

Article

Antecedents of Knowledge Interaction in the Sustainable Interdisciplinary Research Team: A Mixed Research Method

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Abstract: This paper mainly focuses on two questions: (1) Which factors mainly influence knowledge interaction in a sustainable interdisciplinary research team (SIDRT)? and (2) How are knowledge interaction processes structured in a SIDRT? This paper first defines the conception of knowledge interaction in a SIDRT from the complex system perspective. Then the model of key influencing factors in a SIDRT is constructed through grounded theory, including subjects' attributes, objects' characteristics, environment, and resources of knowledge interaction. Furthermore, we propose hypotheses and empirically validate our conceptual model. The combination of the two methods can strengthen the research conclusions from different angles. Finally, based on our qualitative and quantitative results, the theoretical and practical implications are discussed.

Keywords: knowledge interaction; sustainable interdisciplinary team; grounded theory; empirical research

1. Introduction

The term “sustainability” has caused a paradigm change in research methods. Due to these complexity, ambiguity, and dynamic exchanges, many problems, such as sustainable city system study [1], sustainable regulated river management [2], sustainable education, environments, business managements [3], and other sustainable and comprehensive problems often apply an interdisciplinary approach [4]. Therefore, many interdisciplinary (ID) teams have been assembled to solve these problems that are faced in the process of social development, and to ensure that multiple goals and multiple values are both successfully realized [5]. A notable international example is Stanford University Bio-x Interdisciplinary Research Program aiming to benefit human health and lower ecological footprints, which brings together over 600 teachers from all over the world [6]. It is clear that such program involves collaboration among medical doctors, scientists, and engineers. It also requires practitioners or team leaders to make decisions if there are gaps in opinions. This series of complex communications and decisions could explain why knowledge interaction is commonplace in a sustainable interdisciplinary research team (SIDRT). In particular, Hare states that the key to the success of a program, especially a complex program, lies in knowledge communication among team members [7]. Many studies have pointed out that knowledge interaction with high quality is the key to solving difficult and sustainable problems for a SIDRT [8,9].

To date, ID researchers have proposed many conceptual models to identify key antecedent conditions, intervening processes, and outcomes associated with team science initiatives and to explain the interrelationships among them. Many scholars focus on team performance and team innovation research [10–13]. However, the most debated aspect of interdisciplinarity is the process

of “integration” [14–17]. Klein argues that there are four models of integration (common group learning, modeling, negotiation among experts and integration by leader) [18]. Bammer outlines three sets of characteristics (specialization, theoretical and methodological pillars, practical application) that will delineate integration and implementation sciences [19]. Hoffmann et al. combine three types of knowledge integration procedures (common group learning, negotiation among experts and integration by leader) and six categories of integration methods (definition, formulation, development, assessment, modeling and creation) to produce thematic synthesis reports [20]. However, a profound understanding of the challenges related to knowledge interaction, as it applies to ID research, is missing.

For sustainable ID research, it is important to characterize different kinds of dependencies and identify the interaction process that can be used to manage teams well [21]. Over the past decade, a variety of work has explored the various influencing factors of knowledge interaction for a SIDRT, including personal and structural characteristics [22], team leader behavior [23] and team climate [24]. In the aspect of knowledge interaction process, scholars mainly hold the two opposite perspectives, knowledge divergence [25] and knowledge convergence [26]. Researchers generally believe that shared ideas can stimulate other group members to think of other ideas or categories of ideas, further enhance the team creativity [27,28]. Inversely, others hold that knowledge convergence process has been conceptualized as a process of convergent decision-making that takes place after ideas are generated to improve the quality of the group’s creative output [29]. Although prior studies are insightful, they are fairly fragmented and mainly focus on single factor or process. Thus, it is necessary to integrate the processes of knowledge interaction and explore its influencing factors from a holistic perspective to guide SIDRTs towards sustainable development.

Hence, the study is concerned with the following two questions:

- 1) Which factors mainly influence knowledge interaction in SIDRTs?
- 2) How are knowledge interaction processes structured in SIDRTs?

To address these questions, we first identify key influencing factors of SIDRTs using grounded theory. Secondly, we use regression analysis to analyze the mechanism of the influence factors on knowledge interaction and the internal association of knowledge divergence and convergence. Finally, we discuss theoretical and practical implications based on conceptual and empirical work of this paper. The remainder of this paper is organized as follows. Section 2 discusses knowledge interaction of SIDRTs from a complex system perspective. In Sections 3 and 4, a conceptual model of influencing factors is generated through grounded theory. In Sections 5 and 6, hypotheses are proposed and tested. The results are detailed in Section 7. Finally, Section 8 contains the discussion and our conclusions, including theoretical and practical implications, limitations, and future research directions.

2. Conceptual Framework

2.1. Interdisciplinary Research

Of all the definitions that have appeared, multidisciplinary and interdisciplinarity are the most commonly identified processes of cross-disciplinary research, which have been described by Rosenfield [30]. Multidisciplinary is a conglomeration of disciplinary components, in which team members remain their own concepts or methods of their respective fields firmly. In contrast to multidisciplinary, interdisciplinarity involves the integration of perspectives, concepts, theories, and methods from different fields, emphasizing an interactive process.

In the context of this research, our focus is mainly on interdisciplinarity. Following the related literature [22,24,31], we refer to interdisciplinarity as knowledge interaction among team members of different disciplines. The “discipline” here refers to having different academic backgrounds. The differences in skills and job experiences are reflected in the team members themselves. Through the collision between various paradigms, borrowing of theories and methods between disciplines, team members will generate new ideas, methods, and work jointly to address a common research

problem. According to this definition, the core challenge of interdisciplinary is to integrate knowledge of different fields.

2.2. Farming Research for Knowledge Interaction

A common way relating ID research is through the science of team science (SciTS). It aimed at examining the processes of team's organization, communication and conduction [32]. This field needs multilevel and mixed-methods to integrate different disciplines and guide effective policy on team sciences [33]. From a macro level, structural elements of collaboration, such as team size, organization and participant experiences, are connected to internal and external environment of the team [34]. From a micro level, perceived interpersonal collaboration processes and intrapersonal characteristics are predictive for research productivity [35]. In general, the SciTS has been enriched by substantial of knowledge.

