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Tracking the featured topics of the International Science of Team Science conference series and their evolution during 2010–2019

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Abstract

In this paper, we study how research topics and trends have evolved in the field of the science of team science (SciTS). Over the past 12 years, the International Science of Team Science conference has been making efforts to understand and enhance the processes and outcomes of collaborative team science. We argue that the sessions and papers in academic conferences are the best way to reflect the latest research trends. Based on the panel sessions and submitted papers in conference programs during 2010–2019, this study tracks the featured topics and how they have evolved in the field. We extracted terms from the titles of the sessions and papers, and visualized the research hotspots, research topics, and how they have evolved for analysis. We found that the research hotspots are constantly changing, and the research topics present evolutionary characteristics, such as continuation, split, and fusion. Additionally, we examined the models and case studies of team science, the characteristics and dynamics of teams, the interdisciplinary research dynamics in team science, team science education and training, and how team science is measured and evaluated. These results summarize the major research trends and opportunities in the SciTS field.

Keywords Team science · Science of team science · Research topics · Topic evolution · SciTS conference

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Introduction

The complexity, scope, and scale of scientific research have all greatly increased (Fontanarosa et al., 2017). Large-scale, team-based research initiatives have seen an increase in interest and funding since the 1990s as a means of tackling complex, multifaceted issues that call for interdisciplinary collaboration (Jones et al., 2008; Stokols et al., 2008a, 2008b; Wikipedia, 2020). This trend toward increasingly team-based research collaborations has become known as team science (Fontanarosa et al., 2017; National Research Council, 2015).

With the growing scale of research collaborations and teamwork in different fields, team sizes are increasing due to the significant advantages of team science (Wuchty et al., 2007). Furthermore, team-based publications generally have an advantage over individual authors in producing high-impact papers (Börner et al., 2010; Jones et al., 2008; Liu et al., 2020). However, collaborative research also presents many challenges, such as a high diversity of membership, deep knowledge integration, huge team size, goal misalignment with other teams, permeable boundaries, geographic dispersion, and high task interdependence (National Research Council, 2015). The science of team science (SciTS) has emerged as a field to study and address these challenges. This field seeks to understand and enhance the processes and outcomes of collaborative, team-based research (Falk-Krzesinski et al., 2010). SciTS examines the processes by which teams organize, communicate, and conduct research. Understanding and managing circumstances to improve the effectiveness of team science initiatives, such as scientific discoveries, educational outcomes, and the translation of research findings into new practices, patents, products, technological advances, and policies, is of particular interest in this field (Stokols et al., 2008a, 2008b; Börner et al., 2010; Falk-Krzesinski et al., 2010; Little et al., 2017; Yu et al., 2019).

During the early development phase of the SciTS field, efforts to understand and improve team science were scattered and uncoordinated. As a result, in 2010, the first annual International Science of Team Science conference was held. The conference aimed to bring together thought-leaders from multiple disciplines to talk about the best ways to work together as a team, with the goal of achieving scientific breakthroughs that could not be attained individually. Today, the SciTS conference has been successfully held for more than 10 years, bearing witness to the development of the SciTS field. Every year, pioneers from a variety of fields gather at the conference to present and discuss their latest research in the field of SciTS. At present, a great number of researchers, practitioners, and policymakers have become aware of the effectiveness and significance of team science. In addition, many funding agencies and private enterprises have funded interdisciplinary research initiatives to foster collaborations across fields and the development of team science (Börner et al., 2010; Sellers et al., 2006).

Since 2001, publications in the SciTS field have grown considerably (Falk-Krzesinski et al., 2011). Many scholars have discussed issues, such as the definition of terms, methodologies, metrics, and multi-level systems perspectives for SciTS. Stokols et al. (2008a, 2008b), for example, discussed and summarized substantive concerns and research foci within the SciTS field in three respects, including conceptual concerns, methodologic and measurement issues, and translational strategies. Börner et al. (2010) proposed a multilevel systems perspective (macro-level, meso-level and micro-level) for SciTS, roughly classifying different research issues of team science into questions of when (temporal), where (geospatial), what (topical), with whom (network), how (process), and why (modeling). These studies have given us a better understanding of this field.

Others have focused on identifying the main research issues and how to classify research topics in the field of SciTS. Falk-Krzesinski et al. (2011) used a collaborative team science concept-mapping evaluation methodology to develop a comprehensive research agenda for the SciTS field. In this agenda, seven important research topics of team science were identified: (1) measurement and evaluation of team science; (2) definitions and models of team science; (3) institutional support and professional development for teams; (4) disciplinary dynamics and team science; (5) structure and context for teams; (6) management and organization for teams; and (7) characteristics and dynamics of teams. The method also uncovered their relative importance to the SciTS field. Hall et al. (2018) reviewed and summarized the empirical findings from the SciTS literature. They found that the empirical research findings centered around five key themes: the value of TS, team composition and its influence on TS performance, the formation of science teams, team processes central to effective team functioning, and institutional influences on TS. Based on the NIH's conceptualization of team science, a systematic review of the SciTS literature published between 2005 and 2015 made it clear that team science is an example of an effective and useful interprofessional collaborative research practice (Little et al., 2017).

However, these previous studies primarily use qualitative methods to analyze and summarize the key research issues facing the field. Few studies use quantitative methods or visualization tools to reveal research topics and show how they have evolved. Compared to qualitative methods, quantitative methods and visualization tools can more clearly identify the research topics, research hotspots, and their evolutionary characteristics over time. In addition, while most analyses of research topics and trends in a specific field are based on journal articles, conference papers and sessions can reflect the most recent research trends because major conferences serve as a forum for scholars to exchange new ideas. The SciTS conference is one of the most important and authoritative academic conferences in the field and has been funded by the National Institutes of Health (NIH), University of Chicago, Duke University, as well as leading companies such as Elsevier and Thomson Reuters/Clarivate. In this study, therefore, we analyze the research topics of SciTS and their evolutionary characteristics using visualization methods over a period of 10 years. Our corpus comprises conference sessions and papers. The main contributions of this study are a comprehensive and systematic analysis of research topics in the SciTS field; and an illustration of the dynamic evolution of these topics over the last 10 years based on quantitative methods and visualization tools. Additionally, our work not only investigates the development of SciTS, it also provides some references for future work.

