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RESEARCH ARTICLE

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Network Configuration in App Design: The Effects of Simplex and Multiplex Networks on Team Performance

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Abstract

Members of mobile app design teams collaborate with each other to accomplish tasks and/or to socialize. However, how network configuration of instrumental and expressive interactions affects team creativity, efficiency, and satisfaction has not yet been studied. Accounting for both simplex and multiplex social networks in teams, this study develops a research model examining the mechanisms by which the centralization of different types of networks impacts team performance. To test our research hypotheses, we collected data from 62 student teams working on an app design class project. We found that the centralization of the instrumental-expressive multiplex network reduces teams' information elaboration and similarity perception; the centralization of the instrumental simplex network is beneficial to information elaboration; and team information elaboration positively influences team creativity, efficiency, and satisfaction. We also found that team similarity perception negatively affects team creativity and positively affects team satisfaction. To alleviate concerns about the potential simultaneity bias between network configuration and information elaboration or similarity perception, we replicated the results based on a cross-lagged analysis with additional data collected from 48 design teams at two points: at team establishment and at project completion. This paper contributes to the literature on software development by examining the mechanisms via which the configuration of multiplex and simplex networks affects team performance.

Keywords: Multiplex Network, App Design, Team Configuration, Team Performance, Centralization, Expressive Network, Instrumental Network

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1 Introduction

Mobile apps are software programs that operate on mobile devices. With the development of mobile technologies and the widespread use of smartphones, mobile apps have become an indispensable part of daily life. Compared with traditional software design, app design presents unique challenges, e.g., high homogeneity, fierce competition (Guo et al., 2019; Lee & Raghu, 2014), ambiguous user requirements (Wu et al., 2014), and low switching costs (Hong & Xu, 2017). Since design quality is critical to the success of an app in the market (Guo et al., 2019; Lee & Raghu, 2014), an understanding of how successful teams devise creative design solutions efficiently is of value.

App design is a collaborative process that includes tasks such as market analysis, demand management, product positioning, flowchart and prototype drawing, and interaction design (Cabello-Medina & Kekale, 2011). The roles in a team may include analyst, designer, technical expert, and project manager (Uflacker & Zeier, 2011), and team members are interconnected and interdependent (Park et al., 2020). From the perspective of social network analysis, team members can be considered as a set of nodes, and their connections as a set of ties (Park et al., 2020); thus, the social network of a team is a collection of all the nodes and their ties.

Team members may interact with each other to accomplish their assigned tasks and/or to socialize and become friends. Therefore, we can differentiate the networks formed among team members as the instrumental network and the expressive network (Henttonen et al., 2013; Schulte et al., 2012). An instrumental network is a network formed on the basis of the ties through which they exchange task-related knowledge, expertise, and advice (Yang & Tang, 2004); an expressive network refers to network ties formed for the purpose of friendship and social support (Henttonen et al., 2013; Schulte et al., 2012).

In examining the impact of social networks on team performance in software development, prior IS studies have primarily focused on the instrumental network in a team for knowledge exchange and information flow (Latorre & Suarez, 2017). However, the effect of the expressive network that might strengthen emotional support, belonging, and trust have been largely overlooked (Latorre & Suarez, 2017). In addition, it may be insufficient, even misleading, to study instrumental and expressive networks separately and alone because task relationships are inevitably intertwined with personal (or social) relationships (Hood et al., 2016; Methot et al., 2016). Ties among team members can be multiplexed. In other words, the connection between any two members of a team could represent the co-occurrence of both types of ties (Hood et al., 2016), which could potentially affect the nature of interactions and the information exchanged. Therefore, following prior literature (Crawford & LePine, 2013), we distinguish social networks in app design teams into three types of networks: (1) the instrumental simplex, where only instrumental ties exist; (2) the expressive simplex, where only expressive ties exist; and (3) the instrumental-expressive multiplex, in which instrumental ties and expressive ties overlap or are bundled.

The instrumental simplex, expressive simplex, and multiplex networks may have different implications for team process and thus for team performance. This study applies the structure-process-effectiveness framework (Gladstein, 1984) to investigate the effects of three types of team network centralization on team performance. Thus, our research question in this study is: How does the centralization of multiplex network, instrumental simplex network, and expressive simplex network affect team performance? We consider three aspects of team performance including team creativity, efficiency, and satisfaction. To identify the mechanism through which the centralizations of different networks affect team performance, we focus on two mediators, drawing upon the information processing perspective and social classification perspective: information elaboration and similarity perception. Information elaboration refers to the degree to which team members exchange, discuss, and integrate ideas, knowledge, and perspectives relevant to team tasks (Kearney et al., 2009; van Knippenberg et al., 2004). Similarity perception is the degree to which team members view themselves as having few differences (Zellmer-Bruhn et al., 2008).

To test our research model and hypotheses, we developed a course project on app design for students registered in a management information systems course at a major university in China. We randomly separated the students into groups of four or five and asked them to complete app design tasks as a group project for credit. A total of 62 sets of valid data were collected. Our findings indicate that the centralization of the instrumental-expressive multiplex network is negatively related to information elaboration and similarity perception; the centralization of the instrumental simplex network is positively related to information elaboration; information elaboration is beneficial to team creativity, efficiency, and satisfaction; and similarity perception hinders team creativity but enhances team satisfaction. To alleviate concerns about the potential simultaneity bias between network centralizations and information elaboration or similarity perception, we employed a cross-lagged analysis to test related hypotheses with additional data collected from 48 app design teams at two points: at team establishment and at project completion. The cross-lagged analysis replicates our results.

This study makes several contributions. First, in this paper, we emphasize the importance of considering the expressive network together with the instrumental network in app design. Prior literature on software development has focused on the instrumental network such as the advice network but paid less attention to the expressive network. The role of the multiplex network has been largely ignored in the context of software development. Our study shows that the centralizations of the three different team networks play a distinct role in shaping team processes and thus team performance. It is important to consider the instrumental, expressive, and multiplex networks simultaneously because they capture different but complementary types of social interactions, promoting a deeper understanding of team performance in software development.

Second, our study suggests the importance of information processing and social classification in bridging network centralizations and team performance. Prior literature has scarcely investigated the underlying mechanism by which social networks affect team performance. Our research reveals the mediating role of information elaboration and similarity perception. Our study shows that the instrumental, expressive, and multiplex networks affect team performance via different mechanisms. Further, while the centralization of the instrumental network affects team performance via information elaboration, the effect of the multiplex network is channeled through both information elaboration and similarity perception. Our study provides a theoretical explanation for how the configuration of social networks impacts team performance.

Third, prior studies in software development have focused mostly on one aspect of team performance. Our study includes the three distinct and equally important aspects of team performance: team creativity, team efficiency, and team satisfaction, and allows for comparison of the different formation mechanisms of the three aspects within the same theoretical framework. Our study shows that while information elaboration positively contributes to all three aspects of team performance, similarity perception negatively affects creativity, positively affects satisfaction and has no effect on efficiency. The results suggest the complicated role of similarity perception in team performance, and the potential dilemma in achieving both team creativity and satisfaction in software development at the same time.

2 Related Studies in Software Development

2.1 Team Performance in Software Development

Like traditional software, the development life cycle of mobile apps includes requirements analysis, design, development, testing, and implementation (Vithani & Kumar, 2014). In the design stage, developers seek to understand user needs and transform them into feasible solutions. They then implement the solutions with code in the development stage (Lee et al., 2015; Vithani & Kumar, 2014). Because of fierce competition, the life cycle of mobile applications is often short, and the demand for novelty in design solutions is intense. Because of the critical role they play in the success of an app, we selected design teams as the research subjects and the analysis unit for this paper (Lee et al., 2015).

Prior studies in software development have investigated factors that contribute to team performance. Antecedents include the creativity of software solutions, efficiency of the development process, and the satisfaction of team members. Creativity refers to ideas that are both novel and useful regarding products and solutions (Hoever et al., 2012), and software development is an inherently creative process involving the generation of new ideas, solutions, and artifacts (Tiwana & McLean, 2005) for novel business applications and new problem domains (Hevner et al., 2004). In addition, since design teams face changing requirements and dynamic environments (Hevner et al., 2004), team creativity helps preserve the flexibility to respond to changing technologies and markets and succeed amid fierce competition (Farh et al., 2010; Gilson et al., 2005; Goodhue et al., 2009; Peng et al., 2019; Tiwana & McLean, 2005). Team efficiency is defined as a team's ability to transform input into output (Xie et al., 2020) and is related to resource consumption in terms of time, money, and how things are done. The better a team is at problem solving, the less demanding completing the task is for the team. While creativity and efficiency focus on task-driven outcome and process performance respectively, teams' attitudinal performance also plays a key role. The performance of app design teams depends not only on the success of the project but also on the long-term development of the team. Team satisfaction measures how satisfied team members are with their team experience (Costa, 2003; Santos et al., 2015) and captures team members' attachment to the team, affecting both current and future team functionality (Maynard et al., 2019). Since satisfaction fills in the insufficiencies of task-related performance, it is an important dimension of team performance.