However, for SIDRTs, knowledge interaction is very important to the process of communication, which is the core of knowledge management. Through knowledge interaction, team members can communicate in depth between disciplines to address complex problems and accelerate innovations. Hence, we use the term "knowledge interaction" as a process or activity, in which the team members use knowledge communication, knowledge sharing, knowledge collision, knowledge integration of critical information, scientific and technological knowledge, and skills to achieve technical innovation and system innovation [36].

In contrast to other teams, knowledge interaction in SIDRTs has its own characteristics:

1) Stronger dynamics

Since the tasks to be completed by SIDRTs are innovative and challenging, the process of knowledge interaction among team members cannot be predicted in advance. In addition, interdependence between interdisciplinary team members is also unpredictable due to incomplete task information. Members cannot forecast who will interact with them next time and what kind of thinking collisions will occur. Furthermore, the introduction of new technologies, new equipment, and new members requires team members to constantly adjust and adapt to higher requirements.

2) Cyclical

Due to the differences between team members' disciplines and experiences, both sides of knowledge interaction will repeat the loop of "knowledge expression → knowledge interpretation → knowledge divergence → knowledge convergence → knowledge supplement" until they find new ideas and solve complex problems. In the process of cycle, the whole knowledge of the team gradually approaches the optimal solution to the problem.

3) More complex uncertainty

Since the team is conducting sustainable research, the interaction period is long, and the interaction results are uncertain. On the one hand, the source of knowledge is uncertain, due to the randomness of knowledge information acquired by team members, and the ambiguity and inconsistency caused by team members' cognitive differences on knowledge understanding. On the other hand, personnel adjustment and changes in the cognition and behavior of team members can influence the knowledge interaction environment that other team members face.

In total, knowledge interaction spans a large range of dimensions and scales, including team members, environment, and kinds of resources. To facilitate knowledge interaction among team members, the development of shared mental models [36] is crucial. Shared mental models are organized mental representations of the key elements (including related tasks, equipment, work relationships and situations) within a team's relevant environment [37]. They are also the premise of knowledge interaction and help the teams in the communication, problem-solving, and decision-making needed to develop a research plan [36]. In addition, under the premise that various interest mechanisms and trust

mechanisms are guaranteed, knowledge interaction between elements is sometimes a self-organization form, which is the emergence of complex behavior. These properties of knowledge interaction are well reflected from the perspective of system science. Hence, to look at the whole of knowledge interaction and its relationship to the parts, we apply system science framework to address this issue.

2.3. Knowledge Interaction in SIDRTs from a Complex System Perspective

The solution to the major comprehensive problems that plague all human beings, such as social, environment, ecology and energy issues, increasingly requires the collaboration of people from different disciplines. Thus, sustainable interdisciplinary research team is regarded as a powerful means to hit the targets. To explicate how team members interact and achieve their objectives, we introduce complex systems theory.

“System” is one of the most basic concepts in system science. It is an organic whole with specific function that consists of interacting and interdependent parts (elements). The integrity of the system structure is one of the most significant features. As a whole, the system has the functions and properties that independent elements do not have. Xuesen proposed combining system science with thinking science for interdisciplinary research [38], guiding us to apply the concepts and methodology of systems engineering and thinking science in the process of knowledge management and innovation to deal with the application and innovation of knowledge. More recent reviews of team research reflect the emerging perspective of work teams as dynamic, emergent, and adaptive entities embedded in a multilevel system [39,40], i.e., teams are complex dynamic systems that exist in a context, develop as members interact over time, and evolve and adapt as situational demands unfold [11]. Therefore, we will analyze the knowledge interaction process of interdisciplinary team based on complex systems theory. Knowledge interaction is a dynamic and complex process in a SIDRT, which could be viewed as a complex system (see Figure 1). Then we will analyze it from the following aspects.

First, the most basic units of knowledge interaction are elements and associations. The main elements are team members who participate in the knowledge interaction. Any members (ordinary members or team leader) who is related to the task can express their own thoughts, regardless of the position or status. Team members have an independent knowledge structure, and can independently sense, receive and process the surrounding knowledge information to achieve the goal of knowledge integration [41]. According to the needs of the team’s tasks, the elements of knowledge interaction are not static, and the personnel of the knowledge interaction will be constantly adjusted as the task progresses. On the other hand, the association in the system is knowledge interaction, which makes the knowledge interaction system develop towards the optimal solution.

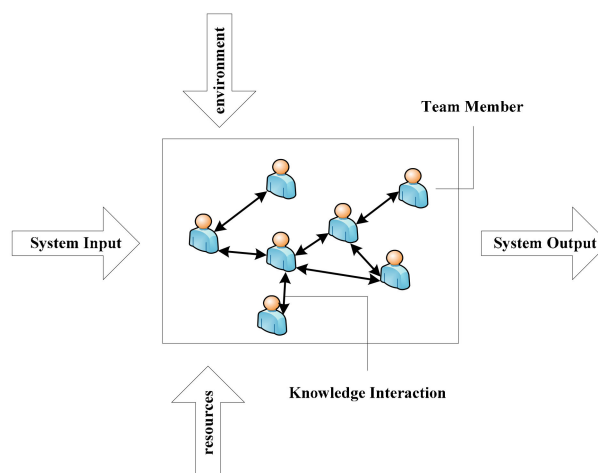


Figure 1. Knowledge interaction in a SIDRT from a complex system perspective.

Second, knowledge interaction is closely related to the environment in which it is located, and cannot exist independently from the environment [42]. Environment of knowledge interaction can be divided into the internal and the external environment. The internal environment is mainly composed of the relevant interests and trusts formed by the knowledge interaction subjects. The external environment is mainly composed of the network environment, cultural environment, and academic environment where a SIDRT is located. Different types of environments play different roles in the process of knowledge interaction. A good internal environment is conducive to promoting the knowledge exchange of knowledge interaction subjects. The external network environment can provide more knowledge interaction channels and resources for knowledge interaction subjects. The cultural environment and academic environment can create an appropriate cultural and academic atmosphere for interdisciplinary teams, and are more conducive to knowledge interaction among interactive subjects.

Third, emergence is the most important feature of knowledge interaction system [43], which presents a dual emergence feature in Figure 2. Emergence is first reflected in the subjects of knowledge interaction. Through the multi-directional knowledge collision, the knowledge interaction subject itself will emerge new ideas or knowledge when the knowledge accumulates to a certain extent. In addition, there will be an emergence among knowledge interaction objects. The knowledge in the objects emerges new knowledge structure through the transfer, integration, and mutation. Furthermore, the team will emerge as a whole. After the emergence of the knowledge interaction subjects and the knowledge interaction objects reach a certain level, the interdisciplinary team will emerge and show the unique characteristics of the whole, such as the ability to solve problems and knowledge innovation.

