Influencing factors of and multiple paths to high performance in multidisciplinary scientific research cooperation in colleges in China: a fuzzy-set qualitative comparative analysis

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Background: In the context of globalization of science and technology, multidisciplinary cooperation plays an important role in enhancing national scientific research strength. Many countries issue policies and reports to promote the implementation of interdisciplinary research. Colleges play a central role in knowledge generation and scientific inquiry and thus frequently contain a variety of scientific research organizations. With rapid advances in science, large-scale scientific research cooperation across disciplines and institutions is increasingly common. Many factors can affect the performance of research collaboration, and the implementation paths of some key factors remain unclear. In addition, no standardized collaboration system has been established in relevant research. Further studies on interdisciplinary scientific research cooperation will be particularly valuable for improving the efficiency of resource allocation and increasing the level of academic research. Here we explored the "joint effect" of various influencing factors on interdisciplinary collaborative research in colleges and the "interactions" among these factors.

Methods: With stratified-cluster random sampling, 358 researchers from 181 research teams at 6 colleges across China were surveyed using a self-administered questionnaire. We used fuzzy-set qualitative comparative analysis (fsQCA) to analyze data to obtain more insight into the status quo of interdisciplinary cooperation among colleges.

Results: The results showed that initiation and organization by an institution was a necessary condition for achieving high-performance scientific research collaboration. The performance incentive method of high-tech collaboration could be divided into four main paths: configuration organized by an institution; configuration organized by an institution, with high policy-based guarantees (PG); configuration organized by an institution, with high cooperation willingness (CW) and high cooperation ability (CA); and configuration organized by an institution, with high CW, abilities, and outputs. The drive mechanism of high performance in scientific cooperation could be divided into two types: organization-led and ability/willingness-driven.

Conclusions: Only the integration of internal changes with the support of the external environment can ensure the stable development of multidisciplinary scientific research cooperation among colleges.

Keywords: Multidisciplinary cooperation; cooperative performance; multiple paths; fuzzy-set qualitative comparative analysis (fsQCA)

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Introduction

A country's scientific research standing is an important indicator of its overall capacity, and enhancing academic competitiveness is therefore critical for every nation. Accelerated globalization and rapid advances in science and technology have promoted both economic development and the integration and dissemination of research and culture. On May 2, 2018, General Secretary Xi Jinping emphasized at the Peking University faculty-student symposium: "*In today's world, science and technology are developing rapidly... Colleges should make great efforts to form interdisciplinary study groups and strong scientific and technological research teams to strengthen the collaborative innovation among different disciplines and to strengthen support for original, systematic, and leading research... Strive to achieve major breakthroughs in prospective basic research and leading original studies*" (1). The development of modern science has introduced new elements to research, including the intersection of different disciplines and the increasing size of scientific research teams. Scientific research is a complex process that requires the input of a substantial amount of brain power. In scientific research activities, it is difficult to achieve quality research results through the efforts of individual scientists. Cooperation among experts and scholars can effectively promote scientific innovations, increase the efficiency of scientific research, reduce the challenges of research, and maximize the talents and skills of researchers through resource sharing.

Previous studies have mostly focused on interdisciplinary citations. Research on measuring the interdisciplinary nature of specific topics through citation analysis has yielded rich results, demonstrating the flow, diffusion, and transfer of knowledge across disciplines (2,3). For example, the interdisciplinary knowledge diffusion law of journal documents between library and information science, computer science, management science, and medicine is displayed by visual method. Many countries currently issue policies and reports to promote the implementation of interdisciplinary research. In 2005, the United States released "Promoting Interdisciplinary Research" as part of the "National A-cademies Keck Futures Initiative" program in the United States. Research provides general action guidelines. In 2008, during his presidential campaign, Obama proposed Investing in the Future of America—Obama-Biden Science and Innovation Plan, which clearly pointed out that innovation comes from the knowledge integration of researchers from different disciplines, and multidisciplinary research should be actively encouraged. Likewise, world-class research universities generally highlight the importance of interdisciplinary research in strategic planning. In the strategic plan "Strategic Plan 2025", Carnegie Mellon University proposes to cultivate a culture that solves learning and research problems with an interdisciplinary approach, and is driven by profound disciplinary knowledge to form new thinking at the edges and intersections of traditional fields. Supported by strategic planning, the university promotes interdisciplinary research practices through infrastructure development and large-scale projects.

In recent years, the Chinese government has also mentioned the importance of interdisciplinary research in various policies. The 2006 Outline of the National Medium- and Long-Term Science and Technology Development Plan [2006–2020] pointed out that major scientific discoveries and emerging disciplines often originate from the intersection and integration of multiple disciplines, and need to be given high attention and focused deployment. The 2016 "National Innovation-Driven Development Strategy Outline" pointed out that in the basic frontier and high-tech research facing the national strategic needs, it is necessary to "integrate interdisciplinary and interdisciplinary superior forces and accelerate key breakthroughs".

