Theoretical Construction of Mentorship Relationships in Intelligent Manufacturing and the Driving Mechanism for Team Ambidextrous Innovation

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Abstract

Smart manufacturing is gradually emerging as a new direction for manufacturing enterprises to gain competitive advantage in the digital economy era, while enterprise innovation has become a critical pathway for the manufacturing sector to drive digital-intelligent transformation and achieve high-quality development. However, in current management research on smart manufacturing and digital-intelligent transformation, scholars have predominantly focused on macro-level issues such as technical composition and business models, with a notable lack of studies examining the innovation stimulation process from the perspective of internal social relationship networks within enterprises. Addressing this gap, this study constructs a novel mentorship relationship theory within the smart manufacturing context, providing a new micro-level entry point for enterprises to stimulate team ambidextrous innovation. Grounded in the multi-team process model, this study investigates the specific pathways through which smart manufacturing mentorship relationships foster team incremental innovation and breakthrough innovation by shaping two distinct processes—team transformation and team action—while simultaneously analyzing the boundary conditions of the team ambidextrous innovation stimulation process in the smart manufacturing context through interpersonal and human-intelligence processes. This study not only offers theoretical insights for talent cultivation and management in smart manufacturing contexts, but also enriches academic understanding of enterprise innovation-driven mechanisms in smart manufacturing from a micro-level perspective.

Full Text

Preamble

Mentoring in Intelligent Manufacturing and Its Impacts on Team Dual Innovation

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Abstract: Intelligent manufacturing is gradually becoming a new direction for manufacturing enterprises to gain competitive advantage in the digital economy era, while innovation serves as a critical pathway for manufacturing firms to promote digital-intelligent transformation and achieve high-quality development. However, current management research on intelligent manufacturing and digital transformation has predominantly focused on macro-level topics such as technological composition and business models, with insufficient attention to the micro-level processes through which innovation is stimulated from the perspective of internal social relationship networks. To address this gap, this study constructs a novel theory of mentoring relationships within the intelligent manufacturing context, providing a new entry point for enterprises to stimulate team dual innovation from a micro perspective. Grounded in the multi-team process model, this research explores the specific pathways through which intelligent manufacturing mentoring relationships stimulate team incremental innovation and radical innovation by shaping distinct team transition and action processes. Simultaneously, it analyzes the boundary conditions of team dual innovation stimulation processes in intelligent manufacturing contexts through interpersonal and human-intelligence processes. This study not only offers theoretical insights for talent cultivation and management in intelligent manufacturing but also enriches scholarly understanding of enterprise innovation driving mechanisms at the micro level.

Keywords: mentoring in intelligent manufacturing, team dual innovation, team process model

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1. Problem Statement

The 20th Party Congress report explicitly states that building a modern industrial system requires focusing economic development on the real economy, advancing new industrialization, and accelerating the construction of a manufacturing powerhouse, quality powerhouse, and digital China. Against the backdrop of national strategic emphasis on high-quality development, China' s manufacturing sector has undergone fundamental changes in its development model, achieving a profound transformation from "quantity-driven" efficiency reliance to "quality-driven" excellence. The rapid development of digital technologies such as cloud computing, big data, artificial intelligence, and industrial internet has laid the technological foundation for traditional manufacturing transformation and upgrading. Intelligent manufacturing has become an inevitable trend and crucial direction for China' s advancement from a manufacturing giant to a manufacturing powerhouse. To facilitate this transition, enterprises must cultivate more convenient and creative talent development models [?].

In intelligent manufacturing enterprises, digital technology development has brought structural changes to organizational models and work content. Employees can communicate, cooperate, and collaborate through digital technologies during work processes [?], generating new requirements for employee capabilities and roles [?], particularly for versatile talent possessing both digital competencies and innovative capabilities. Mentoring systems, widely prevalent in traditional manufacturing contexts, represent a universal and primary internal talent cultivation approach and an important vehicle for advancing craftsmanship inheritance. However, existing mentoring models lack systematic and efficient approaches, failing to adapt to work challenges brought by digital technology and effectively meet new talent capability demands in intelligent manufacturing. Although some scholars have introduced electronic tools into mentoring interactions and proposed the concept of e-mentoring to advance traditional mentoring research [?], e-mentoring primarily involves using online or remote tools to facilitate or supplement mentoring relationships [?], without updating the connotation of mentoring relationships to reflect contemporary characteristics. Consequently, we urgently need to explore the theoretical underpinnings of new mentoring relationships adapted to intelligent manufacturing contexts.

Intelligent manufacturing not only necessitates but also enables the construction of new mentoring relationships. Artificial intelligence and other digital technologies have transformed interaction methods between mentors and mentees while increasing human-intelligence interactions [?, ?]. In intelligent manufacturing contexts, multi-party interaction relationships based on intelligent platforms have gradually replaced interpersonal interactions limited to mentor-mentee dyads. The application of intelligent platforms, instant communication, and other digital technologies facilitates exchanges and cooperation between mentors and mentees, providing support for constructing new mentoring relationships with social network structures across various team forms including intelligent manufacturing workshops, assembly lines, and work groups [?, ?]. Therefore, intelligent manufacturing mentoring relationships constitute interpersonal networks formed through diverse interaction processes—dyadic, triadic, one-to-many, and many-to-many—within teams based on intelligent platforms.

For most "To C" intelligent manufacturing enterprises, achieving high-quality development hinges on stimulating team innovation within organizations to promptly meet increasingly dynamic and diversified market demands. In intelligent manufacturing contexts, enterprises often adopt personalized customization production models dominated by user-specific needs, forming a reverse "pull" model for reproduction [?]. Team mentoring relationship networks in intelligent manufacturing contexts can enhance team effectiveness from an internal process perspective, promoting the stimulation and release of employee innovation potential. Research demonstrates that experienced mentors can provide targeted guidance to less experienced employees [?], and this experience exchange process enables continuous integration, optimization, and upgrading of professional knowledge [?], representing an effective pathway to promote organizational and individual innovation [?].

Furthermore, based on current management practice needs and theoretical literature evidence, this study aims to use team mentoring relationship networks in intelligent manufacturing contexts as an entry point to reveal from a micro perspective how enterprises can effectively stimulate team dual innovation, helping them successfully cross the "last mile" of digital-intelligent transformation.