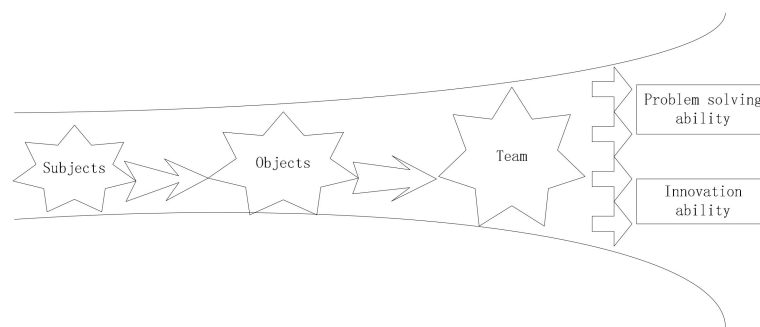


Figure 2. Emerging model of knowledge interaction in a SIDRT.

In conclusion, knowledge interaction in SIDRTs is based on the team members as the elements, through the exchange and sharing of knowledge, and forms an organic whole with certain knowledge functions to solve complex problems and innovate in the network environment, technical environment, and policy environment.

3. Research Methodology and Research Design

3.1. Mixed Research Method

Mixed research method [44–47] is a research method that combines quantitative and qualitative data in a same study. This method has been systematically and formally developed for at least 20 years. The advantage of this method is to strengthen the research conclusions from different angles. According to this purpose, this paper will combine the grounded theory method with the empirical research method. In the first stage, we use the grounded theory method to construct a conceptual model of knowledge interaction. The respondents for this study came from four SIDRTs. In the second stage, this paper uses empirical research method to validate the credibility and persuasiveness of the proposed conceptual model, and the samples were taken from SIDRTs in China. The combination of the two methods provides confirmation to the conceptual model of knowledge interaction from different angles.

It can ensure a well-grounded scientific framework for the empirical undertakings consistent with the assumed objectives.

3.2. Ethical Approval Statement

All subjects gave their informed consent for inclusion before they participated in the study. The study was conducted in accordance with the management scientific research methods and the Academic Research Ethics of School of Management, Harbin Institute of Technology. Every effort was made to protect people's privacy from being violated. All participants were informed of the purposes of the study. Written informed consent was obtained from all participants before the study commenced.

3.3. Grounded Theory

Grounded theory [48] is a qualitative research method first proposed by Glaser and Strauss in 1967. Through open coding, axial coding, and selective coding of the original data, this method gradually enhances the abstract relationships between categories from the bottom up, and links all categories together to form theory. Grounded theory is more suitable for research that has theoretical blanks or that the existing theoretical system is not perfect. Although there has been a large amount of literature on knowledge management in different contexts [49–51], there is little research on knowledge interaction in SIDRTs. Knowledge interaction in the interdisciplinary team is very different from that of the ordinary team, and the knowledge fusion and matching degree of the team are higher. To clarify the complex antecedents of knowledge interaction from different angles, this paper will use grounded theory to develop this research.

3.4. Research Design

We selected four representative interdisciplinary teams from China, all of which are long-term engaged in sustainable research. The basic information of the interviewed team is shown in Table 1 (In order not to reveal the team's information, we hide the teams' name).

Table 1. Basic information of the interviewed team.

Interviewed Team	Engaged Research	Number	Professional Background of Members
1	Perceptual computational heart simulation study	18	Computer, mathematical, biology
2	Competitive robot	67	Electromechanical, automation, electric, computer, software
3	Medical material research	25	Physical, medicine, biology
4	Small satellite research	83	Aircraft design, Information and communication engineering, control theory and application, Human-machine environment engineering

Using the method of theoretical sampling, the number of samples is determined according to the theoretical saturation required by the grounded theory, i.e., the sample is extracted until the newly drawn respondent no longer provides new and important information [52]. In the end, a total of 31 respondents were selected for this interview. The basic data are shown in Table 2.

This study was conducted in a combination of in-depth personal interviews and focus group interviews. Each interview had three members of our research team, including two interviewers and one recorder. In total, there are 19 persons conducting in-depth personal interviews, and each interview took about 30–40 min. Focus group interviews were organized 4 groups with 3 persons in each group, and each interview took about 40–60 min. In the preparation stage of the interview, we contacted the respondents by phone or WeChat, appointed the time and place of the interview, and explained the connotation of knowledge interaction to the interviewees in advance. At the beginning of the formal interview, we explained the meaning of knowledge interaction to the respondents again, to ensure that each respondent can understand our research topic. The interviews in this study are

mainly open-ended interviews, and the interviews mainly focus on the following issues: (1) How do you interact with other discipline members in your team? (2) What do you think are the main factors affecting knowledge interaction? (3) How is the atmosphere of your team's knowledge interaction? (4) Do you have some experiences in knowledge interaction? What are they? (5) Do you think knowledge interaction is helpful to you or your team?

Table 2. The distribution of respondent's characteristics.

Term	Content	Frequency	Percentage (%)
Sex	Male	23	74.2
	Female	8	25.8
Age	<25	4	12.9
	25–29	14	45.2
	30–39	9	29
	40–49	3	9.7
	50–59	0	0
	60<	1	3.2
Education	Master	11	35.5
	PhD	20	64.5
Position	Head of the team	3	9.7
	Ordinary member	28	90.3

We recorded the interview sound with the consent of the respondents. In the course of the interview, we tried to guide the respondents to give some examples of knowledge interaction, and further followed up on the concepts captured around the outline. In addition, we gradually adjusted the interview content and focus according to the effect of the interview, so as to maximize the insight into the psychological changes of the respondents.