Data and framework

Data source and data collection

Conferences are considered to stimulate scholarly communication within a given research topic or discipline through the researchers' presentation and discussion of their research findings, and the unique form of interactions that is only possible through the simultaneity of face-to-face, or, nowadays, virtual meetings (Zhang & Glänzel, 2012). The resulting conference proceedings can even be viewed as the end result of scientific research in some fields (Lisée et al., 2008). Compared to journal articles, they represent a much more rapid dissemination of research outcomes (Furukawa et al., 2015; Halpern & Parkes, 2011; Zhang & Glänzel, 2012). Furthermore, some studies have shown that conference proceedings can "measure the ability to come up with new ideas, whereas journal publication can more strongly contribute to building the knowledge base" (Montesi & Owen, 2008). At the same time, the citation impact of conference articles is often somewhat lower than the extended versions published in journals (Zhang & Glänzel, 2012). Moreover, academic conferences are thought to be specifically designed to advance the frontiers of knowledge within a scientific community (Furukawa et al., 2015).

The titles or abstracts of conference sessions and papers have been used to track the research hotspots and topics (Furukawa et al., 2015; Porter et al., 2012; Porter et al., 2003, 2005). In this study, however, there are large sessions without abstracts. For this reason, and because most of titles highlight the central topic of the session or paper, our analysis is solely based on the titles of sessions and papers. In addition, sessions and papers are distinct categories, but in the data analysis that follows, we didn't make a distinction between the two sources. This is due to the fact that in some years it merely had sessions and no papers. Specifically, we use the conference programs in the SciTS conference during 2010–2019 as a data source. A PDF or Word version of the conference program can be downloaded for all years except 2014, when only the web version of the conference schedule was available. In general, scholars engaged in conversation with others about their papers during conferences. As a result, many session and paper names are identical. If there was a duplicate title in the conference session and paper, we only kept one version. We thus assembled a list of 897 session and paper titles, the details of which are shown in Table 1. The low number for 2012 is due to the fact that the website (https://sts.memberclicks.net/2012-scits-conference) did not provide more information about the submitted abstracts, so the data available for analysis was limited. This may have an impact on the results of the following analysis for 2012. For instance, some research hotspots might be absent in 2012 due to a lack of data. It may also disrupt the continuity of the evolution of research topics.

Framework

The data processing and analysis framework and procedures are shown in Fig. 1. As shown in the figure, based on the obtained data collection, we first extracted the terms from the titles of the sessions and papers. In this procedure, we introduce the ITGInsight software (http://en.itginsight.com/), a scientific text mining and visual analysis tool, for data cleaning. We also used it to extract terms via the PC-Value method (Wang et al., 2022). Specifically, C-value is a domain-independent method for multi-word automatic term recognition that aims to increase the extraction of nested terms (Frantzi et al., 2000). The PC-value method is an improved C-value method that was originally used for patent data but has performed well with a range of different term recognition tasks. More specifically, only candidate terms that occur more than once are kept. The term processing procedure is as follows. After term segmentation, stop words (e.g. an, one, etc.), common terms (e.g., group, science, etc.), as well as low-frequency words (occurring only once) are removed, and words with similar stems are combined. Next, the authors carefully check all terms to ensure that terms with the same meaning are combined

Table 1 The number of records about the conference sessions and papers during 2010–2019

Year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Total
Number	44	55	11	65	99	149	136	94	116	128	897

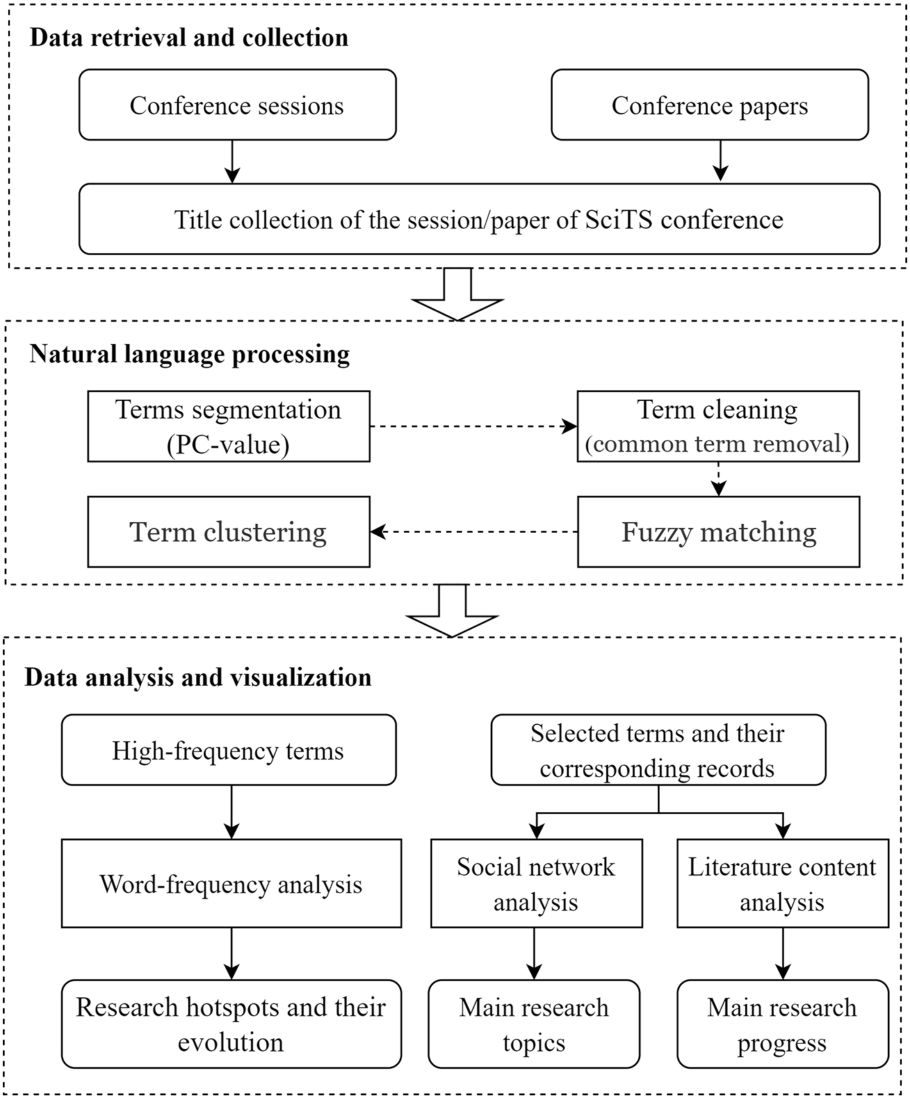


Fig. 1 The procedure and framework for data processing and analysis

and get the term clustering. And then, the resulting terms list could be obtained and was used as the basis for the following analysis.

We analyzed research hotspots, research topics, and their evolution using word-frequency analysis, social network analysis of co-occurring terms, and literature content analysis. In the process of data analysis, we first imported the Excel file with the year and terms into the OpenOffice.org software to create a CSV file that could be imported into the CorTexT platform (https://www.cortext.net/). This platform was used to visualize the research hotspots, research topics, and their evolution, thereby demonstrating the development of the SciTS field in the conference landscape.