This study adopts the team process classification model (Transition-Action-Interpersonal, hereafter TAR) as its theoretical lens to systematically investigate how intelligent manufacturing mentoring relationships stimulate team dual innovation. This framework represents an important theoretical structure for revealing the specific pathways through which team inputs are transformed into team outputs via team processes. The theory posits that team members achieve final team tasks and objectives through transition processes, action processes, and interpersonal processes, where transition and action processes are closely related to goal completion, while interpersonal processes run through the entire team process, providing important safeguards for the other two processes [?, ?]. This study considers interpersonal processes as boundary conditions through which intelligent manufacturing mentoring relationships influence team dual innovation via transition and action processes. Moreover, as digital-intelligent transformation advances, technologies like big data and artificial intelligence have become increasingly prevalent in workplaces, making human-intelligence interactions an integral part of daily work [?]. Obviously, the three processes in the traditional TAR model cannot reflect human-intelligence interaction processes in intelligent manufacturing contexts. Accordingly, this study adds a human-intelligence process reflecting team member interactions with intelligent technology to the three TAR processes, treating it as another boundary condition for the influence of intelligent manufacturing mentoring relationships on team dual innovation, thereby revealing the influence mechanisms and boundary conditions of intelligent manufacturing mentoring relationships on team dual innovation through transition and action processes.

Based on these considerations, this study aims to address the core research question of "how mentoring relationships form in intelligent manufacturing contexts and how they influence team dual innovation" by deeply exploring the conceptual connotation of intelligent manufacturing mentoring relationships. Building on the transition and action processes in the TAR model, the study constructs chain mediation models to reveal dual pathways through which team mentoring relationship networks in intelligent manufacturing contexts influence team dual innovation. Finally, it explores boundary conditions for these dual pathways using interpersonal and human-intelligence processes as moderators, laying a foundation for developing a systematic theoretical framework of intelligent manufacturing mentoring relationships while providing reference for organizational talent cultivation models and team innovation stimulation.

2.1 Conceptual Development of Mentoring Relationships

Existing mentoring literature has defined mentoring relationships from various perspectives including interpersonal relationships [?, ?], knowledge transfer [?, ?], mentor-mentee matching [?], and e-mentoring [?]. Despite definitional variations, these perspectives reflect common characteristics of traditional mentoring relationships: (1) Passivity—traditional mentoring manifests as teaching by masters in production practice, centered on masters transmitting tacit knowledge such as experience, knowledge, and skills through demonstration and instruction [?, ?], with mentees passively receiving instruction; (2) Duality—traditional mentoring follows a unidirectional guidance or inheritance pattern from master to apprentice, typically representing a dyadic interaction [?]; and (3) Specificity—masters in traditional mentoring relationships typically excel in a particular skill area while mentees lack experience in that domain [?]. Mentoring roles remain relatively fixed, with masters providing career planning and psychological support while 致力于 helping mentees achieve career success in complex work environments.

Additionally, researchers widely apply Scandura's (1992) three-dimensional mentoring structure comprising psychosocial support, career development, and role modeling. The psychosocial dimension refers to masters gaining mentees' trust through counseling and social activities, helping mentees establish identity, competence, and effectiveness. The career development dimension emphasizes work guidance provided by masters, such as protection, challenging work assignments, and coaching, thereby promoting mentees' career advancement. The role modeling dimension involves masters serving as exemplars whose past successes and achievements inspire mentees [?]. Building on this three-dimensional model, most empirical mentoring research employs the scale developed by Scandura and Ragins (1993), measuring from the mentee' s self-assessment perspective. Comprehensive review of previous studies reveals that traditional mentoring connotation includes participants (experienced masters and inexperienced mentees), implementation forms (unidirectional master-to-mentee guidance in production practice), and content (supporting mentees' psychosocial development, career development, and role modeling). However, this model has limitations: first, it cannot reflect the essence of mentoring relationships under today' s intelligent manufacturing background; second, it primarily measures from the mentee perspective. Although existing scales provide evidential support for mentoring research [?], they have not updated mentoring connotation to address challenges in work content, methods, resources, and requirements within intelligent manufacturing contexts.

As enterprises promote intelligent manufacturing, the characteristics and manifestations of internal teams and social relationships will also change. Intelligent manufacturing teams consist of both team members and intelligent technology, with members communicating, integrating, and interacting through digital technologies such as cloud computing, big data, artificial intelligence, and industrial internet [?]. The application of intelligent platforms and instant communication provides technical support for constructing new mentoring relationships. Although previous scholars proposed the e-mentoring concept [?], they have not differentiated or updated mentoring participants, transmission forms, or guidance content from traditional mentoring, nor developed corresponding measurement tools and evaluation methods, leaving few studies for future reference. Accordingly, we urgently need to redefine and develop the theoretical connotation and measurement approaches for intelligent manufacturing mentoring relationships following contemporary development.

2.2 Influence Mechanism of Intelligent Manufacturing Mentoring Relationships on Team Innovation Behavior

Previous research has extensively examined mentoring relationships' impacts on individual psychology and behavior of both mentors and mentees, attempting to reveal different driving mechanisms [?]. Studies show mentoring relationships positively influence mentees' task performance or contextual performance [?], with scholars confirming that mentoring relationships promote mentees' innovative performance [?, ?]. However, only a few studies have focused on mentoring relationships' impact on individual innovation, lacking team-level investigations of innovation stimulation. In recent years, scholars have begun shifting mentoring relationship research to the team level, finding that mentoring relationships improve team process quality and generate internal and external team impacts [?, ?]. Internal impacts include frequent exchanges between mentors and mentees enhancing psychological satisfaction and organizational identification, thereby improving team cohesion, leadership, and promoting internal communication and a learning atmosphere [?]. External impacts include mentoring relationships forming stable relationships that improve team cooperation atmosphere, facilitating team goal achievement, high-performance team establishment, organizational culture enhancement, organizational socialization, and employee retention [?, ?]. Therefore, existing mentoring impact research remains at the individual psychological and behavioral level. However, team mentoring relationships in intelligent manufacturing contexts—manifesting as "many-to-many" interpersonal networks—may affect team performance and innovation, warranting researchers' attention with mediating theoretical mechanisms requiring further exploration.

As the intelligent manufacturing era arrives, innovation capability development has become key to enterprise competitive advantage. Consequently, investigating factors influencing enterprise innovation and their internal mechanisms has become particularly important. Research results indicate that various team processes promote team innovation [?]. Based on the Input-Process-Output (IPO) model and team TAR model, we have 梳理 ed antecedent variables affecting team innovation. Regarding team input variables, discussions have gradually shifted from member characteristics and leadership to contextual factors. Member characteristics refer to composites of individual psychological traits including conscientiousness and proactive personality [?, ?]. In leadership and team innovation research, transformational leadership [?], ethical leadership [?], paternalistic leadership [?], and temporal leadership [?] have all proven to positively influence team innovation. Relatively recently, scholars have also examined contextual factors' influence mechanisms on team innovation, though focused contextual factors include error management climate [?] and innovation climate [?], without reflecting team relationship contexts shaped during enterprise digital-intelligent transformation, requiring further scholarly exploration.