Research on software development has investigated various motivations and practices that affect different aspects of team performance; examples of software development studies are summarized in Appendix A. Through reviewing these studies, we found that the three aspects of team performance are not only affected by the process of sharing task-related information and knowledge, but also by the factors related to emotional communication. The antecedents of team performance in software development can be roughly divided into two categories: factors facilitating or hindering the sharing of task-related information and knowledge, and factors related to communicating feelings and emotions among team members. Knowledge sharing has a strong impact on teams (Faraj & Lee, 2000), and creative views can be formed only when team members are aware of each other's knowledge and ideas (Hsu et al., 2012; Park & Lee, 2014) and can comb through those ideas (Perry-Smith & Mannucci, 2015). Many scholars echo that creative idea generation requires teams to share and integrate knowledge in collaboration (Hsu et al., 2012; Lin et al., 2012; Tiwana & McLean, 2005), while a few studies have also suggested that team knowledge sharing and software development efficiency are related (Ajila & Samuel, 2008; Chen et al., 2013; Hsu et al., 2012).

In addition, emotional communication can affect performance. Personal differences (background, knowledge set, personality, etc.) require team members in software development (Alfaro & Chandrasekaran, 2015; Dyaram & Kamalanabhan, 2011; Liang et al., 2012) to develop favorable emotional communication to facilitate collaboration and better understand each other (Lu et al., 2011). A collaborative atmosphere has a great influence on the success of team projects (Hoegl & Gemuenden, 2001). Likewise, a positive team atmosphere is conducive to allowing team members to speak out freely, which can promote innovation (Akgün et al., 2011; Hoegl & Parboteeah, 2007). Also, some studies have suggested that knowledge sharing and exchange are conducive to deepening understanding and mutual recognition between team members, thereby increasing team members' work satisfaction (Lu et al., 2011; Sawyer, 2001; Schaubroeck et al., 2011). Good emotional communication in the team has also been shown to significantly impact the job satisfaction of team members (Akgün et al., 2011).

Most studies in software development have focused on one aspect of team performance, and research examining all three aspects of team performance within the same theoretical framework is rare. In this study, we include all three aspects and compare the mechanisms through which they are formed. This theoretical framework is practically meaningful and theoretically important because it allows us to compare the distinct formation mechanisms of the three aspects of team performance within the same framework and to recognize the potential challenges in simultaneously achieving creativity, efficiency, and satisfaction. The three aspects of team performance may be conflicting; thus, trade-offs need to be made in practical interventions.

2.2 Social Network in Software Development

Social networks in a team are considered an important factor impacting the effectiveness and success of software development (Kudaravalli et al., 2017; Yang & Tang, 2004). Because software development requires different areas of expertise, teams are formed to integrate individual intelligence and work outcomes (Curtis et al., 1988; Scacchi, 1984; Tiwana & McLean, 2005). Collective efforts and social processes within teams are essential for better performance (Tiwana & McLean, 2005), and social networks can be formed based on team members' interactions. The structure of the social network in a team reveals the communication pattern among team members (Colazo, 2010).

Team members build ties among themselves based on task needs and socialization interests. Prior research on social network analysis has distinguished two types of networks: the instrumental network and the expressive network (Henttonen et al., 2013; Schulte et al., 2012). The instrumental network consists of social ties for exchanging task-related resources such as information, expertise, and advice, and reflects the structure of workflow and task interdependence among team members (Magni et al., 2012). A common operationalization of the instrumental network, which we follow, uses the advice network based on whom a team member goes to in order to seek advice about their tasks (Yang & Tang, 2004). The expressive network consists of emotional ties for exchanging personal and social resources that may not be directly linked to the tasks at hand such as trust, friendship, and social support (Zhong et al., 2012). While a common operationalization of the expressive network is based on friendship existing among team members (Klein et al., 2004; Lee et al., 2013), team members may share different information via different networks, and the nature and impact of these two types of networks may be different.

Table 1 summarizes some example studies of social interactions and social networks in software development. Most such studies focus on the instrumental network. Due to the intellectual nature of software development, the instrumental network is of particular interest (Colazo, 2010; Kudaravalli et al., 2017). For example, task-related ties provide an opportunity for team members to form a shared mental model of goals and tasks, learn work habits and patterns, and understand the expertise of each team member (Levesque et al., 2001). Instrumental ties contribute to knowledge flows and influence team performance (Méndez-Durón & García, 2009; Peng et al., 2013). At the same time, software teams should consider not only the technical factors but also the social skills of team members (Latorre & Suarez, 2017). Although friendship ties in the expressive network may affect how teams achieve their desired goals (Lee et al., 2013), the expressive network has received little attention (Park et al., 2020).

In sum, most of the existing research on social network analysis in software development focuses on the instrumental network, while the expressive network, let alone the multiplex network, has been largely ignored. While the instrumental network utilizes the expertise of team members to achieve the overall benefits of team performance (Kudaravalli et al., 2017), decision-making and collaboration also require social capital (Lee et al., 2013). Thus, the expressive network and the instrumental network should be considered at the same time to clarify their influence on team performance. In addition, although centralization has been investigated as a main characteristic of social networks (Crawford & LePine, 2013), the mechanisms it uses to impact team performance remain largely unexamined.

Table 1. Social Network in Software Development

Studies	Research theme	Research content
Levesque et al. (2001)	Instrumental network	Finds that knowledge-related interactions will mediate the relationship between role differentiation and shared mental models in software development teams.
Crowston & Howison (2006)	Instrumental network	Shows that the social structure of project teams has a surprisingly centralized range in the discussion around bug fixing, with some teams highly centralized and others decentralized.
Nan & Kumar (2013)	Instrumental network	Finds that developer team structure and software architecture significantly moderate each other's effect on OSS development performance.
Méndez-Durón & García (2009)	Instrumental network	Analyzes that knowledge flows among projects throughout instrumental networks and their impact on project success.
Grewal et al. (2006)	Instrumental network	Study of the effects of differential network embeddedness on the success of community-based software development projects.
Latorre & Suarez (2017)	Instrumental network and expressive network	Defines a framework to assign people to projects from a sociotechnical perspective.
Peng et al. (2013)	Instrumental network	Investigates the impact of different types and stages of network ties on the success of OSS development.
Lee et al. (2013)	Expressive network	Applies networks in interpersonal friendship or acquaintance to IT service team environment.
Colazo (2014)	Instrumental network	Shows that the collaboration structure network of more temporally dispersed teams is sparser and more centralized.
Long & Siau (2008)	Instrumental network	Examines the relationship between instrumental network structure and knowledge sharing in Open Source Software (OSS) development teams.
Colazo (2010)	Instrumental network	Examines the relationship between new product development team collaboration model project productivity and product quality.
Kudaravalli et al. (2017)	Instrumental network	Distinguishes technology and design collaboration, and examines the importance of configuration in increasing the success of software development teams.
Yang & Tang (2004)	Instrumental network and expressive network	Analyzes the relation between group structural variables, i.e., centrality and cohesion of advice, leadership, obligation, and social network, and the performance among different development phases of information systems.

3 Theoretical Background

The structure-process-effectiveness framework suggests that team structure is connected to performance indirectly through its influence on team processes (Gladstein, 1984). Team structure reflects the connection and arrangement of team members and results from the division of knowledge and tasks, as well as the methods of coordination and control (Gladstein, 1984). Once formed, team structure is relatively stable (Gladstein, 1984), and social networks are one of the manifestations of team structure (Hongseok et al., 2004). We use the centralizations of the multiplex, instrumental simplex, and expressive simplex networks to characterize social networks in design teams.

Team process refers to the cognitive, verbal, and behavioral activities team members apply to accomplish tasks interdependently (Zhong et al., 2012). Process behavior refers to either task behaviors that enable the group to solve the objective problem to which the group is committed or maintenance behaviors that build, strengthen and regulate group life (Gladstein, 1984). Whereas task behavior emphasizes team members' input of knowledge and skills, as well as methods of dealing with task interdependence, maintenance behavior encourages open and smooth interpersonal relationships. In this paper, we focus on information elaboration and similarity perception, drawing on the information processing perspective for task behavior and the social classification perspective for maintenance behavior.

