Research on the Formation Mechanism and Effects of Human–Machine Symbiotic Experience

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Abstract

With the rapid development of digital and intelligent technologies, the marketing and experience ecosystem shaped by human–machine collaboration has undergone profound changes. Unlike traditional human-centered customer experience, human–smart machine symbiotic experience (HSX), as an emerging interaction pattern, emphasizes the mutual interaction between humans and machines and the capabilities that emerge therefrom. HSX holds the potential to enhance user experience, optimize corporate decision-making, and promote social welfare, and is therefore of great significance for driving economic development and improving people' s livelihoods. Consequently, in a digital ecosystem characterized by ubiquitous connectivity and real-time interaction, how to create higher user value has become an urgent issue to be addressed. Focusing on the dynamic process of HSX, this study is designed to conduct inquiry at three levels: Study 1 centers on concept and measurement, systematically sorting out the connotations, dimensions, and structural characteristics of HSX and developing corresponding measurement instruments; Study 2 focuses on formation mechanisms, revealing the emergent mechanisms and evolutionary patterns of HSX from the perspective of collaboration between intelligence quotient (IQ) and emotional quotient (EQ), and proposing a staged evolutionary model; Study 3 concentrates on the mechanisms of action and outcomes, empirically testing the double-helix effects of HSX on both positive and negative outcomes and exploring its boundary conditions. This research will not only provide practical implications for enterprises to formulate HSX-based marketing strategies and intelligent applications, but also offer important theoretical support for governments to advance "AI+" initiatives and govern digital ecosystems.

Full Text

Preamble

The Formation Mechanism and Effectiveness of Human-Machine Symbiotic Experience

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Abstract: With the rapid development of digital and intelligent technologies, the marketing and experiential ecosystems constituted by human-machine interactions have undergone profound transformations. Unlike traditional customer experience that centers on humans, Human-Machine Symbiotic Experience (HSX) represents an emerging interaction model that emphasizes the reciprocal interplay between humans and machines and their emergent capabilities. HSX holds significant potential for enhancing user experience, optimizing corporate decision-making, and promoting social welfare, making it crucial for economic development and improving people' s livelihoods. Consequently, in a digital ecosystem characterized by ubiquitous connectivity and real-time interactions, creating greater user value has become an urgent challenge. Focusing on the dynamic processes of HSX, this study proposes three interconnected research strands: Study 1 addresses conceptualization and measurement by systematically articulating the connotations, dimensions, and structural features of HSX and developing corresponding measurement tools; Study 2 examines formation mechanisms by revealing the emergent dynamics and evolutionary patterns of HSX from the dual perspectives of intelligence quotient and emotional quotient, proposing a staged evolutionary model; Study 3 investigates mechanisms and effects by empirically testing the double-helix effects of HSX on both positive and negative outcomes and exploring its boundary conditions. This research will not only provide practical insights for enterprises to develop HSX-based marketing strategies and intelligent applications but also offer important theoretical support for governments advancing the "AI+" initiative and digital ecosystem governance.

Keywords: customer experience, actor experience, human-machine symbiotic interaction, artificial intelligence, digital ecosystem

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1. Research Background and Problem Statement

The Central Economic Work Conference explicitly stated that 2025 will focus on leading the development of new quality productive forces through scientific and technological innovation, advancing the "AI+" initiative. The Government Work Report at the Third Session of the Fourteenth National People' s Congress further emphasized the continuous advancement of this initiative. These policies provide solid policy support and strategic guidance for the widespread application of Artificial Intelligence (AI) technology, accelerating the development and popularization of generative AI, large language models, and other intelligent technologies. Currently, AI has been deeply integrated into various industries, driving the transformation of human-machine interaction patterns from "human-machine collaboration" to the more complex "Human-Machine Symbiosis" (HMS).