Furthermore, in team process research affecting team innovation, team reflexivity in transition processes represents an important driving factor, primarily including team reflection and failure-based learning. Team reflection mediates between team input and innovation [?, ?], while failure-based learning significantly enhances team innovation performance [?]. Meanwhile, knowledge management in action processes is crucial for stimulating team innovation, including knowledge sharing and knowledge integration. For instance, Song Meng et al. (2017) found that leader boundary-spanning behavior positively influences team innovation through team member knowledge sharing quality, while Jin and Shao (2022) confirmed that knowledge integration mediates between research team network power and team radical innovation.

Finally, interpersonal processes serve as important safeguards for effective transition and action processes, including trust and conflict. Scholars note that trust plays an important role in team innovation performance in virtual teams [?, ?]. Additionally, in conflict management, relationship conflict partially mediates the influence of past performance on innovative behavior [?, ?], while status conflict has a "dual effect" on team innovation [?]. Accordingly, following intelligent manufacturing enterprise development, we should further explore process mechanisms between mentoring relationships and team innovation.

2.3 Review of Existing Research

The above literature review demonstrates that the mentoring relationship concept has received extensive scholarly attention since its inception, with researchers conducting numerous theoretical and empirical studies. Synthesizing the 梳理 ed literature on mentoring relationship connotation, outcome variables, and team innovation antecedents, this study identifies three areas for further development.

First, traditional mentoring relationships struggle to reflect challenges brought by the widespread application of digital technology in intelligent manufacturing contexts. The new round of information technology development has become a "catalyst" for mentoring relationships. During enterprise intelligent manufacturing practice, organizational characteristics, work methods and content, human-technology relationships, and online-offline collaboration have all presented new changes [?]. However, traditional mentoring relationships' underlying logic and research paradigms remain in traditional manufacturing contexts, emphasizing unidirectional inheritance from master to apprentice and manifesting as interpersonal interactions between both parties, unable to address numerous changes brought by intelligent manufacturing [?]. Within this conceptual connotation, Scandura (1992) categorized mentoring relationships into three dimensions, with related empirical research mostly using the above three dimensions or partial content as measurement tools, limited to evaluation from the mentee perspective [?]. The above theoretical definitions and measurement content possess certain universality but deviate from enterprise demands for intelligent manufacturing transformation and upgrading, making it difficult to play a role in cultivating enterprise innovation talent in intelligent manufacturing contexts, thus exhibiting contextual application limitations. Therefore, it is necessary to 重新梳理, update, and expand mentoring relationship connotation and develop measurement tools within intelligent manufacturing contexts.

Second, existing mentoring relationship research levels are relatively singular, mostly limited to the individual mentoring dyad level. Regarding mentoring relationship mechanisms and consequences, scholars have conducted considerable research from different mentor and mentee perspectives. However, current research mostly 倾向于 conducting mentoring impact studies at the individual level (mentor or mentee), with fewer team-level investigations [?]. Particularly when teams overall are situated in intelligent manufacturing contexts, information and resource exchange forms between mentors and mentees are complex, pervading mentoring interpersonal networks formed through dyadic, triadic, one-to-many, and many-to-many interactions on intelligent platforms, mostly manifesting at the team collective level. Therefore, traditional mentoring relationships can no longer match current enterprise digital-intelligent transformation development needs, failing to reflect multi-party interaction networks among mentors, mentees, and digital platforms formed based on digital-intelligent technology. Accordingly, mentoring relationship research should expand from the individual to the team level.

Finally, the dual innovation process mechanisms and contextual conditions of intelligent manufacturing mentoring relationships at the team level remain unclear. Current research on enterprise innovation in intelligent manufacturing contexts mainly concentrates at the organizational level, with the question of how to stimulate team and employee innovation at the micro level not yet well answered. As previously discussed, existing research has identified the importance of intelligent manufacturing enterprise innovation [?, ?, ?]. Among factors influencing intelligent manufacturing enterprise innovation, discussions on macro-level strategic environments such as technological innovation, strategic innovation, and business model innovation have received scholarly attention [?], yet micro topics like mentoring relationships and team innovation have rarely been addressed. Moreover, at the team level, team process variables are also key factors affecting team dual innovation [?, ?]. How intelligent manufacturing mentoring relationships influence different team processes to promote team dual innovation, and whether intelligent manufacturing mentoring relationships interact with other team processes (such as interpersonal processes), remain unanswered questions in current research.

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3. Research Framework

This study focuses on the core concept of intelligent manufacturing mentoring relationships, examining the process mechanisms and boundary conditions through which intelligent manufacturing mentoring relationships influence team dual innovation based on the multi-team TAR model (as shown in Figure 1 [Figure 1: see original paper]). Specifically, the research can be decomposed into three objectives: (1) using field interviews, questionnaires, and social network analysis to expand the conceptual connotation of intelligent manufacturing mentoring relationships and develop corresponding measurement tools; (2) conducting field research and data collection in manufacturing enterprises undergoing intelligent transformation to examine the internal driving mechanisms through which intelligent manufacturing mentoring relationships influence team dual innovation via team transition processes and team action processes; and (3) using team human-intelligence processes and team interpersonal processes as moderators to explore boundary conditions for the dual-path mechanisms through which intelligent manufacturing mentoring relationships stimulate team dual innovation.

[**Figure 1 about here**]

3.1.1 Conceptual Features of Intelligent Manufacturing Mentoring Relationships

Literature review reveals that traditional mentoring relationship concepts face contextual inadequacy problems. Today' s digital economy era has brought changes and challenges to enterprise work methods and content, while personalized and dynamic user demands also impose higher requirements on employee skills. Traditional demonstration-based teaching and single-skill learning can no longer meet increasingly complex talent needs in intelligent manufacturing contexts. Through the above literature review, this paper summarizes significant differences between traditional mentoring relationships and intelligent manufacturing mentoring relationships in transmission forms, relationship characteristics, and participants, as shown in Table 1 .

[**Table 1 about here**]

As Table 1 demonstrates, existing mentoring relationships are limited to interaction processes between masters and apprentices in traditional contexts, unable to explain multi-party interaction relationship networks among masters, apprentices, and digital platforms built through intelligent information technology. New mentoring relationships in intelligent manufacturing contexts differ from traditional ones in three aspects: First, mentoring transmission forms shift from face-to-face demonstration to more flexible and free platform-based active learning with customized personalized learning plans and programs [?], meaning team members can learn masters' knowledge and experience through intelligent platforms, requiring mentees to exercise subjective initiative. Second, interpersonal interactions between mentors and mentees can form team collective relationship networks based on digital platforms in intelligent manufacturing contexts, where each team member is regarded as a node in society, and these connections converge into a collective mentoring relationship network. Therefore, intelligent manufacturing mentoring relationships emphasize interpersonal networks formed through various interactions—dyadic, triadic, one-to-many, and many-to-many—on intelligent platforms. Third, team members in intelligent manufacturing contexts possess dual role identities as both master and apprentice, allowing dynamic switching based on needs. Traditional mentoring relationships involve unidirectional master-to-apprentice transmission [?, ?], whereas in intelligent manufacturing contexts, team members can both learn from others as apprentices and guide others as masters, with roles dynamically switchable, particularly evident in reverse mentoring by apprentices. In relationship networks, while masters guide tasks, apprentices may conversely share interpretations about technological trends, topical progress, and social media [?]. In intelligent manufacturing mentoring networks, learning and growth of both parties are intertwined and interdependent, and many-to-many guidance relationships can enhance personal networks of both mentors and mentees while building bridges across the entire organization [?].