Word-frequency analysis

Word frequency analysis is a method of counting and analyzing the number of occurrences of important words in a document's text in order to select the words with the highest frequency to express the topics of document. It is a useful text mining tool that can be used to quantitatively analyze text content by counting high-frequency words. In this study, the frequency of terms in the titles reflects the extent to which scholars are concerned with the corresponding research issues. The more frequently the terms are used, the more attention the research issues have received. The high-frequency terms were deemed to indicate research hotspots.

In general, a domain will have multiple high-frequency terms per year. The number is determined by the threshold for high frequency. Also, as time passes, these high-frequency terms will change due to shifting scholarly interests. To analyze the high-frequency terms and their changes over the ten-year period, we chose the Epic Epoch (CorText team, 2020b) in the CorTexT platform. We extracted the 10 most-used terms in each of five stages (2010–2011, 2012–2013, 2014–2015, 2016–2017, 2018–2019) and analyzed the evolution of these research hotspots in more detail.

Social network analysis

In the field of bibliometrics, the results of term co-occurrence analysis are commonly used to represent research topics. If a group of terms appears frequently together in the same records, they will form a community in the co-occurrence network. Communities can be viewed as research topics. Moreover, social network analysis can be used to analyze the connection relationship of nodes in a community. Like the changes in high-frequency terms, the network connections between terms and the structure of communities are changing in real time. From a dynamic perspective, there are also some dynamic connections between communities (research topics) formed by the connecting relationships of these high-frequency terms in different years.

Integration between multiple communities (research topics), for example, may occur in the following phase compared to the previous one. Figure 2 illustrates this process. According to the principle that communities are tightly connected internally and loosely connected externally (Girvan & Newman, 2002), terms A, B, C form community 1 (research topic 1) in the previous stage; terms D, E, F form community 2 (research topic 2). In the following

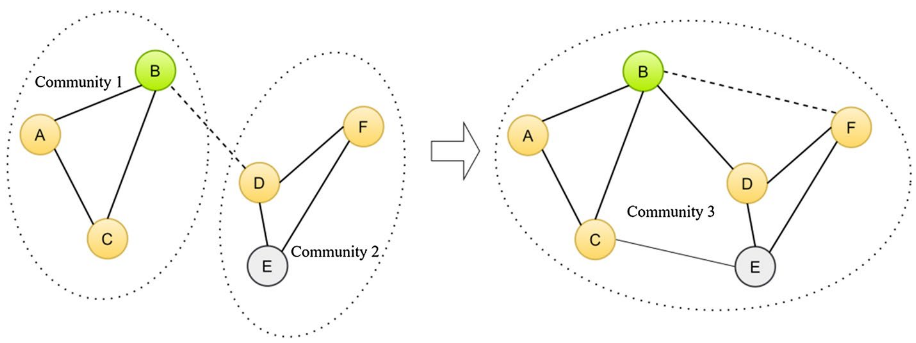


Fig. 2 The evolution of communities (research topics) in networks

stage, communities 1 and 2 gradually merge to form community 3, where the solid lines in the network represent strong relationships between nodes and the dashed lines represent weak relationships between nodes.

In order to analyze the evolution trend of research topics in the SciTS field over time, we selected any terms that appeared more than 10 times in the entire dataset as our main set of terms. We then used the CorTexT platform to visually display their co-occurrence and the evolutionary characteristics of the research topics over time. Specifically, we chose the Network Mapping (CorText team, 2020c) in the CorTexT platform to analyze the research topics and their evolution. The Louvain community detection algorithm (Blondel et al., 2008) was used to group the main high-frequency terms into different topics and identify the main research topics in the field. We also divided the data into five 2-year time slices and used the same community detection algorithm to demonstrate the evolution of each research topic over the 10-year period. To show these evolution in one diagram, we charted the evolution using the Tube Layout (CorText team, 2020a) in CorTexT.

Literature content analysis

Literature content analysis is an analytical method that examines the collected literature on a specific topic to determine the current state of research in that field and to derive one's own point of view from it. It aids the researchers in developing a general impression of the field of study and enables a dynamic grasp of the research topic in the field. In this study, we took the five topics generated by the co-occurrence network of the main high-frequency terms and analyzed the meaning of the terms and their co-occurrence relationships. From this, we further divided the research topics into five new categories. We then identified conference sessions that contained important terms and read papers to inform a deeper review and discussion of the research status of these categories in the SciTS field.

Evolution of hot topics in team science

Research hotspots and their evolution

As the defining term for the field as a whole, "Team Science" was consistently used with the highest frequency (196 times) across the 10 years. However, since it is an implied term in the field, we removed it from our analysis. Figure 3 shows the changes for the 10 next-most frequently occurring terms in each time slice over the period. Each time slice is made up of two consecutive years, for a total of 5 time slices. Since the top 10 terms in each time slice are not the same, we ended up with total of 21 high-frequency terms in the graph. The frequency of terms in each time slice is represented by the width and height of the color bands.

According to the word frequency analysis, there are many research hotspots that scholars are interested in, and terms have a variety of evolution characteristics. The top 21 high-frequency terms and their evolution tendency are shown in Fig. 3: Teams (83); Science Collaboration (49); Impact (46); Evaluation (33); Science of Team Science (32); Team Leadership (31); Team Science Training (28); Interdisciplinary Research (26); Case Study (26); Research Teams (24); Lessons (24); Interdisciplinary Integration (22); Translational Research (20); Research Networks (19); Network Perspectives (19); Bibliometrics (15);

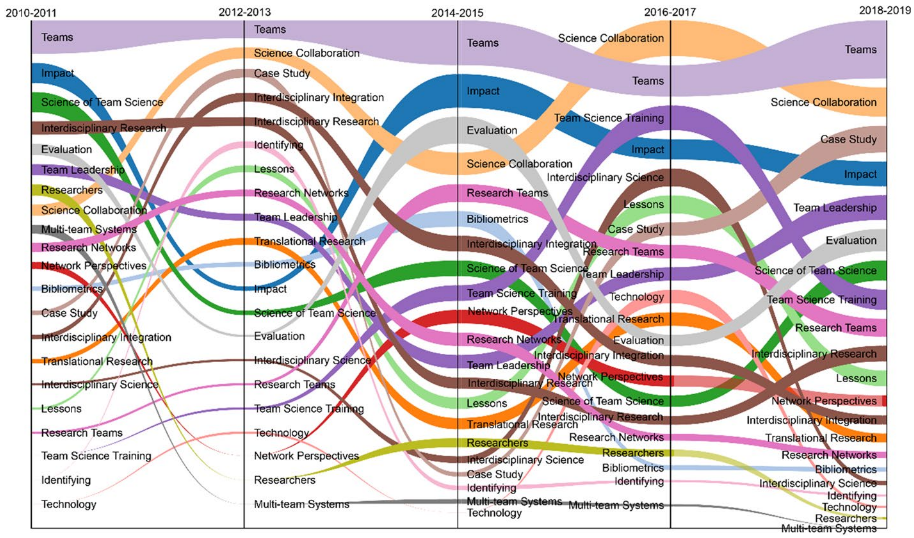


Fig. 3 The evolution of high-frequency terms in the SciTS field during 2010–2019

Interdisciplinary Science (15); Researchers (13); Technology (8); Identifying (7); Multi-team Systems (7).