3.1 Simplex and Multiplex Networks

Team members may have multifaceted relationships among or between each other. A multiplex tie is defined as two nodes simultaneously sharing two or more types of relationship (Park et al., 2020), and the collection of multiplex ties in a team is represented as the multiplex network (Crawford & LePine, 2013; Park et al., 2020). In contrast, the simplex network consists of only a single type of tie among team members (Crawford & LePine, 2013). A few studies in management have recognized the existence of multiple types of relationships between coworkers. For example, while multiplex workplace friendships refer to affective relationships that coincide with colleague relationships (Methot et al., 2016), multiplex coworker friendships consist of the coexistence of interpersonal conflict and friendship (Hood et al., 2016); a multiplex taskwork-teamwork network arises when both taskwork and teamwork coexist (Crawford & LePine, 2013). In taskwork networks, team members work together on tasks, whereas teamwork networks are based on how team members interact to accomplish those tasks (Crawford & LePine, 2013).

Our focus is on the multiplex network consisting of the coexistence of instrumental and expressive ties. Therefore, we consider three types of social networks existing in a team: the instrumental simplex network, the expressive simplex network, and the multiplex network (Figure 1). Specifically, the simplex network has instrumental ties only (solid lines in Column 2 of Figure 1) or expressive ties (dashed lines in Column 3 of Figure 1), while the multiplex network has both instrumental ties and expressive ties between any two team members (bundled solid and dashed lines in Column 4 of Figure 1).

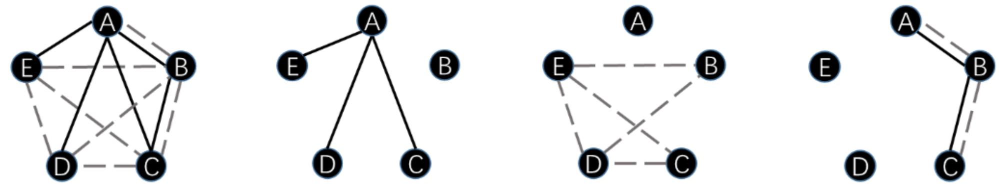
The instrumental network and the expressive network may coexist and are not always consistent (Hood et al., 2016; Magni et al., 2012). On the one hand, team members communicate with others based on task assignments or work roles (Mehta & Bharadwaj, 2015). On the other hand, they are free to interact with others based on personal interests and socialization needs (Mehta & Bharadwaj, 2015). Not all members of a team can become friends, and not all friends need to communicate with each other about tasks (Hood et al., 2016).

Centralization is one of the most important structural characteristics of social networks, and network centralization reflects the extent to which ties are organized around focal nodes (Park et al., 2020). Highly centralized teams tend to interact around one or more core team members, with peripheral team members remaining disconnected (Colazo, 2010). Centralization reflects the (un)equal distribution of resources, such as knowledge and social capital (Magni et al., 2012), but it also reflects the relative importance of individuals in the team network (Colazo, 2010). Column 2 of Figure 1 illustrates a relatively high network centralization, in which Team Member A can directly communicate with Team Members C, D, and E about task-related information, but Team Members B, C, D, and E cannot communicate directly with each other. Therefore, only one team member (that is, Team Member A) dominates task-related communication. This team member has more ties than other team members and acts as a hub for team members who need to use indirect paths to communicate with the other team members. This team member therefore may serve as an information exchange center. Using the example of a software team (Kudaravalli et al., 2017), in a centralized configuration, one key individual leads the team, assigns tasks, organizes technical reviews, and manages progress. In contrast, decentralized configurations may be associated with a more agile approach that emphasizes self-organization, flexible roles, and collaboration.

In a centralized instrumental simplex network, a knowledge leader can act as a manager of resources and drive the team’s knowledge transfer process through task allocation and situation interpretation (Balkundi & Harrison, 2004; Nan & Kumar, 2013). In a centralized expressive simplex network, a member may be a friendship hub for all other members. The interactions among other members are limited socially and their understanding of each other cannot be not consistent or thorough. Different from an instrumental or expressive simplex network, team members in a multiplex network are more closely connected to each other because a multiplex network serves as the pathway for both task and emotional information and therefore team members generally have more contact during information exchange. A decentralized configuration may better facilitate the flow of creative cognition from team members to the team (Shalley & Perry-Smith, 2008) and increase understanding among team members (Zellmer-Bruhn et al., 2008). However, it can be difficult for teams to transmit information smoothly and efficiently in a concentrated multiplex network due to the information load of the central node. In addition, because of the social status of the central node, team members need to consider other nontask factors, such as image, friendship, and conflict when sharing task-related knowledge (Colazo, 2010).

3.2 Information Processing Perspective and Social Classification Perspective

We characterize team processes according to two aspects: the information processing perspective and the social classification perspective. The information processing perspective focuses on task behavior, and the social classification perspective focuses more on maintenance behavior. To do their job effectively, teams need to balance the process of promoting unique ideas with the process of bringing team members together to form a common identity (Shemla et al., 2020).

	Team social network	Instrumental simplex network	Expressive simplex network	Multiplex network
Diagram				
Centralization	----	0.75	0.42	0.50

Note: The nodes represent team members, solid lines represent the instrumental ties, and dashed lines represent the expressive ties among team members.

Figure 1. Simplex and Multiplex Network

From an information processing perspective, teams can benefit from broader, unique, nonredundant, task-related knowledge and skills (Hoever et al., 2012). At the same time, by discussing the task context and information in detail, teams can avoid reaching a consensus prematurely (van Knippenberg et al., 2004). Information elaboration refers to the extent to which team members exchange, discuss, and integrate ideas and knowledge (Harvey, 2015). Information elaboration highlights the need not only to share information but also to process and integrate information within teams (Maynard et al., 2019; Yuan & van Knippenberg, 2020). Information elaboration is closely related to team performance. For example, team creativity requires the pooling of information from team members as well as a consensus on innovative ideas through information elaboration (Hoever et al., 2012; van Knippenberg et al., 2004). Information elaboration also improves knowledge-intensive task performance by helping teams understand and use diverse inputs (Sanner & Evans, 2019). Further, information elaboration affects team satisfaction through open knowledge sharing and positive cooperation experiences (Adamovic, 2020).

For tasks that require elevated information processing, it is not easy to exploit diverse information distributed among team members (Breugst et al., 2018; van Knippenberg et al., 2004). Team structure determines the accessibility of knowledge and affects the team's information processing and decision-making process (Ganguly et al., 2019; van Knippenberg et al., 2004). For example, dense network ties connect individuals and provide them with access to novel information (Ganguly et al., 2019). When processing both intellectual and expressive information, a centralized network has a greater probability of transmitting distorted information due to the great information load of central nodes (Colazo, 2010).

From a social categorization view, individuals in teams classify themselves and others based on similarity and difference (Randel & Earley, 2009; van Knippenberg et al., 2004), and team members are more motivated to trust people in their own category (van Knippenberg et al., 2004). Whether the social classification process is harmful to team performance depends on whether the team classification produces negative results (van Knippenberg et al., 2004). We introduce similarity perception from the social categorization perspective. Similarity perception refers to team consensus on the degrees of difference of multiple characteristics (Zellmer-Bruhn et al., 2008) and can positively affect aspects of team performance such as team member commitment, organizational cohesion, and remain/turnover (Ferguson & Peterson, 2015; Roh et al., 2019; Zellmer-Bruhn et al., 2008). Prior studies have suggested that team members categorize themselves and others based on perceived similarity, which is associated with social attachment and integration within the group and thereby enhances or undermines team outcomes (Zellmer-Bruhn et al., 2008). For example, high social attachment and integration prevent fragmentation within a team, which in turn promotes higher task-related performance (Roh et al., 2019; Zellmer-Bruhn et al., 2008).

Similarity perception is influenced by information about individual differences displayed during team interactions (Zellmer-Bruhn et al., 2008); similarity perception is subjective, and the interest in and attention of team members about characteristics is influenced by events in the environment (Randel & Earley, 2009). Team structure may influence team processes, such as the generation and handling of important events, and thus team perception. In addition, team members initially infer deep-level characteristics based on relatively superficial attributes, thus forming stereotypes (Dunlop & Beauchamp, 2011). Through extensive communication, deep-level features are often discovered (Dunlop & Beauchamp, 2011) and team members' impressions and perceptions of difference can be corrected. Therefore, the configuration of a social network (i.e., communication patterns) could have an impact on similarity perception.

4 Hypothesis Development

We characterize team structure according to three aspects: the centralization of the multiplex network, the instrumental simplex network, and the expressive simplex network in a team. Information elaboration and similarity perception are introduced from the information processing and social classification perspectives, and our characterization of team performance includes creativity, efficiency, and satisfaction. We propose that the centralization of the instrumental simplex network is positively associated with information elaboration, the centralization of the expressive simplex network is negatively related to similarity perception, and the centralization of the multiplex network is negatively correlated with information elaboration and similarity perception. We further posit that information elaboration contributes to team creativity, efficiency, and satisfaction, while similarity perception inhibits team creativity but increases team efficiency and satisfaction. Figure 2 summarizes our research model.