4. Research Data Analysis

4.1. Open Coding

Open coding is the process where the data are broken down into discrete parts, closely examined, compared for similarities and differences, and questions are asked about the phenomena reflected in the data [53]. To reduce the subjective bias of the researcher, we tried to use the original words of the respondents as a label to extract the initial concepts in the coding. To ensure the validity of the code, we asked two members of our research team to independently code to determine the initial concepts and categories. For inconsistent concepts or categories, we modified or deleted them combined with the opinions of experts in the field to improve the objectivity of coding. We obtained a total of more than 450 original sentences and corresponding initial concepts. Since the initial concepts are complex and have a certain degree of intersection, we eliminate those nonsignificant (the frequency of occurrence is less than two) and inconsistent initial concepts when categorizing. Finally, 30 concepts, 9 categories, corresponding relationships of categories are obtained, as shown in Table 3. The words in parentheses at the end of each sentence indicate the initial concept coded from the original statement.

Table 3. Categorization of opening coding.

Respondent Number	Original Statement (Initial Concept)	Category
A02	"He knows a lot of things and has been co-cultivated abroad. So, I often ask him questions." (Empirical heterogeneity)	Team knowledge heterogeneity
A07	"Sometimes everyone holds their own opinions and debates. It may be the gap in the knowledge background." (Subject knowledge heterogeneity)	
A22	"Some members do not know much about computer programming and may not be too active when discussing this issue." (Skill heterogeneity)	
A03	"The starting point of everyone is different. Some students have a good knowledge base from undergraduate to doctoral, which will have a good impact on communication." (Knowledge level heterogeneity)	
A11	"After the team members proposed an innovative idea, some students felt that the idea was not perfect and would supplement this idea according to their own experience." (Complementary thinking ability)	Team creative thinking
A26	"His words gave me some inspirations. I think my research can also refer to his method." (Insight)	
A02	"Some fresh ideas can be generated through discussion." (Divergent thinking)	
A23	"When some members put forward a new perspective or build a new model, I always ask questions first. Is there any reason to do like this?" (Critical thinking)	
A23	"I remember that our team once encountered a very complicated problem involving several disciplines' knowledge. The team members communicated in depth and did not rest well for several days." (Task difficulty)	Task complexity
A11	"Sometimes the content of communication is really difficult to express clearly, because this kind of knowledge has to be shown to others in some special way through demonstrations or other means." (Knowledge embedding)	
A23	"Some tasks are time-limited due to reasons such as some project completions." (Short working period)	
A07	"The atmosphere of our team is not very good. Due to personal interests, some person will reserve knowledge when communicating." (Interest mechanism)	Participation protection
A02	"Our team is mutual trust as a whole. I need to tell my teammates my ideas and let them implement them. If I don't trust them, I can't tell them what I think. Then there cannot be any interaction." (Trust mechanism)	
A01	"The current reward mechanism of our team is still subjective. Each person's research grant mainly determined by the team leader according to his performance. But I believe that with the development of the team, there will be more objective criteria to measure everyone's performance." (Reward mechanism)	
A08	"The overall atmosphere of our team is very good. Everyone is quite cheerful. They are willing to share knowledge, but they often have fierce disputes. Sometimes, one party will convince the other party, sometimes no one can convince anyone, but private relationships are still very good and will not be affected." (Positive atmosphere)	
A28	"The goal of our team is very clear, that is, we want to make some achievements." (Targeted)	Shared vision
A11	"In the discussion, everyone's views often show inconsistencies. But through arguing, we can finally reach a consensus, especially at key decision points." (Research consensus)	
A10	"The goal of our team is very attractive, which can motivate us." (Target incentive)	

Table 3. Cont.

Respondent Number	Original Statement (Initial Concept)	Category
A10	"We have a group meeting every week, sometimes we arrange students to make reports, and sometimes we discuss each other's problems together." (Formal communication within the team)	Social structural capital
A25	"Our team often organizes some gatherings, group tours, and other activities. In the process, everyone will unconsciously explore some academic issues. Sometimes, everyone will talk about problems in the school cafeteria or on the way from the bedroom to the lab." (Informal communication within the team)	
A13	"We often participate in some international conferences. Through these conferences, we can know some authoritative experts in our field. We also can meet some teachers or students from other schools and establish cooperative relationships. In addition, when we encounter some difficulties in the future, we can ask for help from them." (Team external communication)	
A05	"I usually discuss with Teacher Liu. Maybe because our location is very close, it is convenient." (Personal relationship network)	
A03	"Sometimes if the problem is similar to the one I encountered before, I will check the previous information to see how the problem was solved at that time. Maybe I can find some ideas." (Individual memory)	Organizational memory
A06	"Our team has a database, which stores some information that can be used for reference." (Team memory)	
A15	"In the regular meeting, some members will first express their ideas and ask for comments from other members." (Thinking divergence)	Knowledge divergence
A10	"My personal ability to innovate is not strong, so I hope to gain some new knowledge and new inspiration from interaction with others." (Inspiration)	
A06	"Our team members have different opinions on some issues, but I think this is a good thing. Sometimes, there will be unexpected effects through disputation." (Different opinions)	
A11	"I am the sub-head of the team. When I find some new information and knowledge that team members do not know, I will sort out the relevant information and knowledge, and then release it to other members through QQ." (Knowledge integration)	Knowledge convergence
A31	"Our team often conducts in-depth discussion and exchanges opinions on a particular issue." (Deep processing of information)	
A09	"We can use the 3D printer and some other automatic processing equipment to print out the model to see if there is room for improvement. Sometimes there will be contradictions or inconsistencies with previous ideas, and further research is needed until satisfactory results are obtained." (Feedback)	

4.2. Axial Coding

Axial coding is the process of discovering the potential logical connections among categories, and developing the main categories [53]. In other words, the task of axial coding is still to develop categories, but only one step closer to the development of its nature and dimensions. Through repeated thinking and analysis of the initial concepts, this study summarizes 5 main categories. The categories and their corresponding open coding categories are shown in Table 4.

Table 4. Main categories formed by axial coding.

Main Category	Category	Relationship Connotation
Subject factor	Team knowledge heterogeneity	Knowledge heterogeneity affects the way in which knowledge interaction subjects solve problems
	Team creative thinking	Creative thinking affects the way in which knowledge interaction subjects think about problems
Object factor	Task complexity	The inherent attributes of the task affect knowledge interaction
Environment factor	Participation protection	Participation protection affects knowledge interaction
	Shared vision	Shared vision affects knowledge interaction
Resource factor	Social structural capital	Social structural capital helps to get more information resources
	Organizational memory	Organizational memory affects knowledge interaction
Knowledge interaction	Knowledge divergence	Knowledge divergence is an important process of knowledge interaction
	Knowledge convergence	Knowledge convergence is an important process of knowledge interaction

4.3. Selective Coding

Selective coding is to extract the “core category” from the main categories, and form a multi-chord logical relationship centered on the “core category”, which can be called the “story line” [53]. After the completion of the “story line”, a new substantive theoretical framework has been developed. In this study, the typical relationship structures of the main category are shown in Table 5.