It is understandable that those terms associated with team science, such as teams and science of team science, will appear more frequently. As illustrated in Fig. 3, the most commonly used term is "Teams", which sits in first place in all time slices except for 2016 and 2017. Furthermore, studies of team science naturally include collaboration, and team science often involves interdisciplinary teams. As a result, science collaborations, interdisciplinary research, interdisciplinary integration, translational research, impact, evaluation, and team science training with the higher frequency are also important hotspots of interest to scholars.

Figure 3 also shows peaks and troughs for other terms. Changes in the width and height of the color band reflect the scholars' shifting interests. It can be seen that the color bands in 2014–2019 (i.e., the last three-time slices) are wider than those in 2010–2013 (the first two time slices). It indicates that these terms have become more common over the last 5–6 years.

Research topics and their evolution

Next, we applied the Louvain algorithm (Blondel et al., 2008) for community detection to the term co-occurrence network, which grouped the main terms into five topics. These were interpreted as five topics, as shown in Fig. 4. We named these five topics after the two nodes with the highest co-occurrence frequency in each community. Thus, we have: (1) Team Science Education & Science of Team Science; (2) Interdisciplinary Integration & Team Science; (3) Interdisciplinary Research & Evaluation; (4) Research Productivity & Bibliometrics; (5) Case Study & Model. As illustrated in Fig. 4, the five topics are loosely related and have received varying degrees of attention. Interdisciplinary Integration & Team Science is the most important topic.

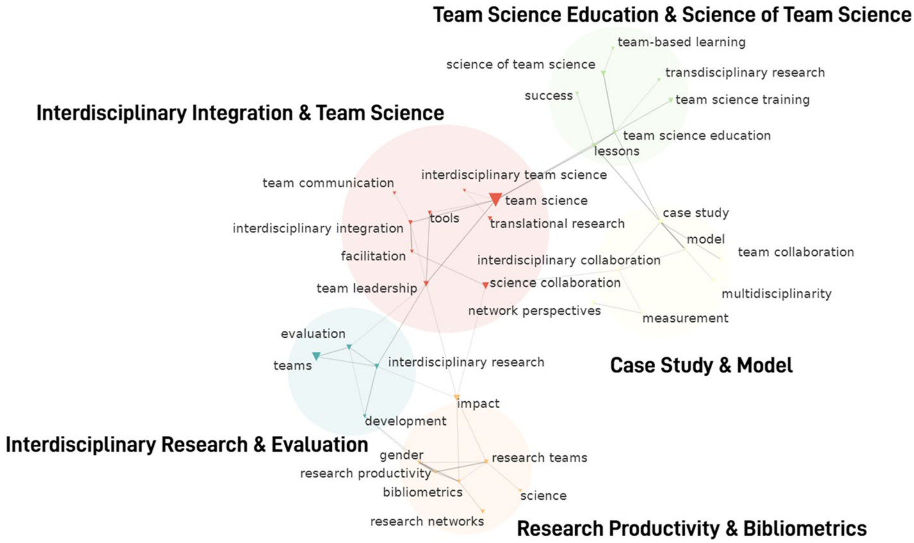


Fig. 4 The research topics of the SciTS field during 2010–2019

In order to clearly demonstrate the evolution of research topics in the SciTS field over the last 10 years, we divided the data into 5 time slices and identified the research topics in these slices (see Fig. 5). The field's main research interests include Bibliometrics, Case Study, Evaluation, Impact, Interdisciplinary Team Science, Research Networks, Science Collaboration, and Team Leadership.

Figure 5 allows us to see research topics and the terms they involve in each stage. There are 3, 6, 5, 5, 5 research topics in these five stages, respectively. However, we are unable to clearly perceive how research topics connect to one another or develop at various stages. For example, the terms of "bibliometrics" and "evaluation" contained in the topic of "Team Science & Bibliometrics" in the first stage (2010–2011) are the same as the terms contained in the topic of "Impact & Evaluation" in the second stage (2012–2013). This suggests that there is continuity between the two topics, and that the latter topic is likely to have developed from the former. In order to observe the connections that exist between these topics in the different stages, Fig. 6 displays the evolution of these research topics over the five stages by the Tubes Layout (CorText team, 2020a) in the CorTexT platform. The inter-temporal matching of clusters broadly consists of measuring the overlaps between the cluster composition—that is, weighing each node according to its centrality in its respective cluster (Cointet, 2019). There are two steps to this algorithm: (1) co-occurrence structure analysis; (2) restricting co-occurrence consideration to successive time periods and evaluating the similarity between network clusters in successive periods (Rule et al., 2015).

There are 24 highlighted topics, whose names are derived from the topics in the five stages (shown in Fig. 5). The size of the topics on the vertical axis represents its frequency in the community. If two topics within adjacent stages share the same nodes and have enough similarity in their community structures, there is a connection between them. The more similar the nodes between the two topics, the darker the gray area. If a topic is not connected to other topics in adjacent stages, it can be considered an isolated topic. The expansion and contraction of the gray area show the changes in its scale over