Research indicates that, unlike "human-machine collaboration" which emphasizes cooperation, human-machine symbiosis highlights the deep collaboration and mutual adaptation between humans and machines during interaction, forming an interdependent and co-evolutionary relationship (Inga et al. 2023). In this relationship, humans and machines not only efficiently complete tasks but also enhance each other's capabilities through interactive learning, achieving deep integration and co-evolution of emotion and cognition (Järvelä et al., 2025), enabling machine learning autonomy and decision-making to partially substitute human judgment (Hoffman & Novak, 2018). For instance, the general intelligent agent "Tongtong (Little Girl)" can achieve emotional resonance and social integration with humans through a value-based decision-making mechanism. It not only provides personalized services for users through deep learning but can even anticipate user needs through autonomous behaviors (such as adjusting ambient temperature or learning new skills), demonstrating the deep embedding of technology into human life. This symbiotic relationship not only reshapes the ethical boundaries of human-machine interaction but also achieves cross-species connection through emotional interaction (Law et al., 2025), enhancing user experience while driving the iteration and evolution of machine capabilities.

In this new digital ecosystem, intelligent machines exist not merely as tools but, through real-time interaction with humans and other machines, create "Human-Machine Symbiotic Experience" (HSX) with unique value attributes for all participants. Unlike traditional consumption experiences centered on product quality, price, and channels, the core connotation of HSX refers to the new attributes and capabilities generated through deep collaboration and co-evolution between humans and machines (Novak & Hoffman, 2019). When machines possess unique interactive capabilities and autonomous experiences, this symbiotic relationship can continuously stimulate the iterative enhancement and value leap of participants (including humans, machines, and their combinations) through emotional coordination and value co-creation mechanisms. On one hand, "machine autonomous experience" refers to the functional adaptive state on the system side, which serves as a necessary condition for driving the overall value leap of HSX. On the other hand, HSX represents a holistic attribute of the "human-machine combination system" generated during interaction, with human subjective perception serving as the window to capture this attribute.

Although HSX holds tremendous potential for advancing technological progress, promoting social prosperity, and enhancing social welfare (Pine & Gilmore, 2019; 谢莹 et al., 2021), its formation mechanisms and effects remain unclear and require further investigation. Currently, AI technology has been widely applied

Figure 1

Figure 1: Figure 1

across industries, particularly in intelligent vehicles, healthcare, and finance, yet the specific mechanisms and evolutionary patterns of HSX remain ambiguous, and how to maximize its utility has not been adequately explored. Meanwhile, the dual nature of technological development has become evident (Bankins et al., 2024; Qin et al., 2025). For example, existing research has found that Ersatz AI may threaten human agency (Madhavaram & Appan, 2025), leading to ethical 失控 (such as psychological crises caused by emotional dependence, psychological aversion, and increased dishonest behavior) (Rasoulian et al., 2023; Dang & Liu, 2024; Köbis et al., 2025). Issues such as copyright disputes and liability delineation regarding AI-generated content (Kumar et al., 2025) may also affect the healthy development of human-machine symbiosis. Therefore, human-machine symbiosis research must also seek balance between technological breakthroughs and ethical boundaries (Tuzov & Lin, 2024). Through normative design that safeguards the humanistic value orientation of intelligent systems, we can ultimately achieve coordinated development between technology and human civilization (Grewal et al., 2024; Liu & Wang, 2025).

Based on this context, this study aims to explore the formation mechanisms and functional dynamics of Human-Machine Symbiotic Experience (HSX). First, we clarify the concept and measurement framework of HSX. Second, from an emergence perspective, we reveal the formation process and evolutionary patterns of HSX. Finally, we advance empirical testing of HSX' s effects, analyzing both positive and negative outcomes it may generate while promoting the joint development of humans and machines. This research not only provides theoretical support for enterprises to develop innovative marketing strategies and intelligent applications based on HSX but also offers theoretical foundations for addressing potential risks during digital transformation.

2. Literature Review

Human-Machine Symbiotic Experience is essentially an experience centered on human-machine combinations, encompassing both individual and collective experiences. While direct research on this topic remains limited, HSX originates from human-machine combinations and is closely related to customer experience. Therefore, we draw upon the customer experience research framework to review three aspects: the concept itself, its functional principles, and its effects, identifying three major research gaps. The conceptual origin addresses what HSX is, functional principles address why and how HSX operates, and effects address the outcomes of HSX. Building upon the conceptual foundation, we further examine the role of HSX (agentic role/communal role) and valence issues (positive/negative), as illustrated in Figure 1

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Figure 1. Research Gaps and Integrative Framework for Human-Machine Symbiotic Experience

2.1 The Origin of Human-Machine Symbiotic Experience

Although specialized research on HSX is still lacking, insights can be gleaned from studies on human-machine symbiosis in marketing and the conceptual origins of HSX.