Table 5. Typical relational structures of main categories.

Typical Relational Structure	The Connotation of the Relationship Structure
Subject factor → Knowledge interaction	Subject factor is the key antecedent of knowledge interaction
Object factor → Knowledge interaction	Object factor is the key antecedent of knowledge interaction
Environment factor → Knowledge interaction	Environment factor is the key antecedent of knowledge interaction
Resource factor → Knowledge interaction	Resource factor is the key antecedent of knowledge interaction
Knowledge divergence → Knowledge convergence	Knowledge divergence affects knowledge convergence

This study identifies the core category of antecedents of knowledge interaction in SIDRTs. The “story line” of the core category can be expressed that subject factors, object factors, environmental factors, and resource factors have important impact on the knowledge interaction of SIDRTs. Based on this storyline, this study establishes an influencing factor model of knowledge interaction in the interdisciplinary team, as shown in Figure 3.

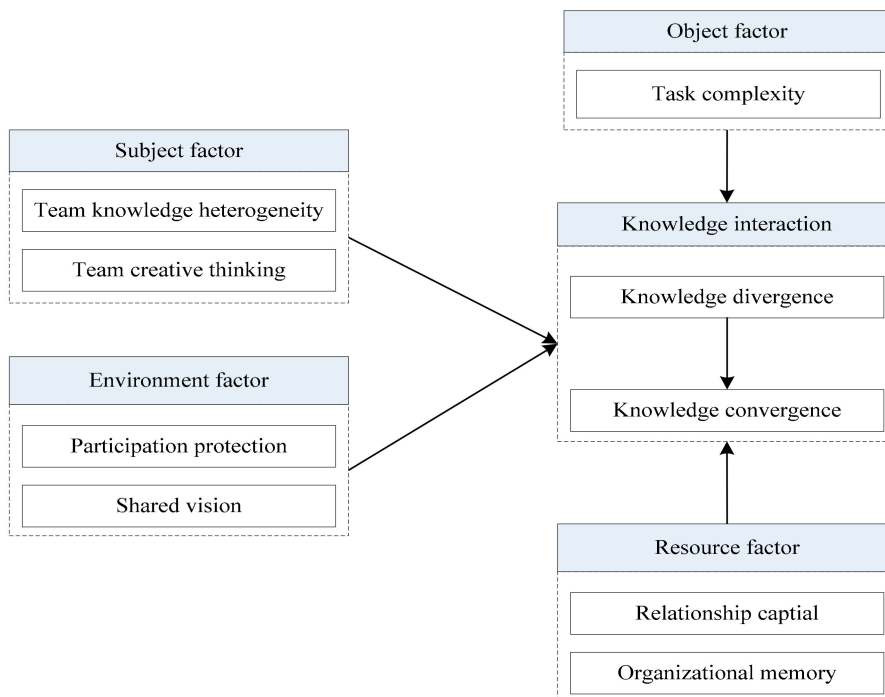


Figure 3. Influencing factor model of knowledge interaction in SIRT.

4.4. Theoretical Saturation Test

This study used the remaining interview records randomly reserved to test whether the model has reached theoretical saturation. The results show that no new key categories and relationships other than the five main categories in the model are obtained, and no new constituent factors are found in the five main categories. Therefore, it can be considered that the above model achieves theoretical saturation.

5. Model Interpretation and Assumptions

5.1. Knowledge Divergence and Knowledge Convergence

Based on the previous model, the knowledge interaction process in SIDRTs mainly includes two core sections: knowledge divergence and knowledge convergence. From a cognitive perspective, creation is a process of thinking divergence and convergence. Mordan and Ghoshal pointed out that the creation of any resource, including knowledge, has to undergo exchange and integration [54]. In the process of knowledge divergence, team members can share some knowledge, ideas, etc., and can also inspire members to generate new ideas based on existing knowledge. On the other hand, knowledge convergence is the process of team members using scientific methods and logical integration thinking to integrate knowledge from different sources, different disciplines, and different levels. Only through the effective knowledge divergence and understanding the individual knowledge can we establish the association between knowledge based on the characteristics of knowledge, and further realize the emergence of individual knowledge into team knowledge. We therefore put forward the following hypothesis:

H1. *Knowledge divergence has a positive impact on knowledge convergence.*

5.2. Knowledge Interaction Subject and Knowledge Interaction

The main characteristics of members in a SIDRT are reflected in knowledge heterogeneity and creative thinking ability. Compared with the ordinary team, the biggest advantage of the SIDRT is that the team can gather people from different professional backgrounds, so that the information

resources of the team are more abundant, and members can think about the problem from different angles [55]. Members with different knowledge types and knowledge backgrounds can generate more innovative ideas, which can promote the knowledge divergence of the team [26]. However, disciplinary differences also can lead to communication problems due to specialized training and terminology and to differences in what is taken for granted by individuals in a given specialty [56]. Especially in the knowledge convergence phase, if team members stick to their own opinions, it is difficult to integrate good ideas together to solve problems.

Creative thinking emphasizes the divergence and transformation of thinking. When a member's idea is stimulated by the idea of another member, a new idea will be generated [57]. Prior research has also shown that shared ideas can stimulate other group members to think of other ideas or categories of ideas [26,27]. On the other hand, team members with creative thinking are often good at integrating cross-category and cross-disciplinary knowledge, information or experience to get a creative new idea [58]. This will help team members build and re-build knowledge in the process of knowledge interaction and promote team knowledge innovation. We therefore put forward the following hypotheses:

H2a. *Team knowledge heterogeneity has a positive impact on the knowledge divergence.*

H2b. *Team knowledge heterogeneity has a negative impact on the knowledge convergence.*

H3a. *Team creative thinking has a positive impact on the knowledge divergence.*

H3b. *Team creative thinking has a positive impact on the knowledge convergence.*