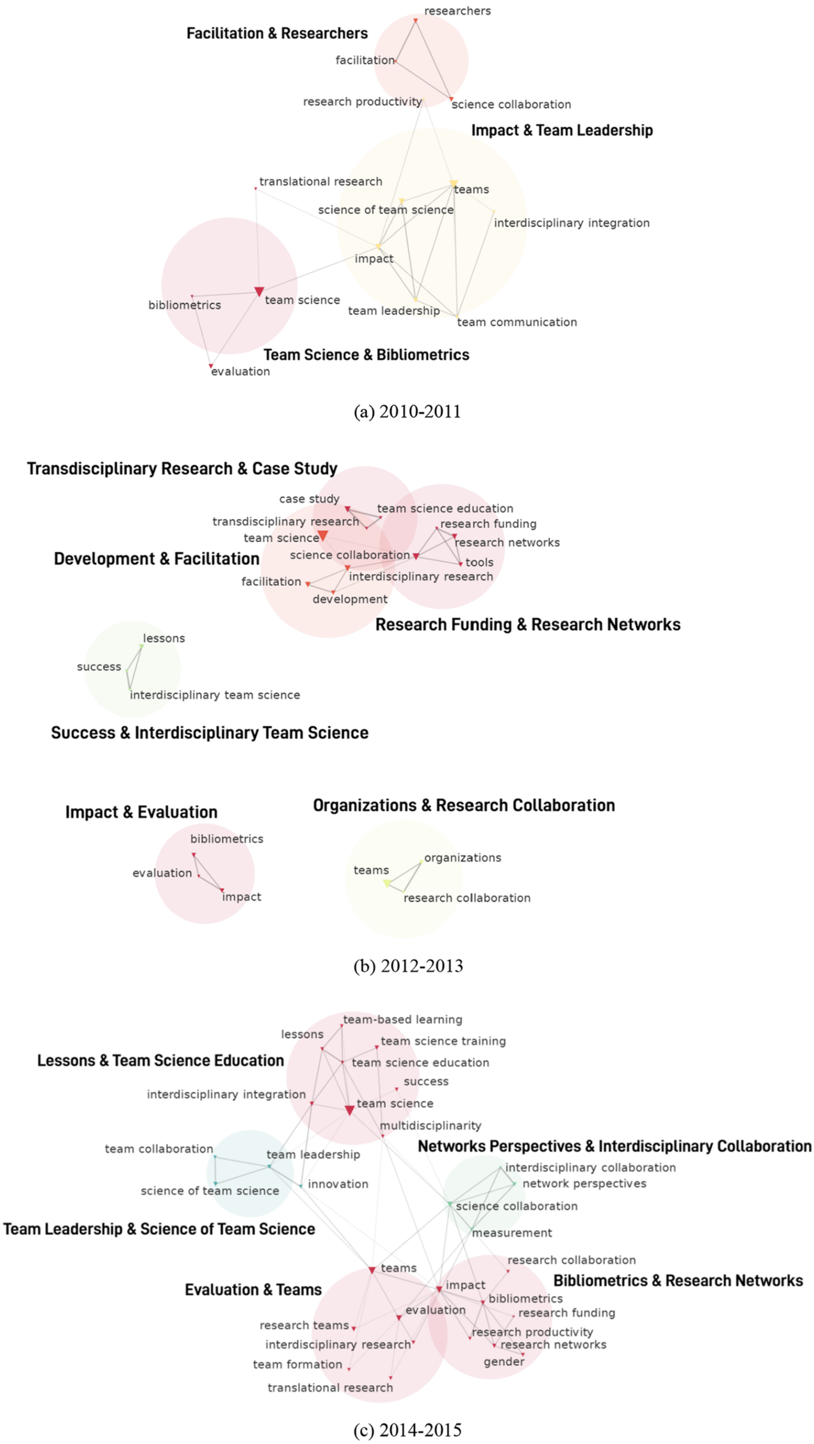
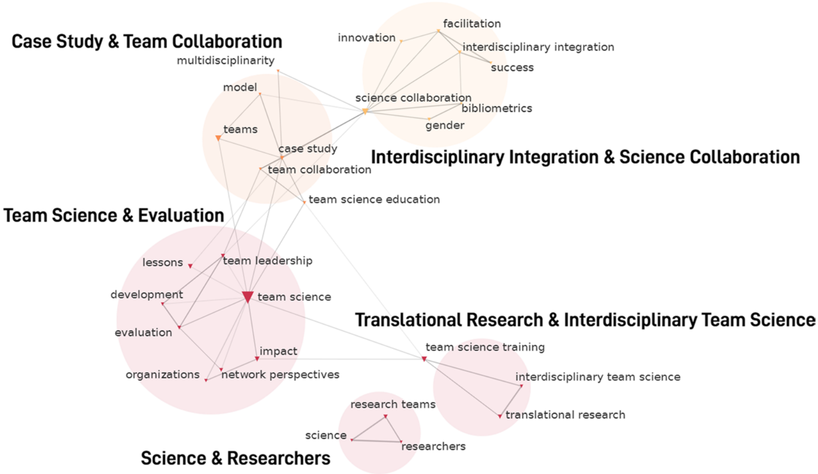
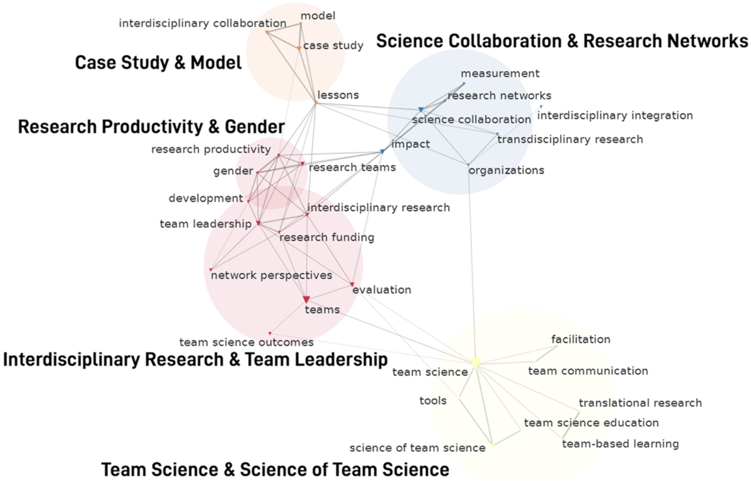


Fig. 5 The research topics of the SciTS field in five stages



(d) 2016-2017



(e) 2018-2019

Fig. 5 (continued)

different time intervals. Thus, Fig. 6 visualizes how the research topics have evolved over the 5 time slices.

