced more papers in 2019 and 2018, but fewer papers in 2016 and 2020. Moreover, the number of chemistry-related papers published in 2019 is almost 1200 more than in 2016. The trends in engineering and physics are similar to those in chemistry; however, for environmental science and ecology, the two years with the least papers are 2016 and 2017. Meanwhile, oncology, plant science, research and experimental medicine, and physical geography exhibit only slight changes in the total number of papers, which are related to the total number of papers in these fields.

3.5.3 The influence of papers in various research areas

The calculated number of citations per paper for the top 20 areas during the 13th FYP period in Gansu Province is shown in Fig. 9, which also reveals the international influence of papers in various research areas. Here, five fields, including science and technology—other topics, chemistry, energy and fuels, material science, and meteorology and atmospheric sciences each exceeded 15 citations, thereby indicating that Gansu Province has significant advantages in scientific research within these fields. The numbers of citations in energy and fuels and meteorology and atmospheric sciences were 18.6 and 15.5, respectively, which indicate good performance. Further, more than 10 citations were received in each of the following fields: environmental science and ecology, geology, physics, agriculture, biochemistry and molecular biology, oncology, plant science, physical geography, and engineering, which indicate fairly good performance. Notably, the number of citations is not absolutely related to the total number of papers in each field. These results also show that research fields such as chemistry, material science, and science and technology—other
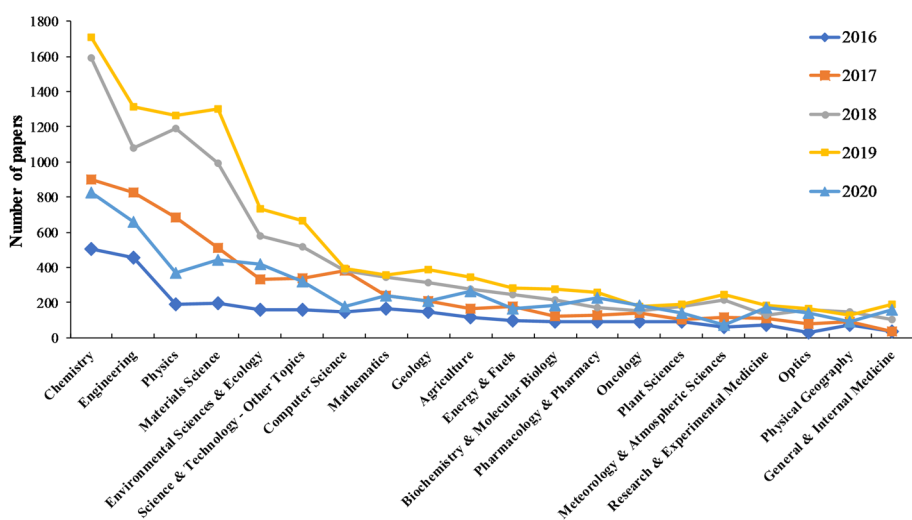

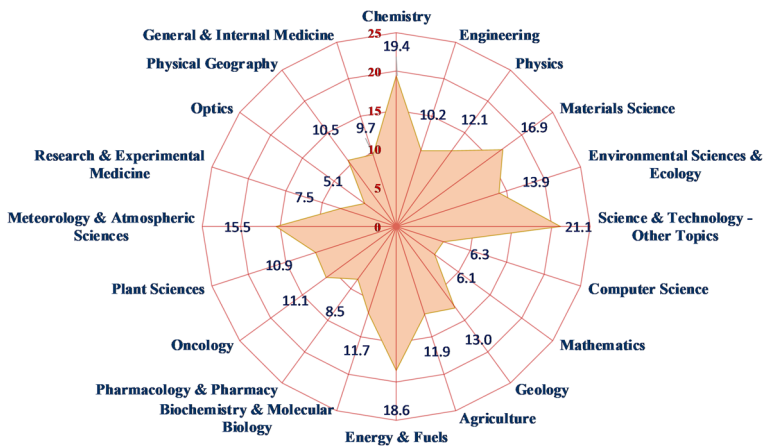**Fig. 8** Year-on-year changes in the Top 20 research areas

Fig. 9 The number of citations per paper for the top 20 research areas during the 13th FYP period in Gansu Province

topics are the most important and advantageous disciplines in Gansu Province. Hence, these fields deserve continuous support and cultivation. However, while energy and fuels and meteorology and atmospheric sciences have a relatively small number of published papers, these areas are expected to experience new breakthroughs in Gansu Province in the future and are worthy of further support and cultivation.