As more colleges are involved in interdisciplinary scientific research cooperation, the processes involved in establishing strong interdisciplinary groups and capable technical research teams, strengthening collaborative innovations among multiple disciplines, achieving major breakthroughs through prospective basic research, and leading original studies have become an urgent focus of research. Many factors can affect the productivity of collaboration, and the implementation paths of some key factors remain unclear (3). However, most of the current domestic research on the influencing factors of interdisciplinary scientific research cooperation only focuses on a certain element, a certain field or a certain research project, and lacks a systematic discussion. Based on different research methods and research paradigms, numerous systematic studies on interdisciplinary cooperation have been conducted in advanced countries (4-8). However, relevant research in China is still at its beginning stages, and a standardized collaboration system has not yet been established. Therefore, it is imperative to construct a model of the influencing factors of interdisciplinary cooperation suitable for China's national conditions and to promote systematic innovation in interdisciplinary scientific research cooperation.

Fuzzy-set qualitative comparative analysis (fsQCA) is an effective method to study "joint effect" and "interaction" and has been widely used in management science in recent years (5). QCA uses Boolean logic to replace the traditional correlation method, establishes causal conditions closely related to specific results, and analyzes the sufficient and necessary reasons for the results, as the basis for forming configuration paths. In the current study, we used fsQCA to analyze, for the first time, data from a large-scale questionnaire-based survey of 375 researchers from 181 research teams at six colleges across China. In-depth interviews were conducted with respondents with good achievements in interdisciplinary cooperation. Based on the multiple theoretical interpretation framework proposed by Chari and Chang (6-8), we explored the "joint effects" of five factors [cooperation willingness (CW), cooperation ability (CA), organizational model (OM), policy-based guarantees (PG), and cooperation output (CO)] on the productivity of cooperative activities and the interactions among these five factors, thereby revealing the drive factors and supporting factors for multidisciplinary scientific research cooperation in colleges. We present the following article in accordance with the SURGE reporting checklist (available at https://atm.amegroups.com/article/view/10.21037/atm-22-2639/rc).

Methods

Research framework and literature review

The performance of multidisciplinary scientific research collaboration in colleges can be affected by multiple factors at different levels. Huo *et al.* (6) provides a complete and systematic multilevel theoretical interpretation framework for multidisciplinary scientific research cooperation in colleges. The framework includes three theoretical explanations: theory of planned behavior (TPB), social exchange theory (SET), and cross-sector collaboration theory (CCT) (6-8). In addition, it involves five important explanatory factors: CW, CA, OM, PG, and CO. We first summarized multidisciplinary and interdisciplinary scientific research collaboration at colleges and then adapted the framework by Huo *et al.* (6) to carry out the current analysis, thus reflecting the generalizability of this multitheoretical interpretation system.

CW

CW is a key factor affecting the performance of scientific research collaboration. Relationship capital is created and utilized through the ongoing maintenance of connections based on trust, commitment, and reciprocity. When scientists experience fairness and mutual trust in scientific research cooperation, they will repeatedly generate or maintain this behavior, producing meaningful communication (9) and enabling the exchange of resources (10), which affects research productivity. Lan *et al.* (11) found that most researchers from sample colleges believed that each element of the scientific research cooperation atmosphere had a "very large" or "large" impact on scientific research cooperation. Guo *et al.* (12) found that the cooperative atmosphere and scientific research ability were the most critical factors. In scientific research collaboration, the sponsoring institution attaches great importance to the comprehensive quality and cooperation status of the partner institutions, and thus the strength and atmosphere of the partners greatly affect the cooperation process and can have a significant impact on research outcomes.

CA

According to management theory, members in an organization have different abilities that complement each other, allowing the organization to minimize risks and achieve better results in various fields. In their empirical research, Zhang *et al.* (13) confirmed that in the field of basic research, learning ability played a mediating role in promoting the performance of international scientific and technological exchanges and cooperation in a scientific research environment. Hu *et al.* (14) investigated whether the effect of coauthorship network centrality on research productivity was affected by author seniority and found that the impact of centrality on productivity was higher with more senior authors. Therefore, strong demand for cooperation, strong research interests, mutual trust, smooth communication, and joint decision-making are factors that lead to high performance in a collaborative research project.

