Science of Research Teams: Connotation, Advances, and Prospects (Postprint)

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Abstract

[Purpose/Significance] Team collaboration is considered one of the effective approaches to addressing complex scientific and social challenges. By clarifying the relevant concepts of team and team science, this study systematically reviews the development process and current status of the emerging interdisciplinary field of the science of research teams, aiming to deepen scholars' understanding and insight into this domain. [Method/Process] Employing methods such as scientometrics, systematic review, and knowledge mapping, and based on clarifying the relevant concepts and connotations of team and team science, this paper examines the rise and evolution of the science of research teams. Subsequently, from the perspectives of research methods, research tools, and main research content, it summarizes the principal research advances in the current field of the science of research teams, and provides prospects and discussion on possible future development directions. [Results/Conclusion] The science of research teams, as an emerging interdisciplinary field, comprehensively utilizes various quantitative and qualitative research methods, and has made significant progress in four aspects: theory and models of the science of research teams, team characteristics and operation, team organization and development, and team measurement and evaluation. Potential future research directions in the quantitative aspect of this field mainly include: focusing on the process and outcomes of research team collaboration to identify and quantify factors influencing team effectiveness; examining team collaboration characteristics across different disciplinary fields and exploring quantitative evaluation methods for team science; linking research findings and discoveries in interdisciplinary fields to explore optimal team collaboration models; and drawing on theories and methods of scientometrics to deepen the understanding and comprehension of the development laws of team science.

Full Text

Science of Team Science: Connotations, Progress, and Prospects

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Abstract:
[**Purpose/Significance**] Team collaboration is considered an effective approach to solving complex scientific and social challenges. By clarifying concepts related to teams and team science, this paper systematically reviews the development and current state of the emerging interdisciplinary field of Science of Team Science (SciTS) to deepen scholars' understanding of this domain.
[**Method/Process**] Employing bibliometrics, systematic review, and knowledge mapping methods, this study first clarifies the concepts and connotations of teams and team science, then traces the emergence and evolution of SciTS. It subsequently summarizes major research progress from three perspectives: research methods, research tools, and main research content, and discusses potential future directions.
[**Result/Conclusion**] As an emerging interdisciplinary field, SciTS integrates various quantitative and qualitative research methods and has made significant progress in four areas: theories and models of team science, team characteristics and operation, team organization and development, and team measurement and evaluation. Future quantitative research directions include: 1) identifying and quantifying factors influencing team effectiveness by focusing on collaboration processes and outcomes; 2) exploring quantitative evaluation methods for team science across different disciplines; 3) investigating optimal team collaboration modes by linking findings from interdisciplinary research; and 4) deepening understanding of team science development patterns by drawing on scientometrics theories and methods.

Keywords: team science; science of team science; research team; SciTS; interdisciplinary research
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2. Research Approach and Related Concepts

2.1 Research Approach

This study conducts a literature review of the SciTS field based on existing Chinese and English publications. English literature was retrieved from the Web of Science platform's SCIE/SSCI/A&HCI databases using the search query "TS=('team science' OR SciTS)" for articles and reviews published between 2006-2020. Chinese literature was sourced from CNKI using the query "SU=(('interdisciplinary team'*'collaboration')+'team science'+'research team')". Important references cited in these documents were also back-tracked, with all retrieval results incorporated into the analysis.

2.2 Related Concepts

2.2.1 Team The concept of "team" originated in the United States. In 1972, economists Armen Alchian and Harold Demsetz first proposed team production theory and introduced the concept of "team" in their paper "Production, Information Costs, and Economic Organization" [5]. Since then, numerous scholars have defined "team" from various perspectives, with Stephen P. Robbins' 1994 definition gaining widespread acceptance: a team is a formal group of individuals who collaborate to achieve a specific goal [6]. Contemporary academic consensus defines a team as a formal group composed of interdependent individuals with complementary skills who share common goals, standards, and responsibilities [7].