5.3. Knowledge Interaction Object and Knowledge Interaction

Task complexity is the main attribute of knowledge interaction objects in SIDRTs, including task difficulty, knowledge embedding, and knowledge implicitness. Nickerson and Zenger argues that a problem's complexity influences the optimal method of solution search and the optimal means of organizing that search [59]. Some studies have confirmed that task complexity has an important relationship with the generation of creative ideas [60–62]. Through complex tasks, the creative thinking of interdisciplinary team members will be stimulated. Team members will change the original negative communication attitude, actively mobilize various resources, and constantly search and learn knowledge and experience inside and outside the team [63], which ensure the effective divergence and aggregation of knowledge, and the successfully completion of task. Therefore, we propose the following hypotheses:

H4a. *Task complexity has a positive impact on the knowledge divergence.*

H4b. *Task complexity has a positive impact on the knowledge convergence.*

5.4. Knowledge Interaction Environment and Knowledge Interaction

Based on the results of the previous qualitative study, a SIDRT's knowledge interaction environment mainly includes team participation guarantee and shared vision. When team members engage in knowledge interaction, the atmosphere created by the team must enable team members to easily express their opinions, and give or receive feedback from each other in order to achieve team innovation [64]. The study also found that only when team members feel they are in a safe, fair, and relaxed environment, they are willing to share their experiences and perceptions [65,66]. In addition, the interpersonal interactions of team members in daily work can enhance the sense of belonging and team identity, and play an important role in alleviating internal conflicts and strengthening team cohesion [67].

Shared vision is defined as the degree to which team members have a clear picture of, and agree upon, the goals of the team [68]. For SIDRTs, team goals may be more diffused, due to the different functional frameworks within which the team members operate [69]. Fay et al. argue that having a shared vision provides the "glue" that holds an interdisciplinary team together [13]. If the

members perform well on a shared vision that the team has identified, then more members will hold the vision more firmly and are more willing to work harder [70]. We therefore put forward the following hypotheses:

H5a. *Participation guarantee has a positive impact on the knowledge divergence.*

H5b. *Participation guarantee has a positive impact on the knowledge convergence.*

H6a. *Shared vision has a positive impact on knowledge divergence.*

H6b. *Shared vision has a positive impact on knowledge convergence.*

5.5. Knowledge Interaction Resource and Knowledge Interaction

Knowledge interaction resources in SIDRTs mainly include social structural capital and organizational memory. Social capital is defined as “the sum of actual and potential resources embedded within, available through, and derived from the network of relationships possessed by an individual or social unit” [71]. According to Nahapiet and Ghoshal social capital can be divided three dimensions: structural, relational, and cognitive [71]. This study mainly focuses on the structural capital, which reflected in a team’s social network structure. The stronger the internal network of team, the higher the communication and informal interaction among members, which in turn helps increase the opportunities for interaction to understand each other’s needs and share knowledge. In addition, team members through the network ties can exchange information to integrate knowledge successfully [72]. In addition, the structural capital is very important to knowledge convergence when teams communicated through lean digital networks or face-to-face communication [73].

Organizational memory is both an important source of knowledge within the organization and an important factor driving organizational innovation [74]. Organizational memory accumulated through team members’ experiences constitutes a valuable knowledge asset and acts as a source of competitive advantage [75]. In addition, organizational memory cannot be lost with the departure of team members. It can not only help the team make decisions for the current team tasks, but also help new team members understand the teamwork as soon as possible and promote the team’s knowledge interaction. Further organizational memory can increase team efficiencies and decrease possible repeated errors [76]. Hence, we hypothesize:

H7a. *Social structural capital has a positive impact on the knowledge divergence.*

H7b. *Social structural capital has a positive impact on the knowledge convergence.*

H8a. *Organizational memory has a positive impact on the knowledge divergence.*

H8b. *Organizational memory has a positive impact on the knowledge convergence.*

6. Empirical Research

6.1. Sample and Data Collection

We choose members of SIDRTs in the research universities as sample, which are different from the four teams interviewed previously. In total, 700 questionnaires were administered, 620 were returned, and 172 were excluded due to invalid responses. Therefore, the final sample was 448. The valid questionnaire response rate was 64%. There were 204 males and 244 females. 97% of respondents are under 35 years old. And the respondents are mainly master’s degree (81.7%). The details are shown in Table 6.

Table 6. Distribution of sample characteristics.

Item	Content	Frequency	Percentage (%)
Sex	Male	204	45.5
	Female	244	54.5
Age	<24	194	43.3
	25–29	210	46.9
	30–34	34	7.6
	35–39	10	2.2
Education	Master	366	81.7
	PhD and above	82	18.3

6.2. Measures

We measure all the constructs in this study based on scales developed in previous research studies. Team knowledge heterogeneity is measured using scale developed by Tortoriello [77], including differences in expertise, values, and cognition. Team creative thinking is measured by three items: idea sharing, idea complementarity, and idea integration, taken from Jiang [78]. Task complexity is measured by a three-item scale used by Campbell [79]. The participation guarantee scale is derived from team atmosphere model by Anderson and West [80]. Shared vision is also from team atmosphere model. Social structural capital is operationalized by three scaled items adopted from Jiang et al. [81]. In addition, three items for organization memory is adopted from Hanvanich [82] and Camison and Villar-Lopez [83]. Knowledge interaction, the dependent variable, is measured by knowledge divergence and knowledge convergence, in accordance with the scales used by Bock [84]. Five-point Likert scale were used for all measures (ranging from 1 = strongly disagree to 5 = strongly agree). The measures for all constructs are shown in Table 7.

Table 7. Constructs and Measurement Scales.

Construct	Item Number	Item
Team knowledge heterogeneity	TKH1	Expertise varies widely among team members.
	TKH2	Values vary widely among team members.
	TKH3	Team members have a great understanding difference on how to accomplish tasks.
Team creative thinking	TCT1	We can share ideas frequently at work.
	TCT2	We can complement ideas frequently at work.
	TCT3	We can integrate ideas effectively at work.
Task complexity	TC1	TC1. Teamwork is highly challenging.
	TC2	Teamwork needs to open up new areas and content constantly.
	TC3	Team work often requires designing new work processes and methods.
Participation guarantee	PG1	We can understand and accept each other.
	PG2	We can share information with each other.
	PG3	We can feel that our team is a whole.
Shared vision	SV1	We are in agreement on the overall goal of the team.
	SV2	Our team's goals are clear and pioneering and can inspire everyone's innovation drive.
	SV3	We can reach consensus on key decisions of the team.
Social structural capital	SSC1	Our team often holds workshops.
	SSC2	We often talk about work in informal places such as cafeterias or lounges.
	SSC3	Our team often organizes informal events such as dinners and networking.
Organization memory	OM1	The knowledge and information of our team is reflected in the organizational structure, systems, and processes.
	OM2	The culture of our team contains ideas and ways of doing things.
	OM3	Our team uses papers, patents, and licenses as an effective way to store knowledge.