4.1 The Effects of Simplex Network Centralization

We expect that the centralization of the instrumental simplex network positively relates to information elaboration in a team, i.e., knowledge exchange, discussion, and integration. On the one hand, individuals at the center node have an information advantage that enables them to identify and locate a wider range of expertise, clarify the knowledge distribution of the software development team, and allocate required resources based on the needs of other team members (Balkundi & Harrison, 2004; Nan & Kumar, 2013). This reduces the probability that team members will have access to the same knowledge with fewer communication costs (Balkundi & Harrison, 2004; Nan & Kumar, 2013). On the other hand, team members at the central node of the instrumental simplex network can holistically understand the task environment (Hollenbeck et al., 2011). A grasp of the overall situation helps the central team member, and thus the team, understand and integrate the ideas or opinions of all team members (Hollenbeck et al., 2011), and information can be reviewed and assessed at the central node for integration (Shaw, 1964). Therefore, we hypothesize that:

H1: The centralization of the instrumental simplex network positively relates to team information elaboration.

We anticipate that the centralization of the expressive simplex network negatively relates to team similarity perception. In the expressive simplex network, team members who show kindness and sincere care are liked by other team members (Jar-Der & Luo, 2005), whereas in the decentralized expressive simplex network, affective interactions between team members are more equal and mutually respectful (Ibarra & Andrews, 1993). This atmosphere creates a sense of closeness and affection among team members, deepens their understanding of each other, eliminates the perception of differences in the types of tasks involved in software development projects, and thus reinforces the perception of similarity within the team. Therefore, in the decentralized expressive simplex network, team members are more likely to think that they have a high level of similarity. We thus hypothesize that:

H2: The centralization of the expressive simplex network negatively relates to team similarity perception.

4.2 The Effects of Multiplex Network Centralization

We expect that the centralization of the multiplex network is negatively related to team information elaboration. First, because the multiplex network in app teams includes both task-related information and friendship, centralized configuration increases the burden of information processing to the central node (Colazo, 2010). When transmitting information, the team member at the central node needs to consider whether different views among other team members may result in emotional contradictions. Thus, the central node information burden increases the difficulty of information exchange, discussion, and integration in such situations. Second, team members in a centralized multiplex network may hesitate to express different opinions to avoid conflict. Software development projects often consist of multiple parallel and diverse tasks (Kudaravalli et al., 2017); in a highly decentralized multiplex network, informal communication between team members can help transfer and infuse individual creative cognition to the team (Shalley & Perry-Smith, 2008). When the multiplex network is concentrated, the central node team member has an overall position of both knowledge and emotion. This team member provides intellectual and emotional assistance to other team members and may be seen in the role of the charismatic leader (Neubert & Taggar, 2004). Information transfer under the expressive ties condition may be more influential (Ibarra & Andrews, 1993): Team members may avoid task or knowledge conflicts with respected people to maintain their image or friendship, and they may agree with others' views without consideration or avoid presenting their own new ideas. Therefore, we hypothesize that:

H3: The centralization of the multiplex network is negatively related to team information elaboration.

We expect that the centralization of the multiplex network negatively relates to similarity perception in a team. On the one hand, in the decentralized multiplex network, where there is a lack of instrumental and expressive centering in design teams, various roles may be equally important (Ibarra & Andrews, 1993).

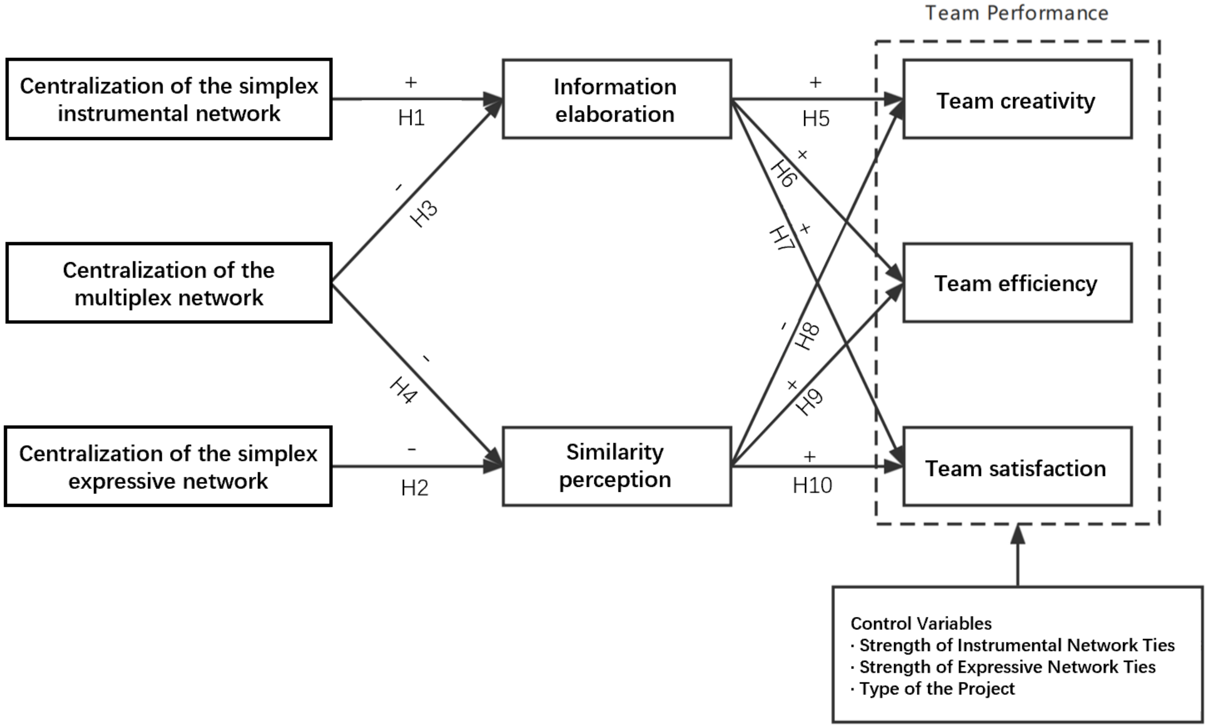


Figure 2. Research Model and Hypotheses

This can improve the autonomy of team members to manage team task-related emotions, including confidence, pressure, and anxiety (Crawford & LePine, 2013). In app design, the consistency of social ties will allow team members to sense the equality of their own and others' tasks, thus improving their autonomy and increasing the level of attention paid to their own knowledge and tasks. Different knowledge among team members can lead to different impressions about each other. On the other hand, through active communication and management initiated by team members, team members can eliminate initial stereotypes about each other (Zellmer-Bruhn et al., 2008), which can thus eliminate initial perceptions of difference and thereby increase the similarity perception. Therefore, we hypothesize that:

H4: The centralization of the multiplex network is negatively related to team similarity perception.

4.3 The Effects of Information Elaboration

Team creativity comes from the collective elaboration of various perspectives to come up with new and important ideas for the team (Ali et al., 2019). Software design is an integrated innovation activity of knowledge and ideas, requiring comprehensive consideration of a variety of novel schemes (Hoever et al., 2012). At the design stage, through higher information elaboration, team members more actively share unique knowledge with each other, thereby expanding the team knowledge base and enhancing the possibility of knowledge integration (Harvey, 2013; Hoever et al., 2018). This provides the condition for the generation of novel ideas. In other words, with greater information elaboration, the team improves creativity by more fully discussing, measuring, and evaluating ideas generated in the divergence stage from various perspectives (Harvey, 2013). Therefore, we hypothesize that:

H5: Information elaboration is positively associated with team creativity.

Higher information elaboration helps teams more efficiently utilize time and resources in solving software design problems. Information elaboration positively correlates with a team's ability to identify and solve key problems in the design process and to understand and coordinate multiple tasks (Breugst et al., 2018). Teams can make effective decisions in design by collecting, processing, and integrating a variety of unique information held by team members (van Knippenberg et al., 2004). Therefore, we hypothesize that:

H6: Information elaboration is positively associated with team efficiency.

When team members believe that each other's knowledge and suggestions will be fully considered and team members can decide how to organize their design efforts, they may experience a higher level of satisfaction (Acuña et al., 2009; Maynard et al., 2019).

Furthermore, software development projects often consist of multiple parallel and diversified tasks (Kudaravalli et al., 2017). Listening to and discussing all sides through information elaboration is essential to identifying potential sources of conflict and resolving them (Balkundi & Harrison, 2006). This helps the team resist harmful relationships or emotional conflicts and creates a favorable atmosphere of cooperation that leads to greater team satisfaction (Balkundi & Harrison, 2006). Therefore, we hypothesize that:

H7: Information elaboration is positively associated with team satisfaction.