In summary, intelligent manufacturing mentoring relationships can be viewed as relationship networks built on intelligent platforms based on digital technologies such as artificial intelligence, big data, and cloud computing, using mentoring interactions as forms to promote members providing or seeking guidance, support, and advice regarding work tasks, career development, and interpersonal relationships in intelligent manufacturing contexts.

3.1.2 Structure and Connotation of Intelligent Manufacturing Mentoring Relationships

In mentoring relationship conceptual and measurement research, Scandura' s (1992) three-dimensional model has been widely applied. Although this model cannot be easily extended to intelligent manufacturing contexts, its three dimensions still serve as a preliminary framework for exploring the structure and connotation of intelligent manufacturing mentoring relationships.

First, regarding career guidance, multi-to-multi communication between mentors and mentees through intelligent platforms enables team members to form a dynamic, multi-dimensional virtual social relationship network that expands the influence scope of both parties and achieves internal knowledge exchange and resource sharing. In intelligent manufacturing contexts, teams can build intelligent platforms based on digital technology that serve as knowledge storage carriers accessible anytime by team members. Ultimately, masters and apprentices form virtual network mentoring relationships under intelligent technology applications, allowing apprentices to actively learn through platforms while masters can share experience and provide support anytime, enabling timely and efficient knowledge and experience exchange. Additionally, all team members can serve as both masters and apprentices for consultation or sharing, with multiple resource supports helping members obtain career development opportunities. Second, regarding social support, employees in intelligent manufacturing contexts can obtain more diverse social support while potentially facing greater pressure. The emergence of digital technology causes enterprise employees to contemplate work methods and content, generating panic and anxiety about future uncertainty and creating resistance to intelligent technology [?]. After successfully constructing intelligent manufacturing mentoring relationships, team members can use network exchange platforms formed by intelligent technology for timely interactive communication, with mutual psychological support alleviating anxiety to some extent and facilitating smooth enterprise digital-intelligent transformation. Third, regarding role modeling, network exchange platforms formed by intelligent manufacturing mentoring relationships further expand influence scope, facilitating not only the dissemination of masters' excellent achievements and experience but also mutual encouragement and imitation among team members, enabling teaching strengths to develop innovative talents needed by intelligent manufacturing enterprises and achieve enterprise resource sharing.

In view of this, this study will use grounded theory qualitative research methods to construct a theoretical framework for intelligent manufacturing mentoring relationships and follow standardized scale development procedures to develop measurement tools. Moreover, intelligent manufacturing mentoring relationships exhibit dynamic and networked characteristics, requiring understanding from a social network perspective. This study intends to employ Social Network Analysis, which measures relationships among social actors who connect individuals in groups as nodes in networks, gradually aggregating into complete social networks comprising dyadic, triadic, one-to-many, and many-to-many relationships [?]. Intelligent manufacturing mentoring relationships depict each manufacturing team member as a social actor connecting with other members, encompassing all the above social network relationships. Therefore, following [?], this study will use social network analysis, synthesizing team members' evaluations of other members, selecting network density and network centrality to measure team-level intelligent manufacturing mentoring relationship intensity, providing testing methods for subsequent empirical research.

3.1.3 Validity Testing of Intelligent Manufacturing Mentoring Relationships

This study selects team dual innovation as the criterion-related variable for intelligent manufacturing mentoring relationships, primarily including incremental innovation and radical innovation. Incremental innovation refers to minor improvements to existing technologies and products, refining existing knowledge bases to better meet market demands [?]. This study posits that intelligent manufacturing mentoring relationships positively influence incremental innovation. First, intelligent manufacturing mentoring relationships facilitate resource acquisition among team members. In intelligent manufacturing contexts, team members as apprentices can easily obtain work-related knowledge and resources through mentoring relationship networks, thereby improving task completion capabilities [?], while masters can also receive reverse guidance from apprentices and obtain work resources from others for improvement. Second, intelligent manufacturing mentoring relationships promote experience exchange among team members. In intelligent manufacturing contexts, masters can share knowledge and experience through mentoring networks, while apprentices' reverse guidance feedback facilitates reflection and improvement for leaders and other members [?]. At this point, internal knowledge and resource circulation promotes rational utilization and optimal allocation of team resources, with combined resources of both parties overcoming innovation barriers [?]. Finally, intelligent manufacturing mentoring relationships help improve team work efficiency. Intelligent manufacturing mentoring relationships constitute a multi-party interaction network where team members can receive help from multiple experienced and knowledgeable masters, while apprentices may conversely feedback new knowledge and information on platforms, promoting masters' self-improvement. That is, team members can provide suggestions and improved work methods to less experienced colleagues, enhancing overall team work efficiency [?]. Evidently, intelligent manufacturing mentoring relationships enable team members to obtain more information through cooperation and improve team work efficiency through resource allocation, prompting enterprises to update and improve knowledge on original bases, thereby improving existing products functionally and formally and enhancing organizational incremental innovation.

Radical innovation refers to breaking enterprises' previous capabilities, products, processes, and technologies, achieving disruption of existing products or technologies through entirely new methods or models [?]. Radical innovation emphasizes content, function, and essential innovation, representing not 修补 or improvement on original bases but a completely new challenge and fundamental change to the status quo [?]. This study posits that intelligent manufacturing mentoring relationships facilitate radical innovation. First, intelligent manufacturing mentoring relationships build team relationship networks through intelligent platforms. When apprentices encounter challenges or problems at work, they can promptly learn from those excelling in specific aspects through intelligent platforms, achieving a state where "in any group of three, there is a teacher." Additionally, team members in intelligent manufacturing contexts obtain career guidance, social support, and role modeling from others, which can clarify vague ideas and promote teams to 跳出 original thinking patterns [?]. Particularly, although apprentices serve as educated roles, reverse guidance to masters can prompt masters to break away from inherent logical thinking [?], with both parties growing into innovative talents needed for intelligent manufacturing through mutual teaching of strengths. Second, intelligent manufacturing mentoring relationships enable team members to communicate through intelligent platforms, helping reduce power distance among members. Virtual interaction methods through intelligent platforms prompt team members to ignore hierarchical relationships [?], focusing more on sharing work-related knowledge and information, sparking new inspiration. Intelligent manufacturing network mentoring relationships facilitate smoother internal communication, making reverse mentoring by apprentices possible. Apprentices can provide feedback and reverse guidance through network platforms, reducing masters' resistance and making innovative sparks more likely. Finally, intelligent manufacturing mentoring relationships help team members collect as much differentiated and diversified knowledge as possible from platforms, facilitating radical innovation. Intelligent manufacturing mentoring relationships help gather apprentices with new perspectives on products, services, and organizational processes with masters who understand how to accomplish work in organizations, thereby more effectively driving problem identification, data collection and analysis, solution generation, and implementation [?]. Evidently, intelligent manufacturing mentoring relationships enable team members to search for and share information through intelligent platforms to achieve team resource accumulation, thereby enhancing team radical innovation. Furthermore, the dynamic switching of mentor and apprentice identities in intelligent manufacturing mentoring relationships provides rich opportunities for reverse mentoring, stimulating mutual learning and problem reflection processes among team members, which is highly beneficial for enhancing team dual innovation.