4 Conclusions, recommendations, and study limitations

4.1 Conclusion

The present study systematically analyzed the bibliometric characteristics of the knowledge graph of scientific and technological (S&T) innovation papers in Gansu Province during the 13th Five-Year Plan (FYP) period, based on the following five indicators: (i) the numbers and types of paper, (ii) co-authorship, (iii) the main publications and their fields, (iv) the main supporting institutions, and (v) the major research fields. The following conclusions were drawn:

(1) During the 13th FYP period, the total number of papers was 29,951, which was about 2.89 times higher than that during the 12th FYP period;
(2) Gansu Province collaborated with 149 countries/regions globally, with the USA, Germany, the UK, Australia, and Japan being the top 5 collaborators. Among the top 50 countries/regions, 22 countries are involved in the Belt and Road (B&R) initiative, and these account for 34.4% of all countries involved in that initiative. Further, Gansu Province maintains good co-authorship relationships with well-known universities, research institutions, and ministries and commissions in China, encompassing fields such as engineering science, atmospheric science, agriculture and forestry science, space science, and energy and resources;
(3) The most papers were published in the journals Medicine, Scientific Reports, RSC Advances, and Science of the Total Environment;

(4) The most funding was sourced from the National Natural Science Foundation of China, along with various ministries and commissions at the national level, and at the domestic level;

(5) The top 20 research areas covered the following 4 disciplines: science, engineering, agricultural science, and medical science, although the publication patterns of each research area varied from year-to-year in differing ways during the 13th FYP period.

4.2 Recommendations

In view of the above results, the following recommendations are made:

(1) Multiple forms of S&T output should be encouraged in the future, and the strategic requirement and importance of S&T output should not be abandoned. Full play should be given to the role of research papers as significant and solid sources for innovation. Hence, the production of high-quality research papers should be encouraged, with a focus on evaluating the influence and multi-dimensional value of these research papers for supporting the strategic layout of S&T innovation, and meeting the requirements of S&T development in the 14th FYP period. The specific mechanism of evaluation needs further attention and should involve a science-based approach;

(2) It is suggested that Gansu province should continue to strengthen the intensity of its international cooperation, deepen and intensify its cooperation with countries involved in the B&R initiative, and expand the scope of its cooperation between provincial institutions and domestic and foreign institutions;

(3) While the intensity of S&T support needs to be strengthened at the provincial level, more attention should be paid to the role of high-quality papers in the requirements for, and evaluation of, the outputs of S&T projects at that level;

(4) The support for the key areas of chemistry, engineering, physics, material science, environmental science and ecology, etc., should continue to be increased, including project investment, platform construction, talent introduction, and other approaches, in order to generate domestic and international influences in these dominant disciplines, and to drive the overall development of S&T innovation activities in the province.

4.3 Study limitations

The retrieval of scientific papers is the basis of all bibliometric analyses. Although the present study searched as comprehensively as possible for S&T papers in Gansu Province, papers in Chinese were not included in the analysis. This is a limitation because Chinese papers are a very important part of the S&T innovation output In addition, although the globally popular Web of Science (WOS) database was used for paper retrieval, many databases, including Scopus and EI Compendex, also contain large numbers of excellent scientific research papers. The choice of only one database therefore leads inevitably to some papers being overlooked.

In future, the research content of the present paper should be expanded in terms of the following aspects: (i) a comparative study between developed and underdeveloped areas; (ii) a comparative study of the knowledge maps for different years; (iii) comparative research between various or additional research areas; and (iv) research into the impact of COVID-19 upon the knowledge map of S&T innovation in less developed regions. All

of these will be of great benefit to the strategic layout of future S&T innovation in Gansu Province.

Data availability Not applicable.

Declarations

Conflict of interest The authors declare that they have no known competing financial interest or personal relationships that could have appeared to influence the work reported in this paper.

Ethical approval Not applicable.

Consent to participate Not applicable.

Consent to publish Not applicable.

References

Amaral, O. B., & Neves, K. (2021). Reproducibility: Expect less of the scientific paper. *Nature*, *597*(7876), 329–331.

Bollacker, K., Evans, C., Paritosh, P., Sturge, T., & Taylor, J. (2008). Freebase: A collaboratively created graph database for structuring human knowledge. In *Proceedings of the 2008 ACM SIGMOD international conference on Management of data* (pp. 1247–1250).

Cavalcante, W. Q. D. F., Coelho, A., & Bairrada, C. M. (2021). Sustainability and tourism marketing: A bibliometric analysis of publications between 1997 and 2020 using vosviewer software. *Sustainability*, *13*(9), 4987.

Carmona-Serrano, N., López-Belmonte, J., López-Núñez, J. A., & Moreno-Guerrero, A. J. (2020). Trends in autism research in the field of education in web of Science: A bibliometric study. *Brain sciences*, *10*(12), 1018.