4.4 The Effects of Similarity Perception

Similarity perception may inhibit team creativity. First, creativity is realized through the connection of knowledge in different fields and the divergence of different viewpoints (Harvey, 2013). Software teams find gaps in software functions by integrating different professional knowledge and synthesizing design schemes out of the collision of viewpoints. When a team has similar personalities and thought patterns, team members are likely to produce fewer unique ideas. Second, when team members feel a higher team similarity perception, they hesitate to put forward their own new ideas in order to avoid relationship conflicts (Hood et al., 2016; Tekleab et al., 2009). Even when different points of view are raised, the views may not be valued and discussed (Faraj & Lee, 2000). Task conflict can be particularly beneficial for a novel design scheme because such conflicts can cause team members to value the views of others, increase divergent thinking, and reevaluate the status quo (Farh et al., 2010). In software projects, team members have tasks of different natures, such as requirement analysis, functional design, and system implementation. When conflicts arise, the team will comprehensively consider the different objectives in all tasks and put forward a more feasible new scheme (Sawyer, 2001). Therefore, we hypothesize that:

H8: Similarity perception is negatively associated with team creativity.

Similarity perception contributes to team efficiency. Similarity attraction theory holds that people tend to cooperate with those who are similar to themselves because doing so reinforces their own attitudes and behaviors (Robert et al., 2018). Software development tasks with a clear division of labor also require coordination and cooperation among team members (Paasivaara & Lassenius, 2003). Team members with similar perceptions work together to streamline the flow of tasks and improve team efficiency. Likewise, social identity theory posits positive attitudes of in-group members and favoritism toward them, and the estrangement of out-group members (van Knippenberg et al., 2004). Thus, when similarity perception is higher, the team pulls together as a whole, rather than dividing into subteams. Thus, the team does not need to invest time in interpersonal relationships and can spend more time on tasks (Methot et al., 2016). In the context of app design, teams can spend more time on the coordination of diverse design objectives and tasks, thus improving the efficient utilization of time and resources in problem solving. Therefore, we hypothesize that:

H9: Similarity perception is positively associated with team efficiency.

Similarity perception may be positively associated with member satisfaction. When the members of a software team have a high degree of similarity perception, the team forms stronger cohesion and be able to deal with conflicts caused by inconsistent tasks in a more collegial way. Prior studies have shown that teams with similar personalities are more cohesive than those with dissimilar characteristics (Dunlop & Beauchamp, 2011). When there is cohesive-enhancing social attachment and integration, team satisfaction naturally increases (Zellmer-Bruhn et al., 2008). Highly cohesive teams are emotionally attached and better able to integrate different tasks and emotional information about each other, thus improving team satisfaction. Therefore, we hypothesize that:

H10: Similarity perception is positively associated with team satisfaction.

5 Methods

5.1 Participants and Procedures

We carried out the study by recruiting all students registered in a management information systems course at a major university in China. A total of 264 students from different majors were randomly assigned to 63 four- or five-member teams. The teams had almost the same number of team members to eliminate the interference of different network sizes. Random assignment achieves two purposes. First, it avoids the influence of prior interpersonal cognition and relationships to the greatest extent possible. Second, to achieve team goals, team members are more likely to build new relationships and interactions. The use of 3-5 member teams is also common in the software development literature (Yang & Tang, 2004). Such team sizes can avoid the free-riding problem that arises when the pressure on team members is dispersed across larger teams.

Each team was required to complete an eight-week project to earn credit. The task was designing a prototype of a mobile app based on current technology and completing a design documentation. Specifically, the teams were required to choose a topic and design an innovative and feasible app prototype based on user needs, market, technical feasibility, etc., and then write a design documentation that included analysis of the consumer, the cost of production, convenience of use, a communication plan, and the function of the app.

Teams were informed that the instructor would rate the app's creativity, including originality and usefulness, based on prototype demonstrations and the business analysis. Over eight weeks, each team was expected to select and integrate team members' knowledge and ideas. We set the project's objectives to align with topics covered in the curriculum. Throughout the course, we focused on the technological foundation of information systems, requirements analysis, system design and development, and business model innovation. These topics helped the students gain the necessary knowledge to complete the project.

In the last week of the course, each group was asked to submit a final business report and complete a questionnaire. After removing all invalid data, we collected data from 62 teams with a total of 260 participants. The recovery rate of the survey was 98.4%.

5.2 Measures

Centralization of a social network: The focus of this study required that we first defined and analyzed two different network ties: instrumental ties and expressive ties. We used the extent to which team members sought advice to measure instrumental ties, and used the extent to which team members socialized to measure the expressive network. We then built three networks based on the overlap of the two types of ties or lack thereof: the co-occurrence of instrumental and expressive ties (i.e., instrumental-expressive multiplex network), the occurrence of instrumental ties only (i.e., instrumental simplex network), and the occurrence of expressive ties only (i.e., expressive simplex network).

In Week 8, respondents were provided with a list of their teammates and asked to answer the following network questions for each team member: (1) "To what extent did you go to this person to ask for advice?" (Klein et al., 2004) and (2) "To what extent did you socialize with this person outside the working context" (Klein et al., 2004). Respondents answered these questions by indicating the frequency from 0 = *not at all* to 5 = *very often*. We used the cutoff value of "greater than 2" to dichotomize (Methot et al., 2016).

The centralization of the network is based on differences between the centrality of the most central point and that of all others (Freeman, 1979), which can be denoted as:

$$\frac{\sum_{i=1}^{n}(C_{max} - C_i)}{(\mathrm{n}-2)(\mathrm{n}-1)}$$

where C is the centralization of the graph, n is the number of points, C_i is one of the point centralities, and C_{max} is the largest value of C_i for any point in the network. Network centralizations of three types of networks in a team were calculated in UCINET 6.0.

Information elaboration: We measured information elaboration using four items adapted from Kearney et al. (2009). The sample items were as follows: "The members of our team complement each other by openly sharing their knowledge"; "The members of this team carefully consider the unique information provided by each individual team member." Every participant rated the degree of these items on a five-point scale (1, *strongly disagree*, to 5, *strongly agree*). Cronbach's alpha for this scale was 0.87. Information elaboration and other constructs below were collected at the individual level. We justified the aggregation of individuals' responses at the team level using the direct consensus model (Kearney et al., 2009; Leroy et al., 2020) based on acceptable interrater reliability and aggregate internal consistency (James, 1982). A mean R_{wg} of 0.89 of information elaboration exhibited sufficient agreement among team members. An ICC(1) of 0.23 showed sufficient reliability of individual ratings. Finally, an ICC(2) of 0.55 revealed sufficient reliability of the group average rating.

Similarity perception: To assess team members' perceptions of similarity, we used three items from Ferguson and Peterson (2015)—for example: "Our team members are very similar to one another" assessed on a 5-point scale (1, *strongly disagree*, to 5, *strongly agree*). Cronbach's alpha for this scale was 0.91. Then, we aggregated these items to the team level (Mean R_{wg}=0.75, ICC(1) =0.08, ICC(2) =0.26).

Team creativity: We evaluated team creativity as the joint novelty and usefulness of a report (Hoever et al., 2012). This means that novel but impractical app designs were not considered creative. For the evaluation, we invited three experts to rate each team's report. The experts were aware of the project assignment specifics and creativity indicators. To assess novelty, they compared each group's app design in the report with competing products in the marketplace on a 7-point scale (1, *not novel at all* to 7, *very novel*). As for usefulness, they coded the entire report on a 7-point scale. The scales had two main objectives: the commercial value and the feasibility of the product. We calculated the degree of consistency for novelty and usefulness before obtaining the team's creativity score. The high intraclass correlation coefficient and *Rwg* values revealed high reliability and consistency among raters (novelty: mean R_{wg}=0.64, ICC(1) = 0.37, ICC(2) = 0.71; usefulness: mean R_{wg}= 0.75, ICC(1) = 0.37, ICC(2) =0.71).

Team efficiency: In this study, the method of self-evaluation was used because the objective performance of the app design task was relatively difficult to obtain. However, some studies in the field of organizational behavior have suggested that perceptual measures are valid predictors of performance (Jones & Harrison, 1996). In terms of team efficiency, the items were adapted from Henttonen et al. (2014) and Stewart and Barrick (2000): (1) "Our team can always find a better solution." (2) "Our team can make good decisions." (3) "Our team is very efficient." Respondents were asked to rate each item on their team on a scale from 1 (*strongly disagree*) to 5 (*strongly agree*). Team members exhibited high reliability and intrateam agreement, α = 0.70, mean R_{wg} = 0.87, ICC(1) = 0.16, ICC(2) = 0.44.

Team satisfaction: Team satisfaction was operationalized as how satisfied team members are with their teamwork (Santos et al., 2015). Items included: (1) "I am satisfied with the other members of the team." (2) "The working atmosphere of the team is very good." (3) "Team members have a very good team spirit." Respondents rated each item on their project team on a scale from 1 (*strongly disagree*) to 5 (*strongly agree*). Team members exhibited high reliability and intrateam agreement, α = 0.93, mean R_{wg}= 0.96, ICC(1) = 0.28, ICC(2) = 0.62.