In the context of team science, "team" more specifically refers to "research teams" or "scientific teams." According to J. Rey-Rocha et al., "team" in scientific contexts can be defined from both output and input perspectives: the output perspective defines teams as collaborators, while the input perspective defines them as members belonging to the same administrative unit (i.e., colleagues) [8-9]. Y. Liu et al. argue that these perspectives overlook interdisciplinary teams whose members typically belong to different administrative units, suggesting that administrative restrictions should be removed from the definition. They propose that research teams are organized wholes formed through collaboration, where each member contributes their efforts to achieve a common goal by sharing information, resources, and expertise to study and discover new phenomena or propose new theories [9].

In practice, many researchers define a research team as co-authors of a paper to explore macro-level issues related to team science, while others set collaboration-related thresholds (e.g., frequency of co-authorship) to identify team members [10, 11]. However, theoretically, defining (virtual) teams based on co-authorship may be inaccurate, as a single paper could be authored by scholars from different teams, making the virtual team merely a group of "collaborators" rather than an actual research team [10]. Using datasets from physical teams (e.g., laboratory teams, project teams) may be more effective and accurate for studying team collaboration, though the current challenge is that such datasets remain

relatively small and costly to construct.

2.2.2 Team Science Team science originated in the medical and health fields, aiming to develop comprehensive theories and solve complex research problems [12]. The U.S. National Institutes of Health (NIH) first defined team science as team members trained in different medical and health fields working together, integrating their knowledge, skills, and perspectives into clinical research projects [3, 13]. This definition is now considered the gold standard by many scholars. Building upon this, numerous scholars and institutions have extended and supplemented the concept. For example, K. Hall et al. view team science as a team-based research approach in complex social, organizational, political, and technological environments that significantly influence work processes [14]. The report *Enhancing the Effectiveness of Team Science* defines "team science" as collaborative research conducted by small teams ($ $10 members) or large teams (>10 members) [3, 15]. Such collaboration requires the team as a whole to share and exchange information, resources, and expertise through internal member interactions to form new insights and solutions, thereby achieving a common goal. Therefore, team science essentially means studying how to advance science through information, resource, and expertise sharing, and since teams are fundamentally based on collaboration, team research naturally includes collaboration research [9].

Many scholars also argue that team science typically implies interdisciplinary (multidisciplinary, cross-disciplinary, and transdisciplinary) collaboration—what is commonly called team science often refers to collaborative research by interdisciplinary teams [4]. Although teams usually consist of several people, an individual can also conduct interdisciplinary research independently [9, 16], making a single person a special form of "single-person team."

In summary, this study argues that team science is essentially closely related to interdisciplinary research—it is a method and strategy that uses teamwork to collect and integrate information, data, technologies, and theories from multiple disciplines to gain fundamental understanding of problems and effectively address issues beyond single disciplines or fields.

2.2.3 Science of Team Science Science of Team Science (SciTS) is an emerging interdisciplinary field focused on understanding how research teams initiate, organize, communicate, and conduct scientific activities [1]. As a branch of Science Studies, SciTS involves understanding, managing, and evaluating the conditions, collaborative processes, and outcomes of team science, and translating research results into new scientific knowledge, advances, clinical practices, and policies [13].

The *Enhancing the Effectiveness of Team Science* report defines SciTS as an emerging interdisciplinary field that employs empirical research to study how research teams (both large and small) organize, communicate, and conduct

research activities [3]. It focuses on understanding and managing environments that facilitate or hinder the effectiveness of collaborative research (including translational research), including understanding how teams achieve scientific breakthroughs through communication, connection, and collaboration—breakthroughs that are typically unattainable through individual effort or simple addition. Like other emerging fields, current descriptions and definitions of SciTS are not yet unified in academia, but the consensus among researchers focuses on its dedication to understanding and strengthening the organization, processes, and outcomes of team science [9, 17].

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3. Emergence and Development of Science of Team Science

3.1 Origin of SciTS

Although research on teams and collaboration has been abundant, the formal establishment of SciTS can be traced back to 2006. In October 2006, the U.S. National Cancer Institute (NCI), part of the NIH, launched the Annual International Science of Team Science Conference to discuss and resolve divisions and gaps in the field, promote knowledge integration, and identify key future research questions [17]. This conference marked the formal launch of SciTS as a new branch with independent research directions [18]. Since then, SciTS researchers have developed the field's research agenda by surveying experts and key stakeholders, continuously producing substantial literature and driving rapid field development.