Table 7. Cont.

Construct	Item Number	Item
Knowledge divergence	KD1	Our team members often share ideas and inspirations.
	KD2	Our team members often share work experience or knack.
	KD3	If other team members request, I will provide the knowledge source or insider that I know.
Knowledge convergence	KC1	Team members can effectively reorganize shared knowledge.
	KC2	Team members can effectively solve the problems encountered through coordination.
	KC3	Team members can clarify the hard-to-express knowledge, communicate, and learn mutually.

6.3. Data Analysis

We conducted a statistical check for common method bias with Harman's single factor test [85]. By using unrotated method of exploratory factor analysis, we obtained the interpretation variation of one fixed factor was 29.11%. The results showed that one-factor solution failed to account for most of the total variation.

In this research, Cronbach's α is used to analyze the reliability of each scale, as shown in Table 8. The Cronbach's α of the scale is greater than 0.7, indicating that the data of this study has considerable credibility. Exploratory factor analysis was used to test the validity of the measurement model. The results showed a good validity for the model: KMO (Kaiser-Meyer-Olkin) is 0.89, $\chi^2(528) = 3284.379, p < 0.001$. The normalized factor loading of all items is greater than 0.5, and the average variance extraction (AVE) is also greater than 0.5.

Table 8. Testing of reliability and validity.

Item	Cronbach's α	AVE	Factor Loading
Team knowledge heterogeneity	0.870	0.796	0.877–0.901
Team creative thinking	0.771	0.689	0.819–0.836
Task complexity	0.728	0.649	0.787–0.831
Participation guarantee	0.704	0.629	0.783–0.811
Shared vision	0.703	0.633	0.782–0.809
Social structural capital	0.812	0.728	0.841–0.867
Organization memory	0.762	0.680	0.786–0.835
Knowledge divergence	0.710	0.637	0.772–0.817
Knowledge convergence	0.755	0.672	0.801–0.844

7. Results

Table 9 presents the descriptive statistics and correlations among the variables. Team creative thinking, task complexity, participation guarantee, shared vision, social structural capital, and organization memory are positively correlated with knowledge divergence and knowledge convergence. Team knowledge heterogeneity is negatively correlated with knowledge convergence. Knowledge divergence is positively correlated with knowledge convergence.

Table 9. Descriptive statistics of means, standard deviations, and correlations.

Variables	M	SD	1	2	3	4	5	6	7	8	9	10	11	12
1. Gender	1.55	0.50												
2. Age	1.67	0.71	−0.11 *											
3. Size	2.20	0.40	−0.18 ***	0.34 ***										
4. TKH	2.65	0.76	0.03	0.15 **	0.10 ***	(0.89)								
5. TCT	4.02	0.61	0.03	0.03	−0.25 ***	−0.05	(0.83)							
6. TC	3.89	0.64	−0.02	0.05	0.02	0.02	0.34 ***	(0.81)						
7. PG	4.25	0.49	0.05	−0.04	−0.14 **	−0.19 ***	0.60 ***	0.27 ***	(0.79)					
8. SV	4.08	0.47	−0.01	0.06	−0.18 ***	−0.13 **	0.57 ***	0.37 ***	0.62 ***	(0.80)				
9. SSC	3.66	0.68	−0.04	0.04	0.12 **	0.08 **	0.23 ***	0.31 ***	0.15 ***	0.25 ***	(0.85)			
10. OM	4.06	0.50	0.03	0.14 **	0.02	−0.07	0.52 ***	0.47 ***	0.51 ***	0.51 ***	0.25 ***	(0.83)		
11. KD	4.11	0.49	0.10 *	0.01	−0.14 **	0.08	0.52 ***	0.38 ***	0.56 ***	0.48 ***	0.34 ***	0.42 ***	(0.80)	
12. KC	4.05	0.51	−0.05	0.09 *	−0.08	−0.14 **	0.55 ***	0.43 ***	0.55 ***	0.63 ***	0.28 ***	0.56 ***	0.48 ***	(0.82)

Note: M is mean, SD is standard deviation, N = 448; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$, two-tailed.

To test previous hypotheses, hierarchical regression analysis was employed. The arithmetic mean was used to characterize the variables with multiple items. Hypothesis testing results are shown in Table 10. In Model 1, team knowledge heterogeneity ($\beta = 0.10, p < 0.001$), team creative thinking ($\beta = 0.12, p < 0.05$), task complexity ($\beta = 0.11, p < 0.05$), participation guarantee ($\beta = 0.37, p < 0.001$), social structural capital ($\beta = 0.13, p < 0.001$) were significantly and positively related to knowledge divergence, thereby supporting H2a, H3a, H4a, H5a, and H7a. Shared vision ($\beta = 0.37, ns$) and organization memory ($\beta = 0.03, ns$) were not significantly related to knowledge divergence. Thus, H5a and H7a were not supported.

In Model 2, team knowledge heterogeneity ($\beta = -0.05, p < 0.05$) was negatively related to knowledge convergence. Team creative thinking ($\beta = 0.11, p < 0.05$), task complexity ($\beta = 0.11, p < 0.05$), participation guarantee ($\beta = 0.14, p < 0.05$), shared vision ($\beta = 0.37, p < 0.001$), social structural capital ($\beta = 0.05, p < 0.05$) and organization memory ($\beta = 0.19, p < 0.001$) were all significantly and positively related to knowledge convergence. Therefore, H2b, H3b, H4b, H5b, H6b, H7b, and H8b were supported. We test the relationship between knowledge divergence and knowledge convergence in Model 3. The regression coefficient between them was positive and significant, thereby supporting H1.

Table 10. Hierarchical regression analysis results.