Control variables: The strength of social ties differs among teams, and this may affect team output or team member satisfaction (Ishii & Xuan, 2014). To control for the overall closeness of the ties in a team in our estimation, we calculated and entered the mean value of all scores of team members on instrumental and expressive ties, respectively, to represent the perceived strength of instrumental and expressive ties in a team (Ellison & George, 1994). In addition, teams chose and developed their own projects, and project type can affect team performance. Some types of projects, such as games, are likely to enjoy a larger audience and wider market than others. Such apps are more likely to produce innovative solutions that affect the team's creativity metrics. To control for the impact of project categories, we coded project types into a binary variable—0 for non-entertainment categories and 1 for entertainment categories—as a control variable.

6 Results

6.1 Cross-Sectional Analysis

Table 2 presents means, standard deviations (S.D.), and correlations among the principal constructs. We see that the centralization of the instrumental simplex network has a positive correlation with information elaboration but has no correlation with other constructs. The centralization of the multiplex network is negatively correlated with information elaboration and similarity perception. Both information elaboration and similarity perception are correlated with team performance.

Cronbach's alpha and composite reliabilities (CR) of all constructs in this study are well beyond the threshold levels, indicating adequate reliability (the lowest Cronbach's alpha was 0.70, the lowest CR was 0.83). To test for the threat of multicollinearity in this research, we calculated the variance inflation factor (VIF) and found it to be well below the acceptable level of 5 (Kudaravalli et al., 2017). In addition, the correlations did not exceed the square of the average variance extracted (AVE), further suggesting discriminant validity.

We performed a structural equation model (SEM) analysis to test each hypothesis at the team level using Amos 24.0. Figure 3 shows path relationships among the constructs. The three control variables had no significant effect on team performance. The centralization of the instrumental network had a significant positive effect on information elaboration (b = 0.342, p < 0.01), supporting H1. The centralization of the expressive network had no significant influence on similarity perception (b = -0.035, p > 0.05). Thus, H2 is not supported. The centralization of the multiplex network had a significant negative impact on information elaboration (b = -0.365, p < 0.01) and a negative impact on perceived similarity (b = -0.629, p < 0.01). Thus, H3 and H4 are supported.

Among the influences of team process on team performance, information elaboration had a significant positive impact on team creativity (b = 0.966, p < 0.001), team efficiency (b = 0.884, p < 0.001), and team satisfaction (b = 0.540, p < 0.001), supporting H5, H6, and H7. Similarity perception had a significant positive impact on team creativity (b = -0.653, p < 0.05) and team satisfaction (b = 0.302, p < 0.001), supporting H8 and H10. However, it had no significant impact on team efficiency (b = -0.133, p > 0.05); thus, H9 is not supported.

In addition, we examined the mediating role of information elaboration and similarity perception between the centralization of a multiplex network and team performance. We tested the mediation using the bootstrapping procedure in Amos 24.0 (Sung & Choi, 2019). Table 4 summarizes the results of the bootstrapping analysis. The mediating effects of the centralization of the instrumental network through information elaboration on team creativity (β = 0.105, 95% CI [0.001, 0.301]), efficiency (β = 0.220, 95% CI [0.030, 0.497]), and satisfaction (β = 0.181, 95% CI [0.031, 0.481]) are significant.

Table 2. Descriptive Statistics

	Mean	S.D.	1	2	3	4	5	6	7	8
1. Multiplex centralization	0.42	0.29	—							
2. Instrumental centralization	0.40	0.32	0.16	—						
3. Expressive centralization	0.22	0.29	0.11	0.10	—					
4. Information elaboration	4.42	0.36	-0.28*	0.29*	-0.13	0.89				
5. Similarity perception	2.68	0.46	-0.42**	-0.05	-0.11	0.36**	0.92			
6. Team creativity	4.10	1.14	0.06	0.16	0.04	0.39**	-0.13	0.06		
7. Team efficiency	4.01	0.37	-0.26*	0.24	-0.07	0.59**	0.36**	0.20	0.79	
8. Team satisfaction	4.40	0.44	-0.24	0.10	-0.15	0.50**	0.48**	0.05	0.55**	0.93

Note: $N = 62$; the square root of average variance extracted along diagonals. *$p < 0.05$. **$p < 0.01$. ***$p < 0.001$.

Table 3. Reliability and Validity Test

	Items	Factor loading	Cronbach's α	CR	AVE
Information elaboration	IE1	0.858	0.873	0.922	0.798
	IE2	0.928			
	IE3	0.892			
Similarity perception	SP1	0.915	0.913	0.945	0.852
	SP2	0.963			
	SP3	0.890			
Team efficiency	TE1	0.846	0.699	0.832	0.627
	TE2	0.861			
	TE3	0.650			
Team satisfaction	TS1	0.908	0.925	0.952	0.869
	TS2	0.941			
	TS3	0.947			

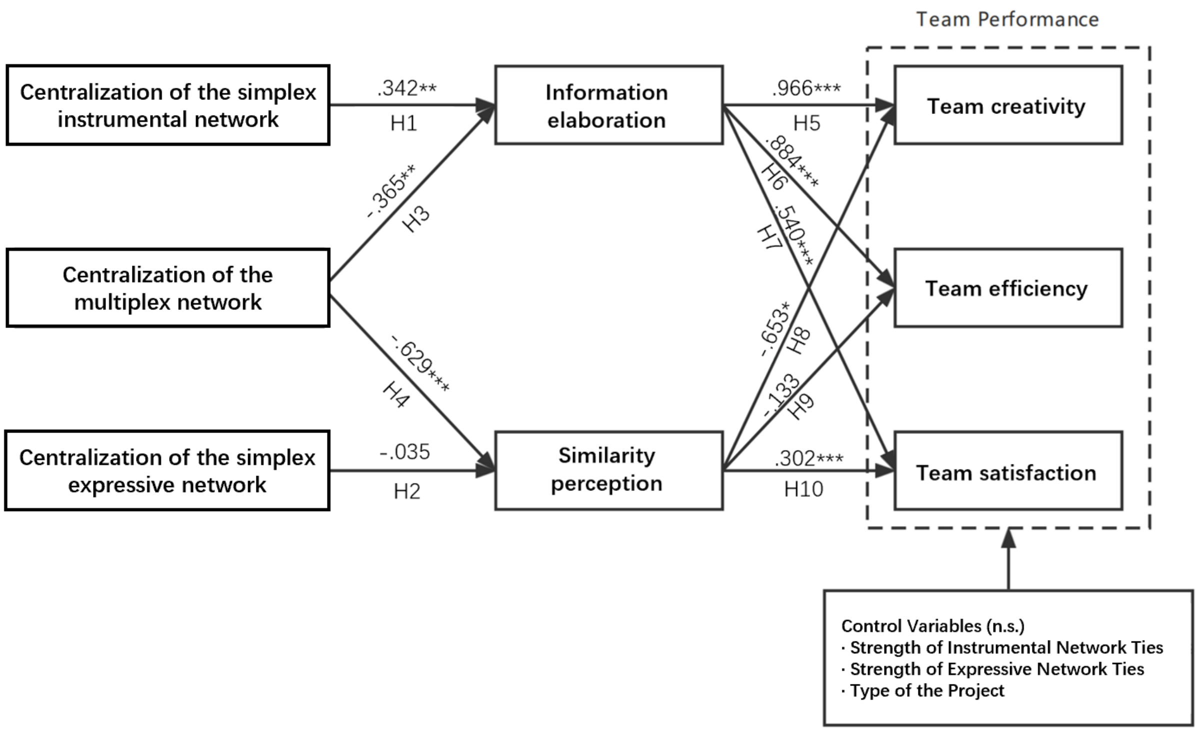


Figure 3. Results of Hypothesis Testing（N=62, χ^2 =196.258, df=125, GFI=0.765, CFI=0.885, TLI=0.843, NFI=0.752, RMSEA=0.097）

Table 4. Results of Indirect Effects

Model	**Indirect effects [95%CI]**
Instrumental centralization → information elaboration → creativity	0.105 [0.001, 0.301] *
Instrumental centralization → information elaboration → efficiency	0.220 [0.030, 0.497] *
Instrumental centralization → information elaboration → satisfaction	0.181 [0.031, 0.481] *
Multiplex centralization → information elaboration → creativity	-0.120 [-0.298, -0.007] *
Multiplex centralization → similarity perception → creativity	0.480 [-0.071, 0.192] *
Multiplex centralization → information elaboration → efficiency	-0.203 [-0.469, -0.019] *
Multiplex centralization → similarity perception → efficiency	-0.082 [-0.385, -0.023]
Multiplex centralization → information elaboration → satisfaction	-0.156 [-0.449, -0.022] *
Multiplex centralization → similarity perception → satisfaction	-0.183 [-0.374, -0.072] **

Note: **p* < 0.05, ***p* < 0.01.