3.2 Development of SciTS

3.2.1 Academic Teams and Organizations As team science developed, practical guidance was urgently needed to address challenges and unlock potential for solving scientific and social problems. To provide such guidance, in 2013, the U.S. National Science Foundation (NSF) requested that the National Research Council (NRC) establish a Committee on the Science of Team Science comprising 13 members. This committee was tasked with discovering and investigating individual, organizational, and environmental factors affecting research team effectiveness and their mechanisms. In May 2015, the committee published the report *Enhancing the Effectiveness of Team Science* through the National Academies Press. The report focused on factors influencing team effectiveness, such as team dynamics, management, institutional structures, and policies, and identified seven key questions: (1) How do individual factors (e.g., openness to different perspectives) affect team dynamics (e.g., cohesion), and how do these factors influence team efficiency and productivity? (2) Which team characteristics (e.g., size, composition, geographic distribution) affect efficiency? (3) How do different management approaches and leadership styles impact team effectiveness? (4) How do current tenure and promotion policies recognize and incentivize academic researchers engaged in team science? (5) What factors

affect the productivity and efficiency of research organizations (e.g., research centers and institutes) that manage and support collaborative science? (6) How do organizational factors like HR policies, practices, and network infrastructure affect team collaboration? (7) What organizational structures, policies, practices, and resources are needed in academic institutions, research centers, industries, and other settings to promote effective research teams? [3, 15, 19].

As SciTS continues to evolve, numerous important conferences on team science have been convened, with the most representative being the International Science of Team Science Conference. In April 2010, the Northwestern University Clinical and Translational Sciences Institute (NUCATS Institute), an early advocate for SciTS, hosted the inaugural conference in Chicago [20]. The conference annually convenes leaders from multiple fields to discuss key issues in team science, aiming to enhance understanding of how to better engage in team science to meet societal needs. Held annually since 2010, the conference has successfully convened 12 editions.

3.2.2 Research Output and Impact Team science research findings have been published successively. Using the Web of Science database, 396 English-language documents were retrieved. Since 2006, the number of publications in this field has been growing, particularly showing a rapid increase since 2015. Given the enormous potential of team science, substantial growth is expected to continue.

In terms of disciplinary distribution, SciTS is most closely related to Medicine Research & Experimental, Medicine (General & Internal), Healthcare Sciences & Services, Oncology, and Public, Environmental & Occupational Health—reflecting its origins in medical and health fields. The field also incorporates substantial knowledge from Information Science & Library Science, Computer Science (Interdisciplinary Applications), Environmental Sciences, and Multidisciplinary Sciences, indicating strong relevance to team-related research in these areas and generating considerable interdisciplinary cross-fertilization.

Comparing early and later stages, the disciplinary distribution in the later stage becomes more balanced, with many new disciplinary areas emerging that were absent in the earlier stage. This demonstrates that as an interdisciplinary field, SciTS knowledge is expanding into more domains with increasing cross-fertilization.

From a country/region perspective, the United States (341 publications) dominates the field absolutely, followed by Canada (26), the United Kingdom (18), and China (16). The significant gap between China and the U.S. suggests that China may need to increase attention and investment in SciTS to advance domestic team science theory and practice.

Science Overlay Mapping can visually present relationships between scientific fields or organizations, intuitively showing disciplinary cross-cutting and clustering of similar disciplines [21]. This study uses overlay mapping to display

the disciplinary distribution of SciTS papers, as shown in Figure 1 [Figure 1: see original paper], where each node represents a WoS category and node size indicates the number of papers in that discipline.

4. Main Research Progress in Science of Team Science

4.1 Research Methods

The emergence of SciTS aims to provide empirical evidence for funding agencies, managers, and scientists to evaluate research team value and develop strategies for successfully leading, participating in, and supporting teams. As an interdisciplinary field, SciTS seeks to integrate methods, concepts, and theories from relevant disciplines such as science policy and economics to address its research questions [14].

Research methods encompass both quantitative approaches (data mining, statistical analysis, complex networks, pattern classification, questionnaires, bibliometrics) and qualitative methods from sociology (ethnographic observation, case studies, interviews) [18]. Three main research philosophies prevail [1]: (1) Testing teams to operate exactly according to researchers' intentions, then comprehensively evaluating results; (2) Collecting, analyzing, and predicting daily team operations through combined quantitative and qualitative observation; and (3) Integrating both approaches to explain SciTS formation and identify drivers of team transformation and progress.