OM

Liang *et al.* (15) conducted an empirical study on industry-university collaboration in Guangdong Province and proposed that government serve as a go-between in collaborative multidisciplinary scientific research, guiding

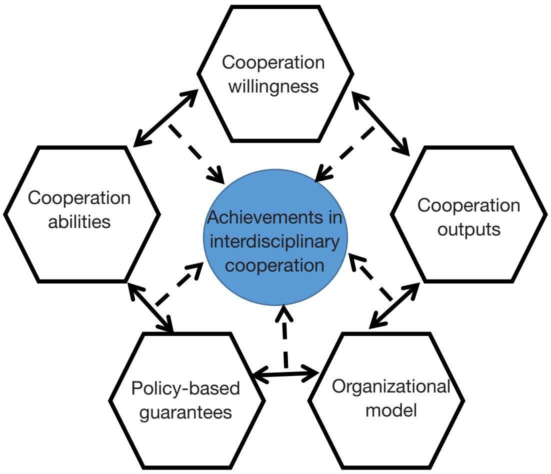

Figure 1 The logical framework of our analysis.

the different partners to carry out in-depth cooperation and helping them to increase the level of innovation, thereby improving the performance of industry-college cooperation in scientific research. However, in a study by Lei *et al.* (16) on the influence of scientific research paper network capital on scientific research performance, the results indicated that social network capital, which was constructed on the basis of scientific research papers, was more closely related to academic recognition than government and market recognition (especially the former). Therefore, in the current analysis, we explored the impact of OM on high performance.

PG

The CCT emphasizes "visionary leadership, political leadership, ethical leadership and their interconnectedness", helping various stakeholders understand and address public-related issues, obtain the required policies and resolutions, and implement new rights-sharing mechanisms. The success of cross-sector collaboration requires collaboration among partners (17). According to Zhang *et al.* (18), good policies and a supportive atmosphere for scientific research can attract and retain more high-tech talent in China and abroad and stimulate their enthusiasm and creativity. Jiang *et al.* (19), whose subjects comprised young scientists from the Chinese Academy of Sciences, proposed that young scientific and technological talents should be offered a more supportive external atmosphere, including rational allocation of scientific research funds and a fair system of scientific research evaluation, which would facilitate the training of young scientists and promote the sharing and dissemination of research findings. We believe that for researchers, solid PG, stable communication channels, and a clear accountability mechanism will help to stabilize partnerships and achieve good cooperation results.

CO

The SET regards individuals and institutions as a research target and assumes that the main purpose of mutual exchanges between individuals, groups, and others is to seek rewards. In other words, the exchange between individuals and organizations, between individuals and individuals, and between organizations and organizations are essentially an exchange of value. For groups and organizations, a more capable partner means more predictable benefits from the cooperation and accordingly, the group/organization is more willing to maintain such a partnership.

Interdisciplinary scientific research collaboration in colleges is unavoidably affected by a variety of factors. However, how the five factors (CW, CA, OM, PG, and CO) jointly affect the performance of interdisciplinary scientific research cooperation in colleges remains an open question. In fact, with rapid advances in science and technology, colleges are devoting more attention to their unique resources and core competitiveness. Thus, the three theoretical explanations are particularly crucial. We used QCA to investigate the driving factors and joint effects of these five explanatory factors on multidisciplinary scientific research cooperation in colleges and explored the mutual influences among the various theoretical explanations. The logical framework of our analysis is shown in *Figure 1*.

Research methods and data sources

Research methods

We used fsQCA to explore how the five explanatory factors (CW, CA, OM, PG, and CO) affected each other and how they affected the productivity of multidisciplinary collaboration in colleges. Based on Boolean algebra, QCA involves a comprehensive comparison and analysis of individual cases to explore the "joint effect" of the interactions among different factors on a specific issue, and thus was a particularly useful tool for our research. The use of fsQCA for analyzing specific technical issues in the current study was based on the following justifications: (I) the conventional regression method was only suitable for analyzing the "net effect" of a single factor, whereas fsQCA could reveal the structure and mechanisms of various factors; (II) although cluster analysis and factor analysis could also be used to verify the correlations among different configurations, they could not effectively distinguish the interdependence among different statuses, the configuration equivalence, or the causal asymmetry; and (III) compared with other QCAs [e.g., clear set QCA (csQCA) and multi-value QCA (mvQCA)], fsQCA had more advantages (20-22). Because the causal conditions in this study were all continuous variables, fsQCA could better reflect the small effects of varying degrees or at different levels.