Chen, X., Jia, S., & Xiang, Y. (2020). A review: Knowledge reasoning over knowledge graph. *Expert Systems with Applications*, *141*, 112948.

Chen, X., Xie, H., Li, Z., & Cheng, G. (2021). Topic analysis and development in knowledge graph research: A bibliometric review on three decades. *Neurocomputing*, *461*, 497–515.

China Science and Technology Development Strategy Research Group, National Research Center for Innovation and Entrepreneurship, University of Chinese Academy of Sciences. (2021). *China's Regional Innovation capacity evaluation report 2021*. Beijing: Scientific and Technical Documentation Press. (In Chinese).

Cooke, P. (1992). Regional innovation systems: Competitive regulation in the new Europe. *Geoforum*, *23*(3), 365–382.

Crane, D. (1977). Technological innovation in developing countries: A review of the literature. *Research Policy*, *6*(4), 374–395.

Dolfsma, W., & Seo, D. (2013). Government policy and technological innovation—a suggested typology. *Technovation*, *33*(6–7), 173–179.

Du, Y., & Li, H. (2021). Measurement of Regional scientific and technological innovation capability based on the evaluation of subsystem collaboration degree—illustrated by the example of Gansu Province. *Forum on Science and Technology in China*, *02*, 91–99 (**In Chinese**).

Edquist, C. (2004). Reflections on the systems of innovation approach. *Science and Public Policy, 31*(6), 485–489.

Edquist, C. (2010). Systems of innovation perspectives and challenges. *African Journal of Science Technology Innovation and Development*, *2*(3), 14–45.

Gong, X. (2019). The belt & road initiative and China's influence in Southeast Asia. *The Pacific Review*, *32*(4), 635–665.

He, L., & Liu, Y. (2015). Based on entropy method regional innovation capability evaluation in gansu province. In *Proceedings of the ninth international conference on management science and engineering .anagement* (pp. 893–901). Berlin, Heidelberg: Springer.

Heinzen, T. E., Mills, C., & Cameron, P. (1993). Scientific innovation potential. *Creativity Research Journal*, *6*(3), 261–269.

Jia, H. (2017). Scientific collaborations shine on Belt and Road. *National Science Review*, *4*(4), 652–657.

Jones, C. I., & Williams, J. C. (1998). Measuring the social return to R&D. *The Quarterly Journal of Economics*, *113*(4), 1119–1135.

Kaczmarski, M. (2017). Two ways of influence-building: The eurasian economic union and the one belt, one road initiative. *Europe-Asia Studies*, *69*(7), 1027–1046.

Kang, D., Jang, W., Kim, Y., & Jeon, J. (2019). Comparing national innovation system among the USA, Japan, and Finland to improve korean deliberation organization for national science and technology policy. *Journal of Open Innovation: Technology Market and Complexity*, *5*(4), 82.

Kapucu, N., & Demiroz, F. (2011). Measuring performance for collaborative public management using network analysis methods and tools. *Public Performance & Management Review*, *34*(4), 549–579.

Ke, H., Dai, S., & Fan, F. (2021). Does innovation efficiency inhibit the ecological footprint? An empirical study of China's provincial regions. *Technology Analysis & Strategic Management*, *34*(12):1369–1383.

Kessler, M. M. (1963). Bibliographic coupling between scientific papers. *American Documentation, 14*(1), 10–25.

Kline, S. J., & Rosenberg, N. (2010). An overview of innovation. Studies on science and the innovation process: Selected works of Nathan Rosenberg, 173–203.

Li, H., Zhang, A., & Yang, W. (2015). Research on science and technology innovation ability of independent scientific research institutes in Gansu Province. *Gansu Science and Technology*, 31(19): 1–51. (In Chinese)

Li, Z., Xu, C., Fu, J., Zulipikaer, M., Deng, T., & Chen, J. (2022). Scientific knowledge graph and trend analysis of central sensitization: A bibliometric analysis. *Journal of Pain Research*, *15*, 561.

Liu, W. H., Zheng, J. W., Wang, Z. R., Li, R., & Wu, T. H. (2021). A bibliometric review of ecological research on the Qinghai–Tibet Plateau, 1990–2019. *Ecological Informatics*, *64*, 101337.

Liu, W., Wang, Z., Li, R., & Wu, T. (2022). A bibliometric analysis of mountain ecosystem services, 2000–2019. *Environmental Science and Pollution Research*, *29*(11), 16633–16652.

López Belmonte, J., Segura-Robles, A., Moreno-Guerrero, A. J., & Parra-González, M. E. (2020). Machine learning and big data in the impact literature. A bibliometric review with scientific mapping in web of science. *Symmetry*, *12*(4), 495.