Variables	Model 1	Model 2	Model 3
	Knowledge divergence	Knowledge convergence	Knowledge convergence
Team knowledge heterogeneity	0.10 ***	-0.05 *	
Team creative thinking	0.12 **	0.11 **	
Task complexity	0.11 **	0.11 **	
Participation guarantee	0.37 ***	0.14 **	
Shared vision	0.07	0.33 ***	
Social structural capital	0.13 ***	0.05 *	
Organization memory	0.03	0.19 ***	
Knowledge divergence			0.50 ***
Knowledge convergence			
Gender	0.07	-0.06	-0.10 *
Age	-0.002	0.04	0.07 *
Size	-0.09	-0.01	-0.08
F value	38.26 ***	50.27 ***	37.78 ***
R ²	0.47	0.56	0.25
AdjustR ²	0.46	0.52	0.25
ΔR^2	0.44 ***	0.51 ***	0.23 ***

Note: N = 448; * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$, two-tailed.

8. Discussion and Conclusion

8.1. Discussion

It can be seen from the results that team knowledge heterogeneity has different effects on knowledge divergence and knowledge convergence process. Consistent with the results reported in prior research [26,86], in the process of knowledge divergence, different professional knowledge, skills, experience, etc. can promote members to generate more innovative ideas and help members to spread knowledge. In contrast, the knowledge heterogeneity may lead to contradictions and conflicts of members' opinions, so it is not conducive to the knowledge convergence process. This result is consistent with the prior research [87].

Inconsistent with previous research [70], the results show that shared vision has no significant positive impact on the knowledge divergence process. This study considers the following rational explanation. In the process of knowledge divergence, the team pays more attention to the creation of innovative ideas, and the opinions of members are often inconsistent. In the process of knowledge convergence, members can consider the overall goal of the team, reach consensus on key decisions and integrate innovative ideas.

In addition, we can also see from the results that there is no significant positive impact between organization memory and knowledge divergence, which is not consistent with previous research [74]. In the process of knowledge divergence, if members are tied to the team's memory, only looking for the team's previous problem-solving processes and methods will hinder team members from knowledge divergence. In the process of knowledge convergence, the team's past knowledge, information, creativity, way of doing things, and patents will provide some clues and experiences for team members to integrate knowledge. Therefore, organizational memory is beneficial to the process of knowledge convergence.

In general, knowledge interaction in SIDRTs has different influencing factors than that in other teams, such as knowledge heterogeneity, task complexity and sustainability, participation guarantee, and social structural capital. For SIDRTs, differences in team members' expertise and skills can inspire members to generate more ideas, provide more innovative ideas to complete tasks and solve difficult problems. Task complexity and sustainability are also the unique influencing factors of knowledge interaction in SIDRTs. The more complex the tasks undertaken by the team, the more motivated the team members are to explore the problem. In addition, participation guarantee can create a free and relaxed environment for the team, to enhance the team's knowledge interaction effect. In addition, social structural capital helps team members to access internal and external resources of the team and obtain important information for knowledge interaction. It is worth noting that the key influencing factors identified by grounded theory are not common to other teams, and they are only for SIDRTs. However, for other teams, they are not necessary influencing factors of knowledge interaction and should be further analyzed.

8.2. Theoretical Implications and Practical Implications

The theoretical contributions related to knowledge interaction in SIDRTs are reflected by two aspects. First, we define the conception of knowledge interaction in SIDRTs from the complex system perspective, including elements, associations, environment, and emergence. Second, we are extending the literature on the knowledge interaction model. Though some literature holds the view that divergent idea generation must be followed by convergent idea selection for creativity to become innovation [88], there is no literature on integrating these two processes together. This research found that knowledge interaction mainly includes the process of knowledge divergence and knowledge convergence, and knowledge divergence positively affects knowledge convergence. Through the organic integration of knowledge divergence and knowledge convergence, interdisciplinary team members can better engage in knowledge interaction, and then solve complex and sustainable projects and achieve knowledge innovation.

In practical terms, our research also has some implications for understanding influencing factors of knowledge interaction for SIDRTs. First, for knowledge interaction object, our research results show that team knowledge heterogeneity has the opposite effect on knowledge divergence and knowledge convergence process. Hence, the interdisciplinary sustainability research team should focus on the selection of team members in order that the team knowledge heterogeneity is neither too large nor too small. Furthermore, it is necessary to continuously stimulate the creative thinking ability of individual, to realize the emergence of the team's overall creative thinking ability.

Second, our research results show that task complexity is positively related to knowledge interaction. Thus, the team should appropriately increase the complexity of the task, and then arouse the team members' enthusiasm and ability for exploring problems and solving problems. However, it is worth noting that due to the limitations of the sample size, we must consider that the capabilities of individual members are limited. Excessively complex tasks can cause serious blows to the overall morale of the team, resulting knowledge interaction not working normally.

Third, for knowledge interaction environment, SIDRTs should create a free, relaxed, trusting, and mutually understanding work environment that gives members a sense of security. In the process of knowledge interaction, team leader should encourage members to speak boldly and make reasonable

guesses so that members can develop their strengths. In addition, ensure that the team members' personal goals are consistent with the team's goals, so that team members can be more fully engaged in knowledge interaction and achieve breakthroughs in innovation results.

Fourth, SIDRTs should broaden the social network within and outside the team so that members can keep up with the frontiers of research and can quickly find helpers when they encounter problems. On the other hand, according to the research results, organizational memory has no significant impact on the knowledge divergence and has a significant positive impact on the knowledge aggregation. Thus, while strengthening the organizational memory, the team should avoid team rigidity caused by the formation of mindset.

8.3. Limitations and Future Research Issues

Although this research studied on the influencing factors of knowledge interaction in SIDRTs systematically, there are still several limitations that will create interesting opportunities for further research avenues and agenda. First, in the section of grounded theory, this study used the remaining interview records from four SIDRTs randomly reserved to test whether the model has reached theoretical saturation. In future research, we can increase the number of our research teams and improve our model. Second, our samples were sufficiently representative of members of the SIDRT to support our findings, they can be generalized strictly only to SIDRTs in China. Future studies should sample a larger set of teams to confirm whether our results hold. Third, the research model only directly explored the influencing factors of knowledge interaction. In fact, knowledge interaction is a very complicated and inherently context-dependent phenomenon [89]. In future research, we can explore the role of the adjustment of knowledge interaction from the aspects of situational factors, such as environmental uncertainty, personnel uncertainty, and technical uncertainty. Finally, we can consider the experimental design approach to study the process of team knowledge interaction, and then artificially control some variables in future work.

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