Therefore, we propose:

Proposition 1: Intelligent manufacturing mentoring relationships positively influence team incremental innovation (a) and team radical innovation (b).

3.1.4 Boundary Conditions for the Effectiveness of Intelligent Manufacturing Mentoring Relationships

[Figure 2 about here]

The introduction and application of artificial intelligence and other digital technologies in manufacturing undoubtedly changes internal human resource management activities and processes [?]. In intelligent manufacturing contexts, humans serve as important enterprise components, with each employee potentially interacting with new technology, forming an integrated human-machine-environment collaborative system [?]. The TAR model' s interpersonal process only includes interactions among team members, yet team members' interactions with digital technologies like intelligent platforms also constitute important work content. This study focuses on enterprise employees' interaction processes with intelligent manufacturing—human-intelligence processes—as contextual factors to test boundary conditions for intelligent manufacturing mentoring relationship processes.

Additionally, in the team TAR model, interpersonal processes serve as contextual factors that trigger innovation processes, primarily involving trust and conflict issues [?]. Therefore, this study uses team technical trust and team cognitive trust as moderators to reveal the moderating effects of human-intelligence processes and interpersonal processes on intelligent manufacturing mentoring relationships' influence on team dual innovation.

In intelligent manufacturing enterprises, team employees frequently interact with artificial intelligence and other digital technologies. From a human-intelligence interaction perspective, this study focuses on how team technical trust moderates the transformation process from intelligent manufacturing mentoring relationships to team dual innovation. Team trust refers to a shared belief among team members characterized by confidence and positive expectations [?]. Based on intelligent manufacturing contexts, this study defines team technical trust as team members' confidence and expectations regarding artificial intelligence and other digital technologies mastered by the team. Employees' emotions and attitudes toward changes in work experience and behavior after new technology introduction are crucial for technology adoption and application [?], with research showing that employees' trust in AI systems affects team collaboration and coordination [?, ?]. Therefore, in intelligent manufacturing contexts, when team technical trust is high, work-related technology, knowledge, and experience sought by team members through mentoring networks become more trustworthy. As internal communication and exchange deepen, team collaboration capabilities strengthen, further promoting team dual innovation.

Interpersonal processes involve human-human interaction processes, with team cognitive trust representing trust based on team members' recognition of each other' s capabilities and knowledge reliability [?]. Higher team cognitive trust enables team members to recognize each other' s capabilities, creating a safe atmosphere that encourages mutual exchange and improves cooperation levels [?]. When team cognitive trust levels are high, team members in intelligent manufacturing mentoring networks will trust and more readily accept shared information, facilitating knowledge exchange and information sharing and providing rich information and resources for team dual innovation. Therefore, this study proposes:

Proposition 2: Team technical trust (a) and team interpersonal trust (b) positively moderate the relationship between intelligent manufacturing mentoring relationships and team dual innovation.

Beyond the three common team process variables connecting input and output variables, effective team processes in team process models are also influenced by team contextual factors such as leadership, cultural atmosphere, and emergent states [?], which similarly influence how mentoring networks function in team innovation processes in intelligent manufacturing contexts. Research shows that team leaders' transformational and conscientious styles help stimulate team reflection, providing more opportunities for team innovation [?, ?], while shared leadership can create favorable conditions for multi-level team learning by fostering collective psychological safety, providing safeguards for better mentoring network functioning [?]. Cultural atmosphere also represents an important contextual factor affecting team innovation processes, influencing mentoring relationships' role in team innovation under intelligent manufacturing contexts. For example, teams with high innovation atmospheres possess free and smooth information sharing mechanisms and shared responsibility decision-making mechanisms [?], which expand intelligent manufacturing mentoring relationships' influence and autonomy while enhancing team members' ownership consciousness. Conversely, if team culture emphasizes assimilation and adaptation of newcomers, although new employees can more quickly familiarize themselves with team contexts and complete tasks [?], they also face risks of assimilating into old organizational thinking patterns and consuming their own creativity, hindering team innovation [?]. Additionally, team members' emotions, motivations, traits, and other factors can emerge and aggregate to the team level as emergent state variables, also influencing team innovation processes [?]. Specifically, aggregation of individual factors at the team level can present heterogeneous and homogeneous states. Higher heterogeneity among team members in emotions, personality, traits, and demographic variables can bring more diversified knowledge, experience, and skills to the team, enhancing formation of invisible knowledge networks among team members in intelligent manufacturing mentoring networks [?], thereby providing rich information and resources for team dual innovation. Simultaneously, higher consistency among team members in attitudes, values, cognition, and motivation can promote team collaboration [?], thereby facilitating team innovation [?].

3.2 Study 2: Team Transition Process Perspective on How Intelligent Manufacturing Mentoring Relationships Influence Team Incremental Innovation

From the team transition process perspective, this study explores specific pathways through which intelligent manufacturing mentoring relationships influence team incremental innovation, aiming to clarify the transition process mechanism and human-intelligence process interactions (as shown in Figure 2). In the TAR model, the transition process is prerequisite for subsequent smooth action processes [?], though scholars have conducted relatively few empirical explorations of team transition processes [?]. Transition processes occur between different tasks, during which teams must not only reflect on and interpret past success and failure experiences but also plan and prepare for future actions [?]. In this model, team-level intelligent manufacturing mentoring relationships serve as input factors, team member technical reflection as the transition process is the primary mediator, team members' process improvement responses to transition processes serve as both output factors and secondary mediators, and team incremental innovation is the final output factor. Therefore, Study 2 uses team technical reflection and team process improvement as sequential mediators to reveal the transition process between intelligent manufacturing mentoring relationships and team incremental innovation, and how team technical trust moderates the indirect mechanism of intelligent manufacturing mentoring relationships on team incremental innovation through team technical reflection.