Data sources

Based on the index systems established by Zhang (13) and Ma (21), we developed an initial questionnaire and carried out a questionnaire-based survey with researchers from six comprehensive universities nationwide via the WJX app. The questionnaire mainly comprised objective-type questions and covered three major aspects: basic information of the respondents; information of the research team and partner; and attitudes toward the factors affecting multidisciplinary scientific research cooperation, including CW, CA, OM, PG, and CO. The questionnaire included 19 multiple-choice questions and 1 open-ended question. After incomplete responses were excluded, a total of 358 valid questionnaires remained. Through the questionnaire-based survey of 358 researchers from 181 research teams at six Chinese colleges and interviews with more than 10 experts in the field of scientific research management, five items scored highest (and thus had the most significant impact on interdisciplinary cooperation), including CW, CA, OM, PG, and CO (*Table 1*). The multiaction paths of their joint effect on multidisciplinary cooperation were also explored. Based on the empirical research findings, we further carried out qualitative research on the specific contents of these five influencing factors, with an attempt to inform the construction of college medical and multidisciplinary innovation systems. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study was approved by ethics committee of the Xiangya Hospital of Central South University (No. 202104090311). Informed consent was taken from all the participants.

Statistical analysis

Reliability and validity analyses

As seen in the reliability and validity analyses in *Table 1*, the Cronbach's coefficients and composite reliability (CR) values of cooperation performance (CP), CW, CA, OM, PG, and CO all exceeded 0.7, indicating the reliability of the questionnaire was fair. Construct validity was tested by exploratory factor analysis (EFA), which returned a Kaiser-Meyer-Olkin (KMO) value of 0.7. The KMO value exceeded 0.7, the cumulative variance contribution rate was at least 56.42%, the factor loading of each item exceeded 0.60, and the average variance extracted (AVE) of all constructs exceeded 0.5, indicating the structural validity of the questionnaire was good.

Data aggregation

During data collection and variable measurement, individual-level raw data were obtained and then aggregated and averaged. The individual-level data were also aggregated to the research team level prior to analysis; therefore, the internal consistency of individual respondents for each variable was first determined. As shown in *Table 2*, the reliability of score within group (RWG), reliability of mean group score intraclass correlation coefficient (ICC)1, and ICC2 were all above 0.47, and all variables met or exceeded the conditions for aggregation.

Measurement and calibration

Each condition (each of the five influencing factors in this paper) and its result (the performance of multidisciplinary collaboration) were regarded as a set, and each case had a corresponding score. Calibration refers to the process of categorizing cases into a score. Consistent with currently available research, our analysis used the direct calibration method to convert the data into fuzzy-set membership scores based on existing theoretical and empirical knowledge, according to the data types of each condition and result. *Table 3* summarizes calibration information for the various conditions and results in this paper.

Result variable

CP: on the basis of existing research (18-20), a 5-point ordinal scale was used to measure CP. For 4 items ("Stable partnership", "High cooperation satisfaction", "Tackling the bottleneck problems in population health", and "Yielding economic and social returns"), CP was scored '4' if all 4 items were consistent, '3' if the first 3 were consistent, '2' if the first 2 were consistent, '1' if the top 1 was consistent, and '0' if all of them were different. Based on the direct calibration method, '4' indicated the union of 2 sets, '2' the intersection, and '0' the complement.

Condition variables

CW: on the basis of existing research (20-22), a 5-point ordinal scale was used to measure CW. For 4 items ("A

Table 1 Reliability and validity of the questionnaire

Variables	Dimension	Minimum factor loading	Cronbach's	CR	AVE
CP	Stable partnership	0.934	0.942	0.751	0.536
	High satisfaction	0.912			
	Tackling the bottleneck problems in population health	0.927			
	Yielding economic and social returns	0.909			
CW	A strong demand for cooperation between two parties	0.935	0.962	0.832	0.618
	Both parties have strong research interests	0.912			
	Both parties trust each other's ability	0.923			
	Smooth communication and shared decision-making	0.935			
CA	The teams have experience in cross-sector cooperation	0.906	0.885	0.890	0.721
	Team members are complementary to each other	0.935			
	Both parties have strong scientific research capabilities	0.933			
	Plenty of time for teamwork	0.924			
OM	Initiated by a research team	0.911	0.876	0.871	0.743
	Organized by an institution	0.907			
PG	Supported by a grant	0.919	0.931	0.882	0.847
	Sophisticated platform and hardware	0.938			
	Clear incentive	0.937			
	Clearly-defined responsibilities, rights, and interests	0.926			
CO	Publications	0.935	0.920	0.853	0.756
	Patents	0.924			
	Awards	0.933			
	Talent training	0.931			
	Rewards and benefits	0.914			

CP, cooperation performance; CW, cooperation willingness; CA, cooperation ability; OM, organizational model; PG, policy-based guarantees; CO, cooperation output; CR, composite reliability; AVE, average variance extracted.