Currently, most empirical studies in the field use descriptive methods focusing on team collaboration patterns. These studies rely heavily on existing data and rarely follow theoretical frameworks, highlighting the need for more complex methodological designs, including mixed methods, causal analysis, experiments, or data-intensive computational approaches [14]. Future research must move beyond simple observational designs and linear models to adopt methods that explain team complexity, which will enhance understanding of SciTS development stages and characteristics. Qualitative methods like case studies also play important roles in analyzing theory generation, indicator development, and complex interactions in practice settings.

4.2 Research Tools

Due to collaboration complexity, obtaining information and resources about team science, scientific collaboration, and interdisciplinary research remains challenging for researchers [10]. Several tools have been developed to support team science research, including Team Science Toolkit, Toolbox Project, Teamscience.net, Research Toolkit, and VIVO.

For example, Team Science Toolkit, developed by NCI, is an interactive web tool encouraging researchers to share results and practices to promote mutual collaboration and support team science and interdisciplinary research. Northwestern

University's Teamscience.net aims to create, evaluate, and disseminate durable, accessible online learning resources to enhance skills needed for interdisciplinary, team-based translational research. Additionally, the Science of Science (Sci2) tool (http://sci2.cns.iu.edu) supports temporal, geospatial, topical, and network analysis and visualization of academic datasets at micro (individual), meso (local), and macro (global) levels, enabling researchers to map science's structure and dynamics using advanced data mining algorithms.

4.3 Main Research Content

Research shows that SciTS topics are extensive. To identify main research directions, H. Falk-Krzesinski et al. developed a conceptual framework based on expert opinions and statistical analysis, identifying seven research directions (measurement and evaluation, definitions and models, institutional support and professional development, disciplinary dynamics, team structure and environment, team management and organization, team characteristics and dynamics) and their relative importance [4]. K. Hall et al. reviewed empirical studies and found research primarily focuses on five themes: value of team science, team composition and its impact on performance, team formation, core processes for effective operation, and institutional influences on team science [14].

Based on the Pareto principle, this study screened key domestic and international literature by citation frequency and other characteristics. Through analysis, this section introduces achievements and current status in four areas: theories and models, team characteristics and operation, team organization and development, and team measurement and evaluation.

4.3.1 Theories and Models of SciTS Conceptually, many studies explore fundamental questions about SciTS. M. Little et al. systematically reviewed SciTS literature from 2005-2015 based on NIH's team science concept, demonstrating that team science is a dimension of interdisciplinary collaborative practice [13]. W. Bedwell et al. argue that multidisciplinary or interdisciplinary collaboration is a comprehensive, multi-level concept requiring a holistic collaborative perspective, with complex adaptive systems providing a framework for understanding dynamic collaboration formation processes [22, 23]. P. Ramos-Villagrasa et al. used systematic review to examine teams as Complex Adaptive Systems (CAS) to enhance understanding of teams and team science [24]. M. Beyerlein et al. provided a framework for understanding multi-level collaboration in complex systems [25]. E. Vico et al. developed a new conceptual tool for analyzing how contemporary academic collaboration is organized at the micro level and its macro-level social and economic impacts [26].

Model-wise, many studies introduce theories or models from other fields to discuss team science properties. M. Tavel and D. Markovits propose that the "epigenetic" model of cell development (used for complex diseases like diabetes and Alzheimer's) could describe and analyze innovative team functions [27]. W. Lawless uses thermodynamic theory to explain interdependencies among science,

scientists, and research teams [28]. K. Wooten suggests using paradox theory to study SciTS because team science involves cooperation and integration across individuals, disciplines, ideologies, and methods [29].

Many studies also identify crucial factors for multidisciplinary teamwork or construct relevant models from practice. For example, N. Hara et al. collected and analyzed collaboration experiences, perceptions, and first-year practices from members of a distributed multidisciplinary research center to develop a framework identifying collaboration forms and influencing factors, providing valuable references for similar centers [30]. S. Paletz discusses four critical aspects for successful multidisciplinary teamwork: shared mental models, communicating unique information, conflict, and analogy [31]. H. Patel et al., through implementing the European CoSpaces project, developed the CoSpaces Collaborative Working Model (CCWM), identifying seven factor categories in collaboration: environment, support, tasks, interaction processes, team, individual, and overall factors, synthesized into a framework to guide practice [32].