Ma, Z. (2022). Evaluation and coupling analysis of scientific and technological innovation and high-quality economic development in Gansu Province. *World Scientific Research Journal*, *8*(8), 593–601.

Mulet-Forteza, C., Genovart-Balaguer, J., Mauleon-Mendez, E., & Merigó, J. M. (2019). A bibliometric research in the tourism, leisure and hospitality fields. *Journal of Business Research*, *101*, 819–827.

Ozkaya, G., Timor, M., & Erdin, C. (2021). Science, technology and innovation policy indicators and comparisons of countries through a hybrid model of data mining and MCDM methods. *Sustainability*, *13*(2), 694.

Paulheim, H. (2017). Knowledge graph refinement: A survey of approaches and evaluation methods. *Semantic Web, 8*(3), 489–508.

Peters, M., Schneider, M., Griesshaber, T., & Hoffmann, V. H. (2012). The impact of technology-push and demand-pull policies on technical change–Does the locus of policies matter? *Research Policy*, *41*(8), 1296–1308.

Price, D. J. D. S. (1965). Networks of scientific papers: The pattern of bibliographic references indicates the nature of the scientific research front. *Science*, *149*(3683), 510–515.

Pujara, J., Miao, H., Getoor, L., & Cohen, W. (2013). Knowledge graph identification. In *International semantic web conference* (pp. 542–557). , Berlin, Heidelberg: Springer.

Sharif, M. N. (2012). Technological innovation governance for winning the future. *Technological Forecasting and Social Change*, *79*(3), 595–604.

Shi, F. Z., Jia, D. Q., Liu, S. P., Zhang, Y. H., & Wang, X. Y. (2017). Study on scientific and technological innovation capacity of industrial enterprises in Gansu Province. *Mechanical Research & Application*, *30*(05), 193–196. (In Chinese).

Smith, M., Busi, M., Ball, P., & Van Der Meer, R. (2008). Factors influencing an organisation's ability to manage innovation: A structured literature review and conceptual model. *International Journal of Innovation Management*, *12*(04), 655–676.

Steil, B., Victor, D. G., & Nelson, R. R. (2002). *Technological innovation and economic performance*. Princeton: Princeton University Press.

Teng, Y., & Zhang, X. (2018). An analysis of science and technology innovation policy in Gansu Province based on policy text. *Productivity Research, 2018*(10), 85–88. (In Chinese).

Tödtling, F. (1992). Technological change at the regional level: The role of location, firm structure, and strategy. *Environment and Planning A*, *24*(11), 1565–1584.

Van Eck, N. J., & Waltman, L. (2011). Text mining and visualization using VOSviewer. arXiv preprint arXiv:1109.2058.

Van Eck, N., & Waltman, L. (2010). Software survey: VOSviewer, a computer program for bibliometric mapping. S*cientometrics*, *84*(2), 523–538.

Wang, Q., Cui, T., & Deng, P. (2022). Medicine-Engineering interdisciplinary research based on bibliometric analysis: A case study on Medicine-Engineering Institutional Cooperation of Shanghai Jiao Tong University. *Journal of Shanghai Jiaotong University (Science)*, 1–16

Wang, S., Zhang, J., Fan, F., Lu, F., & Yang, L. (2019). The symbiosis of scientific and technological innovation efficiency and economic efficiency in China—An analysis based on data envelopment analysis and logistic model. *Technology Analysis & Strategic Management*, *31*(1), 67–80.

Wei, H., & Shi, S. (2021). Evaluation of innovation capability of national agricultural science and technology parks in Gansu Province -- based on entropy weight method and TOPSIS method. *Productivity Research*, *2021*(02), 51–54. (In Chinese).

Xu, D., Yin, X., Zhou, S., Jiang, Y., Xi, X., Sun, H., & Wang, J. (2022). A review on the remediation of microplastics using constructed wetlands: Bibliometric, co-occurrence, current trends, and future directions. *Chemosphere*, 134990.

Yang, L., & Ma, J. (2021). Study on the influence of science and technology expenditure on regional innovation ability in Gansu Province. *Journal of Lanzhou Institute of Technology, 28*(01), 92–99. (In Chinese).

Zhang, C. (2021). *Factors influencing the allocation of regional sci-tech financial resources based on the multiple regression model*. Mathematical Problems in Engineering, 2021.

Zhang, N., Cao, F., & Ye, D. (2014). Regional innovation evaluation of northwest based on grey relational analysis. *Chinese Agricultural Science Bulletin, 30*(17), 76–81. (In Chinese).

Zhao, Y., Huang, L., Liu, M., Gao, H., & Li, W. (2021). Scientific knowledge graph of acupuncture for migraine: A bibliometric analysis from 2000 to 2019. *Journal of Pain Research, 14*, 1985.