Table 2 Data aggregation

Variables	CP	CW	CA	OM	PG	CO
RWG	0.78	0.71	0.72	0.83	0.77	0.86
ICC1	0.15	0.18	0.21	0.22	0.23	0.22
ICC2	0.73	0.68	0.72	0.79	0.72	0.61

RWG, reliability of score within group; ICC, intraclass correlation coefficient; CP, cooperation performance; CW, cooperation willingness; CA, cooperation ability; OM, organizational model; PG, policy-based guarantees; CO, cooperation output.

Table 3 Calibration of results and conditions

Conditions and results	Calibration		
	Union	Intersection	Complement
CP	4	2	1
CW	20	16	13
CA	20	16	13
OM	1	–	0
PG	20	13	5
CO	25	20	15

CP, cooperation performance; CW, cooperation willingness; CA, cooperation ability; OM, organizational model; PG, policy-based guarantees; CO, cooperation output.

strong demand for cooperation between two parties", "Both parties have strong research interests", "Both parties trust each other's ability", and "Smooth communication and shared decision-making"), CW was scored '4' if all 4 items were consistent, '3' if the first 3 were consistent, '2' if the first 2 were consistent, '1' if the top 1 was consistent, and '0' if all of them were different. Based on the direct calibration method, '4' indicated the union of 2 sets, '2' the intersection, and '0' the complement.

CA: on the basis of existing research (20-22), a 5-point ordinal scale was used to measure CA. For 4 items ("The teams have experience in cross-sector cooperation", "Team members are complementary to each other", "Both parties have strong scientific research capabilities", and "Plenty of time for teamwork"), CA was scored '4' if all 4 items were consistent, '3' if the first 3 were consistent, '2' if the first 2 were consistent, '1' if the top 1 was consistent, and '0' if all of them were different. Based on the direct calibration method, '4' indicated the union of 2 sets, '2' the intersection, and '0' the complement.

OM: OM was measured using the cumulative number of scientific research collaboration projects currently carried out by scientific research teams. The OM of a specific collaborative project was regarded as a dichotomous condition, and the value assigned was '0' if the project was initiated by the research team and '1' if organized by an institution.

PG: on the basis of existing research (20-22), a 5-point ordinal scale was used to measure PG. For 4 items ("Supported by a grant", "Sophisticated platform and hardware", "Clear incentive", and "Clearly-defined responsibilities, rights, and interests"), PG was scored '4' if all 4 items were consistent, '3' if the first 3 were consistent, '2' if the first 2 were consistent, '1' if the top 1 was consistent, and '0' if all of them were different. Based on the direct calibration method, '4' indicated the union of 2 sets, '2' the intersection, and '0' the complement.

CO: on the basis of existing research (20-22), a 5-point ordinal scale was used to measure CO. For 5 items ("Publications", "Patents", "Awards", "Talent training", and "Rewards and benefits"), CO was scored '5' if all 5 items were consistent, '4' if the first 4 items were consistent, '3' if the first 3 were consistent, '2' if the first 2 were consistent, '1' if the top 1 was consistent, and '0' if all of them were different. Based on the direct calibration method, '5' indicated the union of 2 sets, '3' the intersection, and '0' the complement.

Results

Analysis of the necessity of single causal conditions

Based on the main QCA theoretical results, we first examined whether a single condition, including the nonempty sets, was necessary for a complete union. From the perspective of set theory, it is necessary to analyze a single condition to identify whether it is a subset of a particular set of conditions. In fsQCA, if a specific condition occurs, this condition will become a necessary condition. A key criterion for a necessary condition is the presence of consistency. A necessary condition requires a consistency of above 0.90. *Table 4* shows the test results of the necessary conditions for the union, as analyzed using fsQCA 3.0 software. The results showed that "organized by an institution" (OM) was a necessary condition for achieving high-performance scientific research collaboration (0.905>0.9); in other words, the absence of this condition would become an obstacle to output. Based on the analysis of necessary conditions, this condition was included in fsQCA to further investigate the configuration that contributed to high performance of scientific research collaboration.

Analysis of the sufficiency of conditional configurations

Comparative analysis of fuzzy sets yields three different solutions: complex solutions (without "logical remainders"), intermediate solutions (using "logical remainders" that are consistent with theory and practice), and

Table 4 Analysis of the necessary conditions for multidisciplinary scientific research cooperation in colleges

Causal conditions	Good cooperation effectiveness	
	Consistency	Coverage
CW	0.7876	0.7857
cw	0.5362	0.8732
CA	0.7876	0.7857
ca	0.5362	0.8732
OM	0.9050	0.7816
om	0.4586	1.0000
PG	0.6968	0.8294
pg	0.6451	0.8311
CO	0.6845	0.8052
co	0.6596	0.8607

Capital letters indicate the presence of the condition, and lower-case letters indicate the absence. CW, cooperation willingness; CA, cooperation ability; OM, organizational model; PG, policy-based guarantees; CO, cooperation output.

parsimonious solutions (using "logical remainders" that can help simplify configuration). In these conditions, the intermediate solution generally does not simplify the necessary conditions; rather, the intermediate solution will be reported and associates with the core conditions and peripheral conditions in the parsimonious solutions. The causal condition is most important if it occurs in both parsimonious solutions and intermediate solutions; in contrast, if a condition occurs only in an intermediate solution, it is a peripheral condition.