As shown in Fig. 6, "Team Science & Science of Team Science" is the largest topic because it has the highest frequency terms. "Team Science & Bibliometrics" is the most important research topic overall, due to its strong continuity, spanning five time periods. "Team Science & Bibliometrics" evolves first into "Impact & Evaluation", and then into "Evaluation & Teams" and "Bibliometrics & Research Networks". "Evaluation & Teams" then splits into "Team Science & Evaluation" and "Translational Research & Interdisciplinary Team Science". Finally, "Team Science & Evaluation" evolves

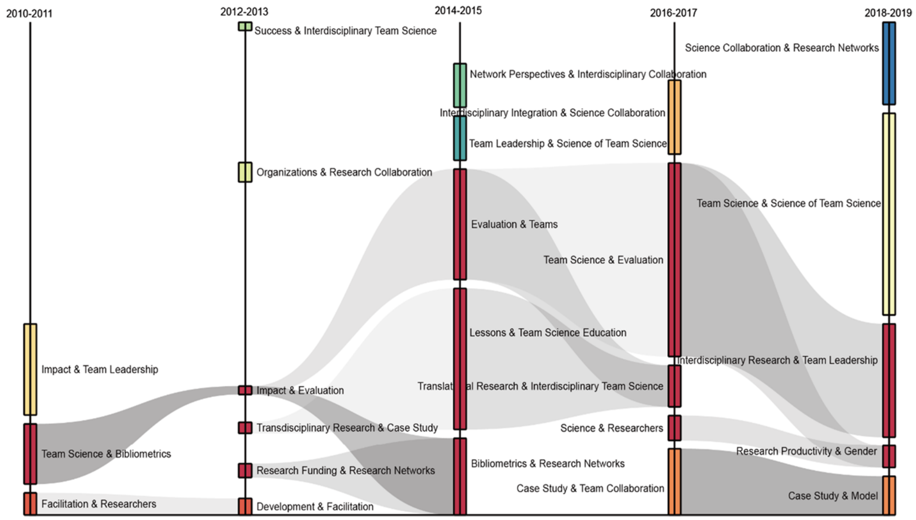


Fig. 6 The evolution of research topics in the SciTS field during 2010–2019

into "Interdisciplinary Research & Team Leadership" and "Research Productivity & Gender".

Research topics across time slices can be related in different ways: continuation, split, and fusion. Continuation implies that, if there is a connection between two topics, the two topics continue their development and evolution. For example, "Case Study & Team Collaboration" is a continuation of "Case Study & Model". There is a split when one topic evolves into two or more topics. For example, "Evaluation & Teams" splits into "Team Science & Evaluation" and "Translational Research & Interdisciplinary Team Science". Lastly, fusion occurs when two or more topics merge to form a single topic. For example, "Impact & Evaluation" and "Research Funding" evolve into "Bibliometrics & Research Networks".

The overall continuity between topics is weak, but this phenomenon has begun to change in recent years. New topics are emerging in each time slice, but their processes of development are relatively independent rather than interconnected with other topics. According to Fig. 6, each time slice contains one or two isolated topics. The degree of connection between topics grows over time, as illustrated in Fig. 5. This demonstrates that there has recently been an increase in the overall continuity, with a wider range of connections between topics over time.

Current status of the SciTS field

From the above, we know that the main terms that appeared more than 10 times formed five topics: (1) Team Science Education & Science of Team Science; (2) Interdisciplinary Integration & Team Science; (3) Interdisciplinary Research & Evaluation; (4) Research Productivity & Bibliometrics; (5) Case Study & Model. In this section, we relabel and regroup these topics in order to obtain clearly interpretable topics, and discuss each of them in turn.

In Fig. 4, we can see that terms in the topic of Team Science Education & Science of Team Science are relevant to team science learning, teaching and training. The same observation applies to the topic of Case Study & Model, whose scope can be clarified by naming it "Models and case studies of team science". However, the terms used in the topic of Interdisciplinary Integration & Team Science appear to involve two related but different research topics: on the one hand, we find interdisciplinary team science, translational research and interdisciplinary integration as they relate to interdisciplinary research and, on the other hand, team communication and leadership as they relate to the characteristics and dynamics of teams. As a result, this topic can be split into two research topics, Interdisciplinary research & team science, and Characteristics & dynamics of teams. Finally, the terms in the topics Interdisciplinary Research & Evaluation and Research Productivity & Bibliometrics are both relevant to research productivity, impact and team science evaluation. So the two topics are both concerned with the same issue—the measurement and evaluation of team science. This way, we obtain five main research topics in the SciTS field:

- Models and case studies of team science,
- Characteristics and dynamics of teams,
- Interdisciplinary research and team science,
- Team science education and training,
- Measurement and evaluation of team science.

We will now discuss the current status of these five main research topics in the SciTS field. The following is a thematic overview of current status made by the SciTS conference over the last 10 years.

Models and case studies of team science

Team Science (TS) is defined as "a collaborative and often cross-disciplinary approach to scientific inquiry" (Bennett et al., 2018; Yu et al., 2019). While it can be single-disciplinary, multi-disciplinary, interdisciplinary (cross-disciplinary), or transdisciplinary in nature, TS is often expected to bridge disciplinary boundaries by combining specialized expertise, theoretical approaches, and research methods to solve complex problems and produce high-impact science (Börner et al., 2010). Although team science has a lot of potential for accelerating scientific innovation and solving challenging research problems, it needs evidence-based approaches to reach its full potential (Börner et al., 2010; Hall et al., 2018). Team science is therefore very complex, and SciTS includes a theoretical as well as an empirical perspective (Liu et al., 2020). In particular, managers and leaders can only know whether, when, and how to best support TS endeavors based on practical needs and empirical evidence (Hall et al., 2018). This indicates that, like theoretical studies, case studies and empirical evidence play a critical role in the SciTS field.

Many scholars have discussed the nature of team science by introducing theories or models from other disciplines to promote an understanding of team science. Tavel and Markovits (2016) proposed the "epigenetic" model of cellular development (which is currently used to understand complex diseases, such as diabetes and Alzheimer’s disease) as models for describing the function of innovation teams. Lawless (2016) explained the interdependence of science, scientists, and scientific teams using thermodynamic theory. Wooten (2017) studied, understood and developed scientific teams using paradox because team science requires the collaboration and integration of various individuals, disciplines, ideologies, and methods.

Many conceptual and analytical models or frameworks are built on case studies and empirical evidence to examine effective team science and best practices and, ultimately to guide the team science practice. For example, Thompson et al. (2019) introduced the ECHO interdisciplinary team scientific model, which can foster investigator collaboration and novel approaches that cross disciplinary boundaries. Pettibone (2019) introduced the NIEHS translational research framework, which was purposely designed to be useful for a wide range of team science and translational research activities.

Characteristics and dynamics of teams

The internal characteristics and dynamics of teams are critical factors influencing team collaboration and effectiveness.

Team communication

Communication is the foundation for team members to conduct collaborative research, and successful teams must work with high-quality communication. Especially in interdisciplinary team science, team members from different disciplines must understand each other and provide corresponding feedback to integrate knowledge from multiple disciplines. Falk-Krzesinski et al. (2012) focused on the methods for overcoming interdisciplinary collaboration obstacles through communication and information sharing. They discussed how team members should learn to speak and listen in order to share knowledge, as well as how to generate new and co-created knowledge by sharing knowledge from an interdisciplinary perspective.