The centralization of the multiplex network had a negative impact on team creativity through information elaboration (β = -0.120, 95% CI [-0.298, -0.007]) and a positive impact through similarity perception β= 0.480, 95% CI [-0.071, 0.192]). The indirect effect of the centralization of the multiplex network on team efficiency through information elaboration is significant (β = -0.203, 95% CI [-0.469, -0.019]). However, the mediating role of similarity perception between the multiplex network and efficiency did not pass the bootstrapping analysis (β = -0.082, 95% CI [-0.385, -0.023]). Finally, the negative mediating effect of the centralization of the multiplex network on team satisfaction through information elaboration and similarity perception is significant (through information elaboration, β = -0.156, 95% CI [-0.449, -0.022]; through similarity perception, β=-0.183, 95% CI [-0.374, -0.072]).

6.2 A Supplemental Study with Cross-Lagged Analysis

Concerns may exist that team processes including information elaboration and similarity perception could change how team members interact and thus affect network structure. To alleviate possible simultaneous bias, in this supplemental study, we collected data at two time points and conducted a cross-lagged analysis (Preacher, 2015).

A common approach to address possible simultaneous bias is to use time-sensitive models because there should be a time interval between a putative cause and its associated effect for the effect to occur or unfold (Preacher, 2015). Cross-lagged analysis is a common analysis method, where each construct depends not only on causal prior constructs but also on a prior evaluation of the same construct (Gollob & Reichardt, 1991).

In the supplemental study, we recruited 202 students at the same university in the same course as the main study and randomly assigned them to 48 groups with four or five students each, as in the main study. In this supplemental study, we focused on the relationships between the centralizations of social networks and the mediating variables. We measured the corresponding constructs using the same questionnaire twice: three weeks after team establishment (T1) and at the time of project completion (T2).

We used the structural equation modeling (SEM) technique to conduct cross-lagged analysis with AMOS 24.0. We tested several competing structural models using full panel designs to study the proposed cross-lagged effects (Hakanen et al., 2008; Jöreskog & Sörbom, 1996): (1) the stability model (M_{stabil}), which includes the autoregressive effects of each potential construct over time but does not include any cross-lagged associations; (2) the causality model (M_{casual}), which contains the autoregressive effect of M_{stabil} and the causal relationship between H1-H4 assumed in the measurement model of this research; (3) the reversed causation model (M_{revers}), which contains the autoregressive effect of M_{stabil} and the reverse effect of H1 to H4 assumed in the main model; and (4) the reciprocal model (M_{recipr}), which is a combination of M_{revers} and M_{casual}.

As seen in Table 5, the casual model (M_{casual}) is the model with the cross-lagged associations between network centralizations at T1 and information elaboration and similarity perception at T2, and the causal model is a better fit with the data than the stability model without cross-lagged associations (M_{stabil}; $\Delta\chi^2$=29.212, Δdf=4, $p < 0.001$). Compared to M_{stabil}, the cross-lagged model with inverted causality (M_{revers}) does not show better fitting statistics ($\Delta\chi^2$ =6.682, Δdf = 0, n.s.). To comprehensively explore the causal relationship between the centralizations and the mediators, we chose M_{recipr} as the final reference model. In M_{recipr} (Figure 4), the centralization of the instrumental network at T1 had a positive effect on information elaboration at T2 (b = 0.414, $p < 0.05$), thus supporting H1.

Table 5. Fit Statistics for Investigating the Cross-Lagged Model (N = 48).

Model	df	χ^2	RMESA	AGFI	CAIC	Model comparisons		
						ΔModel	Δdf	$\Delta\chi^2$
M_{stabil}	161	258.901	0.114	0.607	497.590	-	-	-
M_{casual}	157	229.689	0.099	0.635	488.042	M_{stabil} vs. M_{casual}	4	29.212***
M_{revers}	157	252.219	0.114	0.604	510.393	M_{stabil} vs. M_{revers}	4	6.682n.s.
M_{recipr}	153	223.224	0.099	0.634	500.882	M_{recipr} vs. M_{stabil}	8	35.677***

Note: ***$p < 0.001$

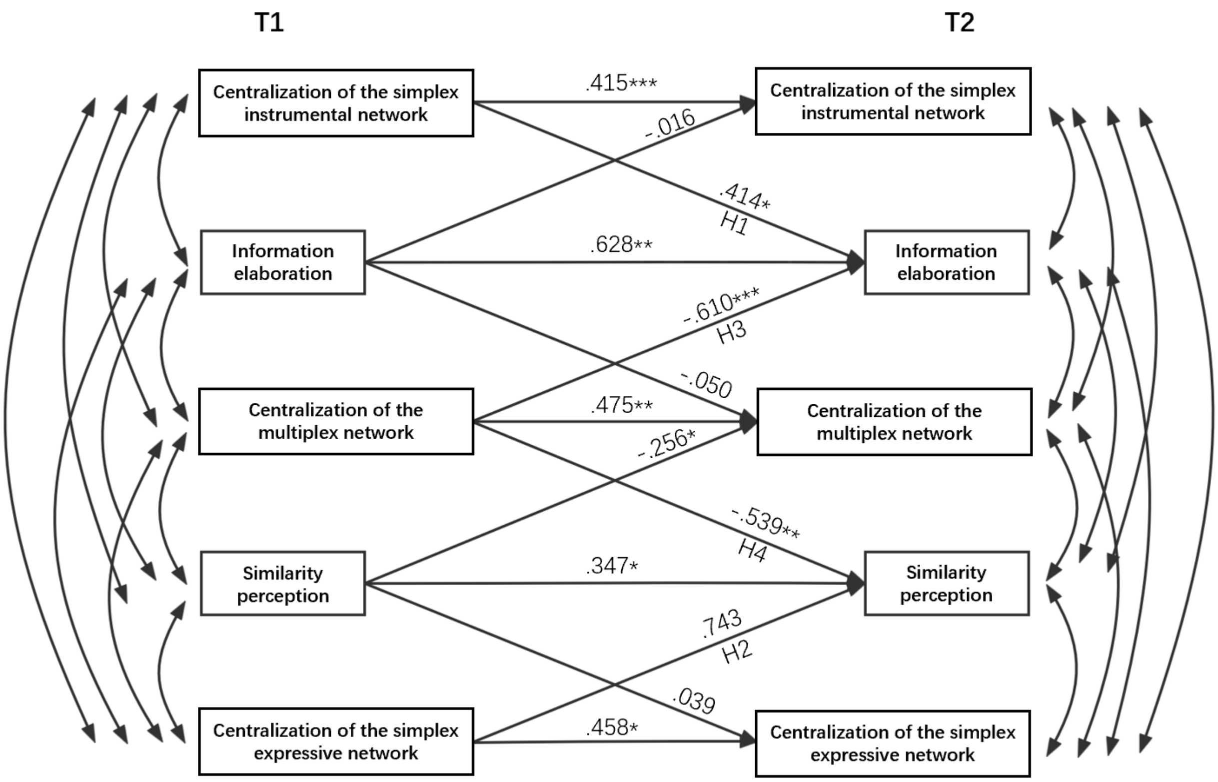


Figure 4. Results of Cross-Lagged Analysis (M_{recipr}) (N = 48, χ^2 = 223.224, df = 153, GFI = 0.733, CFI = 0.878, TLI = 0.848, NFI = 0.708, RMESA = 0.099)

The centralization of the multiplex network at T1 had a negative effect on information elaboration at T2 (b = -0.610, $p < 0.001$), and similarity perception at T2 (b=-0.539, $p < 0.01$), thus supporting H3 and H4. The centralization of the expressive simplex network at T1 had no significant effect on similarity perception at T2 (b = 0.743, $p > 0.05$); thus, H2 is not supported. In addition, similarity perception at T1 also had a significant effect on the centralization of the multiplex network at T2 (b = -0.256, $p < 0.05$). Thus, the supplemental study replicates the results of our main study for the relationship between the centralizations of three different networks and the information elaboration/similarity perception.

7 Discussion

This study establishes a theoretical model to explain how the configuration of social networks facilitates or hinders team performance in app design teams. Considering whether team members overlap in their tasks and social ties, we distinguish three types of networks in a team: the instrumental-expressive multiplex network, the instrumental simplex network, and the expressive simplex network. The results show that the centralization of the multiplex network has a negative impact on information elaboration and similarity perception, while the centralization of an instrumental network is beneficial to information elaboration. The results also show that information elaboration promotes team creativity, efficiency, and creativity. Similarity perception promotes team satisfaction but inhibits team creativity. Table 6 summarizes the results of hypothesis testing.