4.3.2 Team Characteristics and Operation Internal team characteristics and operational processes fundamentally affect interdisciplinary collaboration processes and outcomes. Team composition is crucial for determining team structure and operation, while team formation is the root cause of team assembly, and operational processes ensure effective collaboration.

(1) Team Composition. Whether self-organized, project-organized, or institution-organized, research teams are purposeful organizations formed to achieve certain goals, making composition particularly important [10]. Team members generally share similar attributes: gender, ethnicity, age, nationality, religion, work experience, education, ability, attitude, discipline, and geographic location. Table 1 shows important attributes of team composition [9].

(2) Team Formation. Team composition and formation are distinct: composition research focuses on what factors affect team performance and how, while formation aims to find individuals with different skills to perform tasks [10]. Team formation can be viewed as an NP-Hard problem—finding individuals who can contribute with minimal communication costs to complete specific tasks [33]. Regarding influencing factors, K. Hall et al. summarized physical proximity, social relationships, network brokers, and prior collaboration experience as important factors affecting research team formation [14].

(3) Team Operation. Broadly, teamwork refers to members collaborating to achieve task objectives [34]. Team operation involves activities that transform inputs into outputs, such as efficiency and satisfaction—members must cooperate, share knowledge and perspectives to achieve effective and satisfactory results. Effective operation requires leadership, management skills, trust, and communication [35].

Literature outlines three team states/processes in operation: cognitive states, affective states, and behavioral processes [36]. For example, evidence from team

science research shows close relationships between team cognition and performance [37]. Establishing shared mental models among members is a key characteristic for improving interdisciplinary team performance [14]. Additionally, team leadership and communication during operation significantly affect cohesion, satisfaction, and collaboration efficiency.

4.3.3 Team Organization and Development Teamwork is influenced not only by internal factors but also by external environments. Providing appropriate education, training, and resources at the right time can support interdisciplinary research team development and progress [38].

(1) Institutional and Organizational Factors. Literature shows that institutional and organizational factors—including built environment, organizational structure, and available resources—affect team formation and productivity [14]. For example, interdisciplinary research centers can promote collaboration, generate more integrated interdisciplinary products, more innovative research, and higher productivity [14]. Resource availability facilitates collaboration and correlates with increased productivity, greater impact, and ability to sustain large teams [14]. Funding agency support is crucial for realizing interdisciplinary value, particularly in promoting and supporting collaboration and integration in large-scale interdisciplinary research programs [39]. More complex collaborations may require stronger resources and greater attention to coordination strategies [14].

However, research finds that heterogeneous and diverse teams are less likely to receive funding, suggesting current evaluation processes may be biased against diverse teams [40]. Institutional culture, policies, and workflows also affect team management and coordination. Culture deserves particular attention as it operates both within teams and through external environments to affect team efficiency [9].

(2) Training and Education. Conducting interdisciplinary collaboration requires not only professional knowledge but also collaborative skills and competencies. Team science training and education are widely considered effective ways to enhance collaborative skills and improve team efficiency, as well as important drivers for SciTS field development [41]. SciTS success requires various collaborative skills [42-43], with communication skills and leadership development receiving particular attention [44-45]. Team members' interdisciplinary communication and collaboration abilities can be enhanced through various training and education strategies, ranging from short-term workshops to project-specific methods [46].

4.3.4 Team Measurement and Evaluation Team science focuses on understanding and strengthening collaboration processes and outcomes, making measurement and evaluation crucial for assessing team research effectiveness and how various factors affect collaboration.

Team performance is a key evaluation focus, with many studies using bibliometric methods to assess team output and impact [14]. Bibliometrics can analyze team outcomes and combine with questionnaires, interviews, and social network analysis to discuss how internal and external factors affect outputs and performance. Treating teams as wholes, their task execution capability can be viewed as collective intelligence [47]. Measurable output dimensions include publications, citations, applications, quality, social impact, and innovation (Table 2) [9].