Scholars have focused on the communication of interdisciplinary teams or groups to promote effective collaboration, especially in the field of clinical medicine. Tiferes et al. (2015) investigated team composition in a variety of surgical settings in order to gain a comprehensive understanding of team communication patterns. McLeod et al. (2016) used Video Reflexive Ethnography to identify effective inter-team communication between the frozen section laboratory and breast surgery team at Mayo Clinic. Soukup et al. (2018) examined speeches at the weekly meetings to identify gaps and overlaps in medical team communication.

Another research hotspot is training about communication skills and tools that help team members communicate, such as The Toolbox Project (Malavisi et al., 2019). Scholars also often use The Toolbox Project to engage in dialogue and communication analysis. Vasko (2016) claimed that the philosophically-based Toolbox Project5 could be used to improve conversations and collaborations between STEM and ACD researchers by providing tailored modules, dialogue prompts, and co-creation activities to structure discussions that uncover similarities and starting points for collaborations, and that it can promote innovation across fields.

Team leadership

The essential component of many teams is a leader who can lead and guide all the team members to work together as one. Leadership is the backbone of any organization that brings together the intellectual efforts of members to achieve common goal (DeChurch et al., 2012). There have been many research findings about the theories and models of team science leadership. Wooten and Brasier (2015) proposed the use of constructivist grounded theory to study leadership applicable to team science. Turner et al. (2018) developed a new leadership development model using complexity theory, the Team Emergence Leadership Development and Evaluation (TELDE) model, which is designed to function in complex and non-predictive environments.

Current studies on team leadership focus on leadership experience and leadership training. Researchers and practitioners shared their practices and experiences leading interdisciplinary teams at the SciTS conference. Woodruff (2010) described her experience leading the NIH Interdisciplinary Research Consortium-funded (U54) Oncofertility Consortium, which was an interdisciplinary, multi-institutional collaborative team. Wasielewski (2010) shared his experience as the director of the DOE Energy Frontier Research Center-funded Argonne-Northwestern Solar Energy Research (ANSER) Center.

Training is an effective method for improving leadership skills and developing the next generation of leaders. Leadership training programs are becoming increasingly popular. The Institute of Cancer Research (ICR) used a "team science" approach to support outstanding postdocs to prepare for academic leadership by developing and evaluating a cross-organizational program called "Pathway to Independence; Developing future scientific leaders" (Moore, 2016). Wooten et al. (2016) described the development and implementation of a contextual leadership training program developed for team scientists. Chao et al. (2018) presented their initial experience with leadership training in predoctoral students engaged in team science.

Interdisciplinary research and team science

As an interdisciplinary field, team science emphasizes the integration of different professional knowledge through the collaboration of scientists from various fields to solve some complex scientific problems. This research direction mainly demonstrates the most recent advances in interdisciplinary team science, that is, the latest research status in the cross-integration of various research fields.

Interdisciplinary team science is widely regarded as one of the most promising approaches to accelerating scientific innovation and translating scientific discoveries into effective policies and practices. Interdisciplinary research outcomes are the result of a complex process which is influenced by many factors, and involving many different professional knowledge interactions with one another. At present, the research findings within this research direction are primarily presented at conferences in the form of case analysis, involving research and practice on team science in the fields of health science, biomedicine, biotechnology, medical care, clinical and translational, astrobiology, social environment, agriculture and natural resources, humanities and arts and others (Boix-Mansilla et al, 2012; Klein et al., 2013).

The majority of studies in the interdisciplinary team science are related to the fields of medicine, health science, and translational science. Thornhill et al. (2015) reviewed and summarized lessons learned from the Team Health Science Initiatives at the University of Saskatchewan. The development of team science in the arts and humanities has also received a lot of attention. Janz et al. (2017) defined and demonstrated collaborative research and education in the cross-disciplinary field of Digital Humanities, which will establish a framework for collaborative research and education that bridges humanities and technology. Furthermore, many scholars have introduced methods and practices that adopt artistic & humanistic approaches to team science (Cardenas, 2019; Moll & DeJoy, 2019). Besides, many other fields have also begun to incorporate team science to their own fields. For instance, Haddad et al. (2019) discussed how the scientific research in the field of agriculture and natural resources both relies on and informs team science.

Team science education and training

The provision of education, training, and resources at the appropriate time can aid in the development and improvement of interdisciplinary research teams (Billings et al., 2015). Interdisciplinary collaboration requires scientists to have not only professional knowledge but also good collaboration capacity and skills.

Team science education and training have long been regarded as one of the most effective methods of enhancing team collaboration skills and competences, as well as teamwork efficiency (Salazar et al., 2017). There are many types of collaborative skills and competencies required for the success of team science (Fiore et al., 2013; Khuri & Wuchty, 2015). For example, people pay more attention to the development and improvement of communication skills and team leadership (Moore, 2016; Schultz et al., 2019).

Team science education and training are critical for research collaboration. Moreover, the international conference has never stopped discussing how to train and develop scientific teams, as well as how to better cultivate the next generation of scientists, particularly for students (e.g., undergraduate students, Ph.D. Students), early-career investigators, faculties (Blakeney et al., 2018; Chao et al., 2018; Gadlin, 2010; McCormack, 2017; Plaisance et al., 2016). At the conference, participants from various disciplines often shared their practical experience in team science education and training, including different training models, implementation processes, results and evaluation of training programs (Bachrach et al., 2015; Barlow et al., 2016; Bosque-Perez et al., 2016). This demonstrates that team science education and training can produce excellent results, and a large number of people can benefit from this activity (McGee & DeLong, 2010; Rowe et al., 2015; Salazar & Lant, 2017).

Measurement and evaluation of team science

The SciTS field is concerned with understanding and enhancing the processes and outcomes of team science. Additionally, measurement and evaluation are crucial tools for determining the impact of team research activities and different policies on team science. Measurement and evaluation are also needed to know what aspects of team practice need to be improved.

Perspectives of measurement and evaluation

The measurement and evaluation of team science involve a variety of internal and external factors at multiple levels. For example, factors can be classified as macro, medium, and micro levels. Furthermore, the factors within each level are interrelated, and the factors between different levels have complicated relationships as well.

According to the existing studies, the focus of team science evaluation is on team science outcomes, impact, and effectiveness. Bishop & Richters (2015) used hierarchical modeling methods to assess the factors that contributed to the productivity of 20 interdisciplinary synthetic research groups that took place over 6-year period at The National Institute for

Mathematical and Biological Synthesis (NIMBioS). Dahlander (2010) presented his NSF-supported study that evaluated the impact, effectiveness, and consequences of interdisciplinary centers. Moreover, many scholars also paid high attention to the factors that influence team productivity and team effectiveness. Zinner & Campbell (2010) investigated the effects of scale, scope, and team structure on the productivity of academic labs, and discovered that coordination and communication issues across large teams have the potential to significantly impact on the efficiency of scientific discovery in laboratory teams. Börner et al. (2013) investigated the impact of group size and heterogeneity on research team productivity using NSF ITR data. Cummings and Kiesler (2015) analyzed the relationship between prior experience and productivity in distributed, interdisciplinary science teams.