Unlike necessary condition analysis, configuration analysis aims to reveal the sufficiency of results obtained from various combinations of multiple conditions. From the perspective of set theory, whether the set represented by the group consisting of multiple conditions is a subset of a result set is explored. While the adequacy of the configuration is also measured by consistency, the recognized minimum criteria and calculation methods are different from those of necessary condition analysis. According to Schneider *et al.*, the consistency level of sufficiency must be above 0.75. Some other studies have used different consistency thresholds (e.g., 0.75 and 0.80) for specific experimental situations (22,23).

We used fsQCA 3.0 to analyze the relevant data from 67 teams and identified combinations with a frequency of 1, a consistency level of higher than 0.8, and a consistency with proportional reduction in inconsistency (PRI) of higher than 0.75. Four configurations with high CP were obtained (*Table 5*), and the consistency indices of these 4 configurations were high (0.991, 0.979, 0.972, and 0.875, respectively). These 4 configurations provided an adequate basis for realizing high-level scientific research cooperation and they could also explain the high performance of high-level scientific research cooperation.

(I) Organization-led type:
H1: ~CW*~CA*OM*~CO;
H2: ~CW*~CA*OM*PG;

(II) Ability/willingness-driven type:
H3: CW*CA*OM*~PG;
H4: CW*CA*OM*CO.

As shown in *Table 5*, there were four configurations (H1, H2, H3, and H4) of the path to high-performance in scientific research collaboration. Among them, OM appeared in each configuration as a necessary condition. In H1, regardless of the presence (or not) of uncertain PG, the condition OM (core condition) could produce high performance in scientific research collaboration. In H2, under an uncertain environment of high CO, there was a lack of high CW and CA. However, scientific research teams with high level of OM (core condition) and high PG (core condition) could achieve high performance in scientific research collaboration. In H3, under an uncertain environment of high CO, scientific research teams with a high level of OM, CW (core condition), and CA (core condition) could achieve high performance in scientific research collaboration. In H4, under an uncertain environment of high PG, scientific research teams with a high level of OM, high CW (core condition), and high CA (core condition), and high CO (core condition) could achieve high performance in scientific research collaboration.

Comparisons among these four configurations showed that H4, which had higher coverage values than H1, H2, and H3, explained 63% of research results and covered 20 cases, indicating that most research teams carried out high-level research cooperation in this way. This clearly explains the impact of the configurations involving "willingness", "ability", and "organized by an institution" on collaboration performance. The coverage of H1, H2, and H3 were 48%, 40%, and 51%, respectively, which also shows that the paths to high performance in scientific research cooperation are diverse, and an uncertain competitive environment and

Table 5 Analysis of the configurations for multidisciplinary scientific research cooperation in colleges

Causal conditions	Solutions			
	H1	H2	H3	H4
CW	ⓧ	ⓧ	●	●
CA	ⓧ	ⓧ	●	●
OM	●	●	●	●
PG		●	ⓧ	
CO	ⓧ			●
Consistency	0.9909	0.9794	0.9715	0.8748
Raw coverage	0.4842	0.4027	0.5110	0.6315
Unique coverage	0.0408	0.0040	0.0338	0.1401
Solution consistency	0.8410			
Solution coverage	0.8893			

H1: ~CW*~CA*OM*~CO; H2: ~CW*~CA*OM*PG; H3: CW*CA*OM*~PG; H4: CW*CA*OM*CO. ● indicates presence of a core condition; ⓧ indicates absence of a core condition; and a "space" indicates that such a condition can be either present or absent. CW, cooperation willingness; CA, cooperation ability; OM, organizational model; PG, policy-based guarantees; CO, cooperation output.

intrapreneurship culture also have certain impacts. Thus, QCA was highly valuable in explaining the configuration effect among various factors, which could not be interpreted by conventional statistical analysis tools.

Robustness test

The robustness test was performed by adjusting the consistency level (from 0.80 to 0.85), and QCA was validated accordingly based on combinations of various configurations and the difference of fitting parameters in various configurations (24,25). The conclusions of our study were found to be robust.