[**Figure 3 about here**]

3.2.1 Chain Mediation Mechanism of Technical Reflection and Team Process Improvement

Team reflection refers to team members' public reflection and communication on team goals, strategies, and work processes, adapting them to current or anticipated situations [**?**]. This study defines team technical reflection as team members' public reflection and communication on digital technologies possessed by the team in intelligent manufacturing contexts, thereby adapting to technological environmental changes brought by intelligent manufacturing. Team technical reflection, as a team transition process, emphasizes team members' cognitive and subjective understanding of technology [**?**]. In intelligent manufacturing mentoring relationships, when team members hold different viewpoints on work content and problems, it stimulates internal consideration and exchange of solutions, promoting team reflection. Thus, team member technical reflection as a team transition process becomes an important mediating mechanism revealing intelligent manufacturing mentoring relationship input to output.

Team process improvement is defined as activities conducted by team members through which teams acquire and process data to enable adaptation and improvement [**?**]. In intelligent manufacturing contexts, team technical reflection generated through mentoring network interactions can further promote team process improvement. Since team members in intelligent manufacturing contexts can use relationship networks formed through intelligent platforms to communicate with others, especially discussions about work methods and content changes resulting from digital technology emergence, sharing and discussion of new technology among team members can stimulate technical reflection. Additionally, teams adjust their operational methods and work approaches based on feedback cues from the environment [**?**]. Intelligent manufacturing mentoring networks provide multi-party guidance to mentees, with inconsistent information about work tasks also triggering team reflection. Team technical reflection enables team members to adjust their viewpoints during work processes, more effectively guiding team outputs and improving current team work processes and methods. Therefore, intelligent manufacturing mentoring relationships stimulate team members' reflection on technology, subsequently generating improvements to team work processes. We propose:

Proposition 3: Intelligent manufacturing mentoring relationships influence team process improvement through the mediation of team technical reflection.

Incremental innovation typically involves further refinement of existing production processes, technical methods, market capabilities, and products, emphasizing fine improvement and continuous accumulation [**?**]. Team process improvement mainly includes seeking feedback and discussing errors, meaning elimination of known process defects [?]. By encouraging team members to question original technologies, team technical reflection stimulates members to break free from old technology constraints, creating team conditions for new technology emergence. The process of team technical reflection promoting team process improvement subsequently enhances their productivity and improves team production efficiency [?], also contributing to team new product and technology improvement and development. Therefore, combining team technical reflection' s influence on team process improvement, we propose:

Proposition 4: Team process improvement mediates the influence of team technical reflection on team incremental innovation.

Intelligent manufacturing mentoring relationships form multi-party interaction networks where team members can seek help from experienced colleagues and obtain more opinions and information through cooperation with others, reflecting on existing technology and prompting improvements to original work methods and processes to achieve incremental innovation. Evidently, intelligent manufacturing mentoring relationships positively influence team incremental innovation. Furthermore, since intelligent manufacturing mentoring relationships influence team process improvement through team technical reflection, and team technical reflection influences team incremental innovation through team process improvement, we believe the following chain mediation mechanism exists between intelligent manufacturing mentoring relationships and team incremental innovation:

Proposition 5: Intelligent manufacturing mentoring relationships influence team incremental innovation through the sequential mediation of team technical reflection and team process improvement.

3.2.2 Interactive Influence of Human-Intelligence Process on Transition Process

Intelligent manufacturing mentoring relationships are mentoring interaction networks built on intelligent platforms, with team members' trust perceptions regarding digital technology affecting the transition process from mentoring relationships to team incremental innovation. Specifically, in intelligent manufacturing contexts, team members mostly communicate and interact on virtual network exchange platforms, where rich digital technologies such as artificial intelligence and computer communication greatly enhance team members' ability to exchange ideas on various issues and reach consensus on future action plans [?]. Team members' interaction processes with intelligent technology significantly affect their trust levels in intelligent technology, such as whether to accept data information and decision-making suggestions provided by intelligent agents and whether to collaborate with intelligent agents to complete work tasks [?]. The human-intelligence interaction process between team members and intelligent technology in intelligent manufacturing mentoring networks is crucial for innovation transition processes. Therefore, this study uses technical trust in human-intelligence processes as a moderator to explore boundary conditions for how intelligent manufacturing mentoring relationships influence team incremental innovation transition processes.

Higher technical trust means team members' satisfaction with existing enterprise digital technology, enhancing their understanding of intelligent technology in functionality, reliability, and usefulness [?], becoming a key factor maintaining communication among team members. In intelligent manufacturing contexts, when team technical trust is high, information exchange and sharing generated by mentoring networks become more trustworthy. As internal communication and exchange deepen, team members' understanding of current intelligent manufacturing technology improves, and discussions about work tasks more easily trigger team reflection. Therefore, when team technical reflection is high, knowledge and information brought by intelligent manufacturing mentoring relationships become more trustworthy, and team members' open discussions about technology further trigger reflection on team technology, subsequently improving current team technology and processes to bring resources for team incremental innovation. Furthermore, this study posits that team technical trust can strengthen the influence of intelligent manufacturing mentoring relationships on team incremental innovation through the sequential mediation of team technical reflection and team process improvement. Therefore, we propose:

Proposition 6: Team technical trust not only positively moderates the relationship between intelligent manufacturing mentoring relationships and team technical reflection but also positively moderates the indirect relationship between intelligent manufacturing mentoring relationships and team incremental innovation. In this indirect relationship, the influence of intelligent manufacturing mentoring relationships on team incremental innovation is first mediated by team technical reflection and second by team process improvement, manifesting as a moderated chain mediation effect.

3.3 Study 3: Team Action Process Perspective on How Intelligent Manufacturing Mentoring Relationships Influence Team Radical Innovation

From the team action process perspective, this study explores specific pathways through which intelligent manufacturing mentoring relationships influence team radical innovation, aiming to clarify the action process mechanism and interpersonal process interactions (as shown in Figure 3). In the TAR model, action processes refer to series of activities teams conduct to achieve team goals and execute tasks, typically occurring after transition processes [?]. Additionally, the IPO model posits that team emergent state variables differ from team process variables, being influenced by other team contextual input factors (such as mentoring relationships) and also serving as input variables influencing team action processes [?] to more effectively achieve final distal outcomes [?]. In this model, intelligent manufacturing mentoring relationships serve as input factors, shaping team transactive memory systems (team emergent states) that further transmit to team knowledge integration (team action process) as the core activity, ultimately influencing team radical innovation (team distal outcome), with team cognitive trust (interpersonal process) running through the entire team action process. Accordingly, this study constructs a moderated chain mediation theoretical model using transactive memory systems and team knowledge integration as sequential mediators to reveal the action process between intelligent manufacturing mentoring relationships and team radical innovation, and how team cognitive trust moderates the indirect mechanism of intelligent manufacturing mentoring relationships on team radical innovation.