Many other factors have been measured and evaluated, such as interdisciplinarity of research outputs, and integrative capacity in interdisciplinary teams. Bhat et al. (2015) quantified interdisciplinarity with Jensen-Shannon divergence and entropy. Salazar et al. (2015) developed and tested survey-based scales to measure integrative capacity in interdisciplinary teams.

Evaluation methods

The complexity of team science leads to the use of many different methods for team science measurement and evaluation. Compared with the evaluation of individual scientists, team science measurement and evaluation require not only the evaluation of research outcomes and impacts but also the process of team collaboration, such as the interaction and communication between team members, which is the focus and key of team evaluation. Furthermore, the observation of specific indicators usually requires the use of multiple methods and dimensions.

Generally, social network analysis and bibliometrics are often employed in this field. Team members and their collaborative networks have long been regarded as critical research issues of team science. Social network analysis can be used to explore the networks of individuals and organizations in team science, as well as to investigate the interactions and influences of scientists, to understand better and strengthen team science. Huang et al. (2010) analyzed how team success and leadership development are affected by prior co-authorship and citation network configurations in scientific research groups, based on theories of transactive memory and shared mental models.

In addition, bibliometrics is an important method in team scientific evaluation. It can be used not only to analyze team accomplishments but also in conjunction with other research methods, such as questionnaire surveys, interviews, and network research, to discuss how various factors influence team science (Norman et al., 2010; Stokols, 2010). Big data methods are also a focus of attention in the process of team science measurement and evaluation. In the future, with the increasing size of teams and the increasing data related to team science, traditional research methods may not be able to solve some specific research problems, and big data methods, such as machine learning, have the potential to be used frequently in the future and will be a better choice.

Discussion and conclusion

With the increasing scope of scientific team collaboration, SciTS has received much attention as an emerging field. Nonetheless, despite the field's forward momentum, definitions of fundamental terms and typologies of SciTS-related practice and theory far too frequently remain impressionistic or parochial; areas of investigation are still largely disjointed; and there are few methodological approaches (Falk-Krzesinski et al., 2011). In other words, the current development of SciTS is still in the early stages of growth and it has not yet matured into a mature and real "discipline".

Over the last decade, researchers from various research fields have been involved in the field of SciTS. The International Science of Team Science conference provides an important platform for scholars to exchange and share information, as well as promote the development of the SciTS field. In this study, we presented methods for studying how research topics have evolved and applied them to the SciTS field. More specifically, we used a corpus of conference programs and papers to track the research hotspots and topics in this field, analyzed their evolutionary characteristics, and discussed the current status of the main five research topics in detail.

We noticed that many scholars have studied the research issues in the field from various perspectives. There are many research hotspots that scholars are interested in, and they are constantly changing. The most important topic is Interdisciplinary Integration & Team Science. Because interdisciplinary knowledge integration plays such an important role in generating scientific and technological innovation, the composition, management and evaluation of interdisciplinary teams is bound to be one of the areas of interest in the SciTS field. Scholars will continue to pay attention to interdisciplinary team science. Throughout the 10 years that the conference has been held, the evolution of research topics has presented obvious evolutionary characteristics, such as continuation, split, and fusion. This also demonstrates that the field is currently progressing, and the research content and topics tend to be diverse and complex. Overall, there is a lack of continuity, which reflects the fact that this young field of study has not yet fully converged on a core set of topics. To provide an in-depth analysis of the current status, the study reviews and discusses five research directions derived from the textual analysis. According to the results of quantitative analysis and literature review, the five research directions are interconnected and have received different amounts of attention. For instance, some draw a lot of attention, while others receive less. It can be found that some research topics are in larger networks with more nodes while others are in smaller networks with fewer nodes. As an emerging interdisciplinary field, the field of SciTS requires more insights from various perspectives. Scholars can conduct in-depth research on the core research topics while also attempting to pay more attention to understudied research topics in the future.

The key research issues in SciTS are to understand how research teams work and what factors can contribute to the success or failure of teamwork. An important goal for the SciTS field is to identify and measure the factors that can influence the teamwork process and outcomes in order to find the best way to work together as a team. Moreover, to understand how teams work and what leads to their failure or success requires a collaborative, interdisciplinary and international effort (Liu et al., 2020). The SciTS field seeks to integrate and expand on approaches, concepts, and theories from a variety of relevant disciplines and fields (Hall et al., 2018). Quantitative and qualitative methods from relevant fields, including scientometrics, are used to identify new research opportunities to further promote the development of SciTS and better inform policies and practices for effective team science (Liu et al., 2020).

Overall, based on quantitative analysis, this study systematically analyzes the research topics in the field of SciTS, illustrating the dynamic evolution of these topics over the past 10 years. Our work can help to fill a research gap and provide some reference for scholars and practitioners to better understand the research trends of team science. However, there are some limitations to this study. For example, it is based on high-frequency terms in titles and their co-occurrence relationship as the primary analysis basis. Topics that are not reflected in the network formed by high-frequency words are not discussed in our study. Indeed, as a reviewer has pointed out, some relevant topics—such as social interactions among team members, team building, and team management—remain invisible in our analysis, even if some of them have been discussed at the SciTS conference. Therefore, this is not to say these topics were not mentioned at the SciTS conference; rather, those terms that are significantly related to them did not appear in the network. In addition, the number of conference sessions and papers varies across years, which may affect the results.

As an emerging interdisciplinary field, SciTS requires more insights from various perspectives. We intend to combine various data sources in future research. For example, to compensate for the shortcomings of this study, we will analyze peer-reviewed research papers indexed in databases, such as, Web of Science. Secondly, we can combine more different data sources and analyze them from multiple perspectives, such as authors, institutions, and disciplines, to further reveal more about the current status in the SciTS field. Thirdly, we also hope to further investigate the reasons for the formation and evolution of research topics in order to understand the SciTS field better. In the future, scholars in the SciTS field should work together to link team science to practical issues and create greater connections between different research topics in order to produce more meaningful and significant findings. We should also attract more researchers to this field and establish some relevant academic communities to further widen and deepen this field's impact. Additionally, as it offers a venue and a forum for researchers in this field to communicate annually, the SciTS conference is a crucial building block for the growth of the field. It is expected to continue operating as before in the future, providing more standardized conference proceedings as well as other data-based material to encourage sharing and enhance the influence of the conference and the field in the online era.

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Declarations

Conflict of interest The co-author (Lin Zhang) is the Editor-in-chief of Scientometrics.

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