Discussion

Theoretical bases

In the current study, fsQCA effectively identified 4 paths to high performance in scientific research collaboration in colleges, indicating that the influencing factors were diverse, parallel, and target-oriented. We used interviews and a questionnaire-based survey to reconfigure the environmental and organizational conditional factors of 181 scientific research teams in China. Multiple factors and causal mechanisms of multidisciplinary cooperation at different levels were explored. Our main conclusions included the following: (I) initiation and organization by an institution was a necessary condition for achieving high-performance scientific research collaboration. (II) The performance incentive method of high-tech collaboration could be divided into 4 main paths: configuration organized by an institution; configuration organized by an institution, with high PG; configuration organized by an institution, with high CW and high CA; and configuration organized by an institution, with high CW, CA, and CO. (III) The drive mechanism of high performance in scientific cooperation could be divided into two types: organization-led and the ability/willingness-driven. According to the core conditions contained in these four paths and the explanatory logic behind them, we divided them into two types of cooperation modes: organization-led and ability/willingness-driven. An organization-led cooperation project mainly relied on the initiation and guidance of institutions and policies and thus could be carried out even without strong personal willingness and ability. An ability/willingness-driven cooperation project was organized by an institution, even in the absence of PG or CO. Therefore, by using multiple explanatory frameworks and perspectives, including the TPB, SET, and CCT, we further elucidated the above two types of cooperation paths.

TPB

According to TPB, beliefs can guide an individual's perception of behavior. However, because of environmental factors and the unique characteristics of a specific belief, only a very small number of beliefs can be perceived, known as "salient beliefs". Salient beliefs include behavioral beliefs, normative beliefs, and control beliefs. By affecting the subject's perception, salient beliefs will produce heterogeneous emotions (positive or negative), perceived social expectations and pressures, self-efficacy, and self-control capabilities for a specific behavior and then produce judgments about the subjective probability of the behavior, thus indirectly affecting the behavior. In the current study, we believe that for scientific researchers, a stronger CW ensured a more stable partnership, and greater trust predicted larger CO.

SET

SET regards individuals and institutions as a research target and assumes that the main purpose of mutual exchanges between individuals, groups, and others is to seek rewards. In other words, the exchange between individuals and organizations, between individuals and individuals, and between organizations and organizations are essentially an exchange of value. SET regards all activities of human interaction as an exchange relationship, and the net value obtained through exchange by an individual affects his/her behavior and attitude. In a macroscopic structure, the exchange process among groups/organizations is similar to that among individuals, and it also involves mutual attraction, exchange, norms, power, and conflict among the groups/organizations. SET deeply analyzes the nature of social exchange and has a strong foundation in sociology. It has been widely applied in disciplines such as anthropology, social psychology, and organizational behavior studies. In the current study, for a group and an organization, a more capable partner meant more predictable benefits from the cooperation and accordingly, the group/organization was more willing to maintain such a partnership. For an individual researcher, his/her perception of equity and fairness affected their willingness to cooperate and this was transmitted to the value of the relationship. Perception of fairness was a significant predictor of their willingness and confidence in long-term cooperation.

CCT

CCT focuses on three aspects of leadership, including vision, politics, and ethics, and the correlation among them. CCT can help different stakeholders understand social issues, address public problems, obtain and implement the necessary policies, and leverage the new rights-sharing regime. Cross-sector cooperation requires cooperation between partners. The relevant measures include: building trust in ongoing collaboration, exploring solutions to power imbalances, dealing with changing relationships among members, developing supportive processes, and developing systems for evaluating results and strengthening accountability. Otherwise, the cooperation will not move forward. The initial conditions, processes, structure/governance, contingency factors and outcomes, and accountability mechanisms have important influences on the initiation, operation, and structure of a cooperation project. We believe that for researchers, solid PG, stable communication channels, and a clear accountability mechanism will help to stabilize the partnership and achieve good cooperation results.

Policy recommendations

The amount of cross-college, cross-regional, and/or cross-national research is rising and needs to be further promoted by establishing appropriate measures and policies. In fact, efforts by researchers themselves or based on the support or capacity-building of the college have many limitations. As shown by our research on interdisciplinary scientific research collaboration between colleges in China, such cooperation could be restricted by both internal and external factors. Only the integration of internal changes with the support of the external environment can ensure the stable development of multidisciplinary scientific research cooperation among colleges.

Developing policies for interdisciplinary scientific research cooperation organized by institutions

Sophisticated policies can ensure the implementation of interdisciplinary scientific research activities in a normal and orderly manner, provide a sound and orderly environment for the interdisciplinary research, and mobilize the enthusiasm and initiative of researchers. A sound, reasonable, and legal interdisciplinary cooperation mechanism is of great significance to all colleges and will play a very important role in regulating interdisciplinary collaboration (26).