Unlike individual researcher evaluation, team assessment must evaluate both research outcomes and collaboration processes, including how members interact, communicate, and cooperate. Studies show collective intelligence correlates not with average or maximum individual intelligence but with average social sensitivity and proportion of women in groups [48]. Team performance and creativity relate more to interactive social processes than individual personality traits [49]. Key predictors of team success include team members, collaboration norms, and interaction patterns [49], demonstrating that collaboration processes critically affect success.

Unlike output measurement, process analysis generally requires qualitative methods like questionnaires and interviews. Researchers often use scales to measure interaction effectiveness or explore factor impacts. For example, M. Salazar et al. developed and tested a questionnaire-based scale to measure interdisciplinary team integrative capacity [50]. F. Martín-Alcázar et al. designed a scale to measure research team social capital from relational, cognitive, and structural dimensions [51]. Funding agencies particularly focus on collaboration process and quality across project phases, with studies proposing specialized scales to measure project collaboration levels [52].

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5. Summary and Outlook

As scientific collaboration deepens, SciTS has emerged as a new interdisciplinary research field. From a disciplinary life cycle perspective (gestation, growth, development, maturity, transformation) [53], SciTS is currently in its early growth stage (formation phase). Although academic papers, books, reports, tools, and conferences are increasing, and institutions like Northwestern University's Clinical and Translational Sciences Institute and NIH are dedicated to team science research, the field has not yet established a fully mature theoretical and methodological system or recognized disciplinary paradigm.

The key research question in SciTS is understanding how research teams work and what causes success or failure. Identifying, measuring, and evaluating factors affecting collaboration processes and outcomes to find optimal collaboration modes represents an important development goal. Quantitative research questions in this field are closely related to scientometrics, which should be actively

drawn upon. Future SciTS research, particularly from quantitative perspectives, should focus on four main directions:

(1) Focus on research team collaboration processes and outcomes to identify and quantify factors influencing team effectiveness. Team effectiveness is essential for team operation and development, representing a team's ability to achieve goals and affecting both collaboration motivation (member satisfaction and willingness) and research outcomes [3]. Effectiveness evaluation must consider both outcomes and processes. Influencing factors span individual, team, and organizational levels. From a quantitative perspective, identifying and quantifying these factors, especially process-related ones, is key to evaluating team science.

(2) Explore quantitative evaluation methods for team science across different disciplines. Different research fields or team development goals may lead to different collaboration processes and outcome types. Basic research teams may produce many papers, while application-oriented teams may generate patents. Interdisciplinary teams may produce diverse outcomes with very different collaboration processes. Therefore, suitable evaluation methods for different team types need exploration. Team evaluation differs significantly from individual evaluation, requiring sociological, management, and psychological knowledge and mixed methods for accurate measurement. Evaluation perspectives must shift from individuals to teams.

(3) Associate interdisciplinary research findings to explore optimal collaboration modes. Seeking optimal collaboration modes is an important SciTS goal. Since team science primarily addresses major, complex social problems, its outcomes are typically interdisciplinary. Therefore, team science measurement and evaluation are closely related to interdisciplinary research. Future work should link SciTS with interdisciplinary research to explore whether optimal collaboration modes exist, whether they differ across disciplines, and how to determine them.

(4) Draw on scientometrics theories and methods to deepen understanding of team science development patterns. Scientometrics uses quantitative methods to study scientific activity inputs (researchers, funding), outputs (papers, citations), and processes (information dissemination, network formation) [54], while SciTS focuses on understanding, managing, and evaluating team collaboration conditions, processes, and outcomes to translate results into new knowledge, advances, and policies [13]. Future work should integrate these two fields' theories, methods, and findings. Particularly, SciTS urgently needs to borrow from scientometrics to deepen understanding of development patterns. For example, current evaluation metrics focus on individual scientists, but team science requires exploring how to combine individual and team evaluation, especially regarding credit allocation for collaborative outcomes to avoid fairness issues that reduce effectiveness or cause team dissolution.

In conclusion, team science research has many directions requiring exploration.

While many international scholars show great interest in SciTS theory and practice, domestic attention remains relatively insufficient. This paper aims to attract more scholars to this field and hopes research management institutions will recognize its important value and increase funding and support to advance team science in China.

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Note: Figure translations are in progress. See original paper for figures.