7.1 Theoretical Implications

Our study indicates three main implications for researchers. First, we suggest the important role of an expressive network together with an instrumental network and introduce the multiplex network view into the study of software development—app design, in particular. Both the social and technical skills of team members play critical roles in successful software development (Ozer & Vogel, 2015). Most studies on social networks in software development focus on the instrumental network; the expressive network and the multiplex network have received less attention. We introduce the multiplex network to study the synergistic coexistence of information-based or emotion-based relationships and found different effects between the centralization of the two simplex networks and that of the multiplex network. By introducing the multiplex instrumental-expressive networks together with the instrumental and expressive networks, this research provides a deeper view of social interactions existing in app design teams and offers a new perspective to understanding team performance.

Second, most software projects are carried out within teams, connecting the expertise of many individuals (Tiwana & McLean, 2005). However, few studies have probed how expertise is connected and how this can impact team performance. We introduce information elaboration from the perspective of team information processing, and similarity perception from the perspective of social classification, to characterize the coordination process in app design. The centralization of the instrumental network is associated with information elaboration, and in such a team, the central team member has information advantages for knowledge dispersion and integration. The centralization of the multiplex network is negatively associated with information elaboration, and the central team member may play the role of the charismatic leader or try to avoid conflict when opinions are exchanged. The centralization of the multiplex network also reduces similarity perception since team members lack equal and active communication, especially across different roles. By introducing information elaboration and similarity perception as mediating variables, we gain a better understanding of why and how network configuration affects team performance.

Third, our study includes the three distinctive aspects of team performance: team creativity, team efficiency, and team satisfaction. The team performance of software development is a complex multidimensional issue; our research allows for comparison of the distinct formation mechanisms of the three aspects of team performance within the same theoretical framework. Prior studies on software development have mainly focused on one aspect of team performance. Our study shows that while information elaboration positively contributes to all three aspects of team performance, similarity perception negatively affects creativity, positively affects satisfaction and has no effect on efficiency. The results suggest the complicated role of similarity perception in team performance and the potential dilemma associated with achieving both team creativity and satisfaction in software development.

7.2 Practical Implications

Our research can help managers understand how the configuration of social networks may help to improve app design team performance and consider whether to restrict fraternizing or promote friendship in task completion. We find that the centralization of the instrumental simplex network is beneficial to the transfer and management of knowledge; thus, it is necessary to encourage the team leader to play an active role and provide a formal communication channel for task-related information for all team members. At the same time, a decentralized multiplex network facilitates information elaboration and similarity perception.

Table 6. Results of Hypothesis Testing

Hypothesis	Hypothesis content	Results
H1	Instrumental centralization → Information elaboration (+)	Supported
H2	Expressive centralization → Similarity perception (-)	Not supported
H3	Multiplex centralization → Information elaboration (-)	Supported
H4	Multiplex centralization → Similarity perception (-)	Supported
H5	Information elaboration → Creativity (+)	Supported
H6	Information elaboration → Efficiency (+)	Supported
H7	Information elaboration → Satisfaction (+)	Supported
H8	Similarity perception → Creativity (-)	Supported
H9	Similarity perception → Efficiency (+)	Not supported
H10	Similarity perception → Satisfaction (+)	Supported

Therefore, companies could set up technical communities to encourage free communication among team members, such as encouraging and rewarding team members to share knowledge and brainstorm to solve design problems. Companies should also provide means to build friendships. Friendship among colleagues promotes closer and deeper communication and a greater sense of social inclusion. In this way, creating a solid network configuration can be beneficial for team performance.

Second, to achieve different team goals in software design, the intervention process may differ. Our study finds that the effects of information elaboration and similarity perception on creativity, efficiency, and satisfaction vary. In app design, maintaining competitive advantage in a complex and dynamic environment requires the constant improvement of team creativity (Alguezaui & Filieri, 2010). Our study shows that information elaboration has a positive effect on team creativity, while similarity perception has a negative effect. Organizations should encourage the free expression of ideas and establish a reward system for technical knowledge sharing to promote the psychological safety of team members. At the same time, teams need to pay attention to any subtle differences of opinion about the design solution, without letting social relations be dominant. If the primary goal of a software design team is to improve efficiency—that is, to obtain the optimal design solution with minimal cost and input—then the key is to facilitate information exchange and discussion among team members. In this case, perceptions of differences and commonalities within the team become less important. If building a satisfied development team is the primary goal, information elaboration and similarity perception need to be improved in order to create a harmonious and satisfying team atmosphere.

7.3 Limitation and Future Research

This article has certain limitations. First, the sample of this study is college students, and the project is course related. In future research, we plan to recruit professionals and carry out a field study for the generalizability of our results. In addition, the measurement of team outcomes could be more objective. For example, the efficiency of the team may rely on data such as the time and cost required to complete a design project (Aladwani, 2002). Second, we use a self-reported item to construct social networks. While this is a common method used in prior studies, in future research, multidimensional items or an interaction log could be used. Third, our study used a team size of 4-5 students. As team size may change how team members interact (Schreiber & Zylka, 2020), in future research, we plan to extend the study to actual development teams and explore the performance of large teams.

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Appendix A: A Summary of the Influencing Factors of Software Development Project Team Performance

Factors	Study	Literature	Key finding
Information-related factors	Expertise location, shared task understanding	He et al., 2007	Software project teams must be able to utilize the expertise and knowledge of participants. To efficiently leverage individuals' knowledge and expertise, software project teams develop team cognition structures that facilitate their knowledge activities.
	Expertise specialty, credibility	Lin et al., 2012	Expertise specialty, credibility, and their interaction positively affect team behavioral integration, leading to enhanced project team performance in ISD teams.
	Shared mental model	Xiang et al., 2016	The task-related shared mental model and the team member-related shared mental model are beneficial to ISD team performance in the requirements analysis stage.
	Teamwork mental model	Hsu et al., 2011	The teamwork mental model (teammate mental model and interaction mental model) is positively associated with information utilization and project performance.
	Transactive memory systems	Hsu et al., 2012	A mature TMS can effectively enhance the performance of IS development teams directly, and indirectly through improving the communication and coordination process.
	Learning effects	Kang et al., 2017	ISD project teams' experience in prior projects translates into performance gains for the current ISD project when the prior and current projects share the same domain, technology, or customer knowledge elements—domain, technology, and customer being the most essential knowledge types for ISD.
	Knowledge network	Del Rosso, 2009	By identifying knowledge networks, important coordination points can be found within the software development team.
	Expertise Coordination	Faraj & Lee, 2000	Expertise coordination processes are positively related to team performance in software development teams.
	Knowledge sharing	Park & Lee, 2014	Dependency and trust have a strong influence on knowledge sharing, thus improving the project performance of software development team.
	Knowledge sharing	Ozer & Vogel, 2015	Acceptance of knowledge from other software developers is positively correlated with the performance of software developers who receive knowledge.
	Knowledge sharing	Lu et al., 2011	Management support, team characteristics, communication quality, knowledge sharing, and task clarity all have significant effects on ISD team performance.
	Team wisdom	Akgun, 2020	Software development wisdom-related mechanisms, joint epistemic behaviors, correlate with team wisdom processes, and thus with effectiveness.
	Knowledge delivery	Ajila & Samuel, 2008	There is a correlation between knowledge delivery factors and software development team efficiency.
	Collaboration network structure, network size, network centralization	Nan et al., 2013	Development projects with high levels of interdependence require larger team sizes and centralized structures to achieve better project performance.

	Collaboration structure	Colazo, 2014	Collaboration structure networks of those OSS teams that are more temporally dispersed are sparser and more centralized.
	Design collaboration, technical collaboration	Kudaravalli et al., 2017	Decentralization of design collaboration leads to greater coordination success and less team conflict. By contrast, technical collaboration benefits from centralization.
Emotional-related factors	Social coordination	Kwan et al., 2011	High consistency between technology dependency and social coordination in the project results in a high probability of building success.
	Internal coordination	Gopal et al., 2011	Both customer (external) coordination and supplier team (internal) coordination have a positive impact on software quality, but not on development speed.
	Communication quality	Lu et al., 2011	Management support, team characteristics, communication quality, knowledge sharing, and task clarity all have significant effects on ISD team performance.
	Social factors	Datta, 2018	Tools like collaborative development environments (CDE) are used to facilitate interaction between members of such teams, with the expectation that social factors around the interaction would facilitate team functioning.
	Team reflexivity	Kakar, 2017	Team reflexivity and outcome interdependence have both synergistic and antagonistic impacts on team performance of Agile Software development projects.
	Social capital	Lee et al., 2015	Team social capital will play an important role in ISD projects. Expert knowledge and communication are the key antecedent variables leading to team performance.
	Emotional capability	Akgün et al., 2011	Managers should improve the team's emotional capacity to improve project performance, especially to promote courage, joy, and collective empathy.
	Team climate	Açıkgöz et al., 2015	Team climate was positively related to team problem solving; team problem solving positively influenced team learning; team learning was positively associated with software quality.

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