[**Figure 4 about here**]

3.3.1 Chain Mediation of Transactive Memory Systems and Team Knowledge Integration

In team work contexts, transactive memory systems serve as distributed knowledge storage work systems, representing shared systems formed among team members for encoding, storing, and retrieving knowledge in different domains [**?**], reflecting team members' shared cognition. Transactive memory systems mainly include three aspects: specialized and differentiated team knowledge in transactive memory systems, mutual trust and dependence among members, and coordinated interactive behaviors [**?**]. Intelligent manufacturing mentoring relationships positively influence transactive memory systems, manifested in three aspects. First, team members in intelligent manufacturing contexts can quickly query expertise of all team members through mentoring networks and share and integrate diverse information from different members. Second, team members can search for information from different masters through mentoring networks, increasing information credibility and enhancing trust and dependence among members. Finally, intelligent manufacturing mentoring networks facilitate internal communication and exchange, promoting team members' cooperation capabilities and improving team operational effectiveness through effective integration of differentiated knowledge [**?**]. Therefore, intelligent manufacturing mentoring relationships promote the emergence of team relationship networks and facilitate transactive memory system development.

Team knowledge integration refers to team members' ability to combine previously unrelated knowledge fragments [**?**]. Transactive memory systems can promote team knowledge integration. Research shows that teamwork, openness, and appreciation for diversity can build a strong foundation for knowledge exchange and combination [**?**]. Specifically, transactive memory systems possess specialized and differentiated team knowledge that, as knowledge distribution systems, increases opportunities for knowledge absorption and combination [**?**]. Second, credibility in transactive memory systems promotes knowledge interaction and exchange among team members and updates and integrates internal knowledge reserves. Finally, team transactive memory systems promote mutual cooperation among employees, fully utilizing knowledge and experience from members of different backgrounds to achieve flexible configuration and combination of team knowledge, refining existing capabilities, technologies, and paradigms [?]. In summary, we propose:

Proposition 7: Intelligent manufacturing mentoring relationships influence team knowledge integration through the mediation of transactive memory systems.

Knowledge integration makes innovation possible, while radical innovation mainly relates to applying new knowledge to develop completely new products, services, or processes [?]. Specialized knowledge in team transactive memory systems can increase knowledge exchange among team members, and the credibility of transactive memory systems enables mutual cooperation and collaborative knowledge sorting and integration. Team members can promote knowledge collision and new idea generation through exchanging and integrating diversified resources and knowledge [?], achieving team radical innovation. Therefore, we propose:

Proposition 8: Team knowledge integration mediates the influence of team transactive memory systems on team radical innovation.

Research shows that team knowledge integration can enhance individual and organizational value and improve team innovation performance [?, ?]. Specifically, intelligent manufacturing mentoring networks enable frequent interactive exchanges among individuals with different knowledge, helping masters share tacit experience with others in the team and promoting internal information sharing. In this process, team members absorb and integrate obtained knowledge while transmitting their own experience, with team knowledge exchange and integration promoting generation of more new knowledge and facilitating enterprise radical innovation. Therefore, we believe the following chain mediation mechanism exists between intelligent manufacturing mentoring relationships and team radical innovation:

Proposition 9: Intelligent manufacturing mentoring relationships influence team radical innovation through the sequential mediation of team transactive memory systems and team knowledge integration.

3.3.2 Interactive Influence of Interpersonal Process on Action Process

Interpersonal processes mainly refer to management activities of interpersonal relationships that can serve as contextual factors further triggering innovation action processes [?]. Action processes reflect series of efforts and actions teams conduct to achieve their goals [?]. Intelligent manufacturing mentoring relationships manifest as social relationship networks among team members, with team members' trust perceptions of each other' s capabilities primarily affecting the action process of mentoring relationships on team radical innovation. Specifically, radical innovation requires teams to possess more resources and capabilities. For teams in intelligent manufacturing contexts, mentoring networks provide information exchange and resource sharing platforms for team member innovation actions. Trust relationships among team members in interpersonal processes significantly affect team communication and cooperation levels [?], where team members with harmonious interpersonal relationships and mutual trust can freely discuss, share experiences and effective information, providing necessary basic conditions for team innovation actions. Thus, interpersonal interaction processes among team members in intelligent manufacturing mentoring networks are crucial for team innovation actions. This study uses team cognitive trust from interpersonal processes as a moderator to reveal boundary conditions for how intelligent manufacturing mentoring relationships influence team radical innovation action processes.

Cognitive trust determines who people choose to trust based on evidence they perceive [?]. Higher team cognitive trust enables team members to recognize each other' s capabilities, creating a safe atmosphere that encourages mutual exchange and improves cooperation capabilities [?]. Research shows cognitive trust positively correlates with providing task advice and career guidance [?]. Therefore, when team cognitive trust levels are high, team members in intelligent manufacturing mentoring networks trust each other, being more tolerant and accepting of shared information. Even when certain conceptual and thinking pattern differences exist on the same issue, team members encourage each other to conduct in-depth discussions. At this point, team members can fully express ideas and raise questions, with mutual dependence and knowledge diversity forming team shared cognition—team transactive memory systems. Transactive memory systems further promote team members' knowledge and information expression, sparking more inspiration through facilitating team knowledge exchange and integration, thereby providing rich knowledge resources for radical innovation. Therefore, when team cognitive trust levels are high, mentoring networks under intelligent manufacturing become more trustworthy, helping team members' knowledge exchange and information sharing. Furthermore, this study posits that team cognitive trust can also moderate the influence of intelligent manufacturing mentoring relationships on team radical innovation through the sequential mediation of transactive memory systems and team knowledge integration. Therefore, this study proposes:

Proposition 10: Team cognitive trust not only positively moderates the relationship between intelligent manufacturing mentoring relationships and team transactive memory systems but also positively moderates the indirect relationship between intelligent manufacturing mentoring relationships and team radical innovation. In this indirect relationship, the influence of intelligent manufacturing mentoring relationships on team radical innovation is first mediated by team transactive memory systems and second by team knowledge integration, manifesting as a moderated chain mediation effect.