In order to prevent academic misconduct (e.g., impropriety of authorship), it is important to formulate management systems and policies for college-level scientific research collaboration (27). Therefore, an interdisciplinary scientific research cooperation system at the college level is required to reduce risk and standardize research cooperation in multiple fields. While there are many ways to carry out cross-field scientific research collaboration between colleges, very few colleges have developed formal scientific research cooperation mechanisms or have formulated/implemented cross-field scientific research collaboration policies. Therefore, developing such mechanisms and policies for scientific research cooperation has become a top priority. Firstly, the main contents of a multidisciplinary/interdisciplinary scientific research collaboration agreement should include the project name, aim, institutions, responsibilities, and obligations, which should fully reflect the visions and interests of all parties involved, thus creating a win-win situation and establishing a close partnership (28).

A project management office with clearly-defined terms of reference (ToR) to facilitate, standardize, and regulate the work of the office staff is necessary. A cooperation agreement signed by a college and its partner must clearly define the cooperation content, rights, and obligations of both parties, standardization of work procedures, methods for addressing problems, and liabilities for a breach of agreement. In the event of certain risks, consultations can be conducted according to the terms of the agreement. Once the basic principles of the collaboration are defined, the budget, implementation and supervision systems, and cooperation processes should be clarified. Complex interdisciplinary research collaboration often involves many resources, and it is necessary to define the ownership of property rights. Regulations should be formulated to protect both the college's rights in tangible assets and the intellectual property rights of individual researchers engaged in interdisciplinary scientific research collaboration. The signing and implementation of the cooperation agreement provides a justification for multidisciplinary collaboration among colleges and promotes its development in a standardized and orderly manner.

Provide external guarantees and incentives and establish effective cooperation mechanisms

(I) Incentive mechanism: it is important to encourage scientific researchers in various fields to be involved in collaborative projects. Relevant policies and measures should be established. Teams with outstanding achievements in research cooperation should be offered rewards and incentives. Meanwhile, a good research cooperation atmosphere among different fields should be valued and not measured (and rewarded) based on the research output alone.

An internal evaluation system should be established to encourage teams that have participated in multidisciplinary research cooperation. Such a system enables the assessment, evaluation, and summarization of collaboration, and the results will be fed back to the college, the partner, and other stakeholders, which is an indispensable link in multidisciplinary cooperation (29). Such an internal evaluation system will mobilize the enthusiasm and initiative of research teams and encourage them to be actively involved in multidisciplinary research collaboration. Internal evaluation can also reveal the problems in multidisciplinary research and inform the research team to address these problems, strengthen their relationship with more partners, and promote the sustainable development of research in multiple fields.

(II) Talent training: it is recommended that a dual-tutor system for master students or doctoral students who are involved in interdisciplinary studies be established, offering them relevant interdisciplinary courses. Barriers to knowledge sharing must be removed to strengthen in-depth communication among different disciplines. The single-tutor system cannot meet the needs of interdisciplinary research (30). It is important to expand incentives for researchers participating in interdisciplinary research cooperation and recognize the equal intellectual contributions made by researchers from different disciplines in interdisciplinary research collaboration.

Create a supportive environment and maintain a positive atmosphere

In the early stages of collaboration, the parties should determine the project's aim and predict its results, which will help promote interdisciplinary research in colleges. However, the results of the collaboration can be disappointing due to differences among the parties and/or due to information asymmetry (31). When the predicted results are inconsistent with the actual results, researchers should fully perform their research duties and distribute the research results based on their contributions to the project. Findings from the interviews we conducted also showed that in order to promote the development of multidisciplinary cooperation and achieve a win-win situation for all parties, interviewees expected a better return from the collaboration through scientific and reasonable distribution.

Rationally predict results and achieve win-win goals

As shown in our survey results, both the respondents who had participated in multiple research collaborations and those who had not believed that the result factor was the most influential factor. More specifically, "obtaining satisfactory non-economic benefits" ranked second for respondents who had not been involved in any research cooperation and ranked fifth for researchers who had participated in multiple research collaborations. Therefore, obtaining satisfactory non-economic benefits was the most important consideration for researchers (32). A clearly-defined collaboration aim is a premise for a good cooperation result. In the early stages of interdisciplinary scientific research collaboration, it is important to discuss research processes, formulate specific methods, define the aim, and identify the goals of individual researchers. The integration of individual goals with the overall aim will ensure the realization of interdisciplinary scientific research cooperation and achieve a win-win outcome.

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Footnote

Reporting Checklist: The authors have completed the SURGE reporting checklist. Available at https://atm.amegroups.com/article/view/10.21037/atm-22-2639/rc

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