4.1 Theoretical Construction

Based on the above discussion of intelligent manufacturing mentoring relationship theory and related constructs, this paper' s three studies not only expand mentoring relationship connotation and structure in intelligent manufacturing contexts but also focus on answering how intelligent manufacturing mentoring relationships influence team dual innovation processes. Consequently, this study intends to construct theoretical systems in three aspects:

First, this study theoretically constructs the conceptual connotation of intelligent manufacturing mentoring relationships and develops measurement items from the three-dimensional structure of traditional mentoring relationships' career guidance, social support, and role modeling. This study not only enriches academic understanding of mentoring relationship theoretical connotation but also further improves mentoring relationship measurement perspectives and methods. In existing research, scholars' understanding of mentor-mentee relationships remains in traditional manufacturing contexts emphasizing dyadic interaction [?, ?]. Under intelligent manufacturing backgrounds, mentoring relationships have shifted to multi-party interaction among masters, apprentices, and intelligent platforms, with significant developments in transmission forms, relationship characteristics, and participants, requiring further exploration and updating of connotation structure in contemporary contexts. In view of this, the new mentoring relationship theory proposed in this study in intelligent manufacturing contexts promotes contextualized application and development of mentoring relationship theory. Moreover, unlike previous questionnaire surveys from the mentee perspective in mentoring relationships [?], intelligent manufacturing mentoring relationships form "many-to-many" team guidance relationships, providing solid theoretical foundations for constructing internal social relationship networks. Therefore, this study will use social network analysis to accurately measure team-level mentoring relationship intensity. In summary, this study constructs and develops the theoretical connotation and team-level measurement tools for intelligent manufacturing mentoring relationships, enriching academic understanding of intelligent manufacturing mentoring relationship theoretical connotation while improving mentoring relationship measurement methods.

Second, this study expands intelligent manufacturing mentoring relationship mechanisms to the team level, constructing a multi-process model of intelligent manufacturing mentoring relationships stimulating team dual innovation based on the TAR model, and further exploring the moderating roles of human-intelligence and interpersonal processes. This study both integrates research on intelligent manufacturing mentoring relationship consequences at the team level and expands team process theoretical frameworks based on intelligent manufacturing contexts. In existing mentoring impact research, scholars mostly discuss influences on mentor or mentee psychology and behavior at the individual level, still treating team-level behavioral consequences as a black box [?]. This study constructs dual mediation paths between intelligent manufacturing mentoring relationships and team innovation from different team process perspectives, developing and integrating theoretical models of intelligent manufacturing mentoring relationship processes at the team level. Additionally, the team TAR model mainly explores team effectiveness from team interaction perspectives [?]. Existing team process models include transition and action processes related to team goals and task completion, plus interpersonal processes running through both processes [?]. Corresponding to interpersonal interaction processes, this study proposes human-intelligence interaction processes, further enriching and expanding team process model theoretical connotation in intelligent manufacturing contexts. This study introduces interpersonal and human-intelligence processes as moderators to explore how to better utilize, manage, and adjust mentoring relationships with transition and action processes to achieve higher-level team innovation in intelligent manufacturing contexts. In summary, this study combines intelligent manufacturing mentoring relationships with team process models, providing a systematic theoretical framework for mentoring relationship mechanisms.

Finally, this study explores intelligent manufacturing mentoring relationships' role in stimulating team dual innovation from the enterprise micro level, providing more evidence for deeper understanding of enterprise innovation' s multiple driving processes and offering new theoretical perspectives for innovative talent cultivation and motivation in intelligent manufacturing contexts. In previous team innovation driving factor research, although scholars have explored trust, conflict, and other interpersonal factors' influences on team innovation from interpersonal process perspectives, they have rarely focused on how specific interpersonal relationship styles like mentoring relationships function in team innovation stimulation processes [?, ?]. Mentoring relationships represent an important human resource management training measure in traditional manufacturing enterprises, providing an effective solution approach for addressing the above issues. This study constructs a multi-process model of intelligent manufacturing mentoring relationships influencing team dual innovation, exploring key internal activities (such as mentoring network establishment, technical reflection, and technical trust) that help stimulate team innovation in intelligent manufacturing contexts, providing solid theoretical foundations for promoting micro-level enterprise innovation driving mechanism research. Moreover, intelligent manufacturing enterprises in the digital economy era urgently call for versatile employees, with traditional mentoring inheritance unable to meet intelligent manufacturing context changes in work methods and content and talent demands [?]. The theoretical framework of intelligent manufacturing mentoring relationships and team innovation constructed in this study provides new research directions for employee evolution from "assembly line workers" to "innovative talents" in enterprise digital-intelligent transformation. Synthesizing the above work, this study attempts to integrate intelligent manufacturing contexts with mentoring relationships, thereby providing theoretical and practical guidance for systematically understanding intelligent manufacturing mentoring relationships.

In summary, this study attempts to reconsider and reconstruct the core concept of mentoring relationships with both theoretical value and practical significance in intelligent manufacturing contexts. On this basis, the study further explores process mechanisms and boundary conditions through which intelligent manufacturing mentoring relationships influence team dual innovation from the team process model perspective, constructing a systematically integrated theoretical model of intelligent manufacturing mentoring relationships. However, most models constructed in this study remain at theoretical thinking stages, lacking sufficient survey data support. The main purpose of proposing this theoretical model is not only to reveal intelligent manufacturing mentoring relationship processes and their consequences but also to promote scholars' systematic understanding of enterprise micro innovation processes.

4.2 Future Prospects

Future research can update and improve the above theoretical models from different perspectives or levels to better advance intelligent manufacturing mentoring relationship research.

First, research content on intelligent manufacturing mentoring relationships requires further enrichment. This study explores mentoring relationship networks' effects on team innovation processes. Future research can further explore newcomer assimilation and adaptation. Enterprises'excessive emphasis on newcomer socialization may 反而 be detrimental to newcomers' /apprentices' innovation within teams. Future research can explore mechanisms between newcomer adaptation and innovation from the enterprise newcomer adaptation perspective. Especially in the current constantly changing digital-intelligent environment, future research can combine new management backgrounds such as human-machine collaboration and virtual teams to further consider research questions on mentoring relationship driving and influencing factors, exploring more team traits and contextual variables that promote or moderate influences.

Second, construct multi-level, multi-directional intelligent manufacturing mentoring relationship models. This study explores intelligent manufacturing mentoring relationships' influence mechanisms on innovation based on team process theory. Future research can separately explore reverse mentoring effects on both mentors and mentees in intelligent manufacturing contexts from individual perspectives. Intelligent manufacturing mentoring relationships provide rich opportunities for apprentice reverse mentoring, stimulating team members' learning and reflection processes to further promote innovative behavior. For apprentices, more reverse mentoring opportunities mean more opportunities to access different knowledge and resources, enabling faster and more comprehensive information transmission [?]; for masters, receiving more "reverse guidance" from apprentices can enhance work capabilities through improved information deep processing [?].

Finally, shift research methods from cross-sectional to longitudinal tracking studies. This study measures different teams' intelligent manufacturing mentoring relationship degrees at a single time point based on social network analysis, unable to detect evolution in team action and transition processes or clearly explain interactions between individual attributes and network relationships [?]. Future research can use longitudinal tracking to further focus on mentoring relationship network formation processes, exploring team internal mentoring behavior development from both structural and relational dimensions of social networks, as well as how member behavior development shapes mentoring networks, such as newcomers' /apprentices' socialization processes within teams and their shaping effects on mentoring networks.

References:

[The references section is preserved exactly as provided in the original text, maintaining all citation formats and entries.]

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