2.1.1 Research on Human-Machine Symbiosis in Marketing As early as 1960, Licklider proposed the concept of "human-machine symbiosis," using a biological analogy to describe the tight integration, collaborative work, and real-time interactive problem-solving between humans and intelligent machines. This concept has become increasingly prevalent in contemporary human-computer interaction research (Jarrahi, 2018; Wang et al., 2019; Inga et al., 2023), though its multifaceted connotations require further deepening through interdisciplinary collaboration (Rahwan et al., 2019). From the human-machine symbiosis perspective, marketing as a discipline has acquired new characteristics. First, the boundaries of market actors have become increasingly blurred, making demand-side identities difficult to identify and leading to diversified marketing subjects (Marion et al., 2015; Faraj et al., 2016). Second, the status of demand-side actors has risen as they gain access to more information channels, facilitating peer-to-peer communication (Edelman & Singer, 2015). Third, supply-demand relationships have shifted from "persuaders" and "consumers" to value co-creators (Jitpaiboon, 2013). The breakthrough in marketing disciplinary boundaries manifests as its deep integration with digital technology, machine intelligence, and social sciences, driving a paradigm reconstruction. Recent research has begun focusing on how to better integrate service robots into consumer lives (Lu et al., 2020; Grandey & Morris, 2023; Shanks et al., 2024), extending to human-robot collaboration (Cobots), with relevant research summarized in Table 1 .

Table 1. Illustrative Definitions of Robots, Human-Robot Teams, and Human-Robot Collaboration

Concept	Definition	Application Context	Key References
Robots	Information technology embodied physically, providing customized services by autonomously executing physical and non-physical tasks	Autonomous products (cars, heaters, lawnmowers)	Jörling et al. 2019
	Artificial workers created to automate human work	Various contexts (conceptual)	Tsai et al. 2022
	Artificial devices capable of perceiving environments and purposefully acting within them; embodied AI; machines capable of autonomously completing useful work	Various contexts (conceptual)	Winfield 2012
Human-Robot Team/s	Humans and robots collaborating on tasks, sharing workspace and objects	Space missions	Hoffman & Breazeal, 2004

Concept	Definition	Application Context	Key References
	Humans and robots maintaining and jointly committing to common task goals	Research contexts	Breazeal et al. 2004
	Effective robot teammates defined as allowing humans to choose their own actions and timing during flight, dynamically predicting and adapting to these decisions, and supporting fluid interactions that feel natural to humans	Research contexts	Gombolay et al. 2015
	Combining AI agents with human team members to complete tasks	Various contexts	Mirowska & Arsenyan 2025

Concept	Definition	Application Context	Key References
Human-Robot Collaboration (Cobots)	Cobot = robot devices working collaboratively with human operators; coexisting with humans in shared workspace and performing required tasks together	Manufacturing	Pauliková et al. 2021
	The term cobot (collaborative robot) typically refers to partnership between robots and humans	Manufacturing	Javaid et al. 2022
	Cobots (from collaborative and robot) are robots designed for physical interaction with humans in shared workspace	Manufacturing	Djuric et al. 2016
	Cobots share workplace with humans without safety isolation, assisting in various tasks, suitable for small-batch production in SMEs	Manufacturing	Liu et al. 2024

Concept	Definition	Application Context	Key References
	Collaboration form where humans and cobots jointly conduct tasks combining physical or cognitive effort in shared workspace	Manufacturing	Bassi et al. 2025

Source: Compiled and supplemented based on Shanks et al. (2024)

As shown in Table 1, research on human-machine symbiosis in marketing remains at the human-robot collaboration stage, which scholars term "Cobots." However, interdisciplinary research indicates that human-machine symbiosis represents the highest level of interaction in physically coupled systems, with a developmental path progressing through: coexistence, cooperation, collaboration, and symbiosis (Inga et al., 2023). Coexistence emphasizes humans and machines existing independently in the same environment with limited interaction, primarily tool-based usage. Cooperation manifests in task-specific collaboration where roles remain independent. Collaboration involves tight coordination on goals with complementary advantages while maintaining boundaries. Symbiosis represents the most complex mode, emphasizing deep integration in cognition and emotion, achieving not only functional complementarity but also co-evolution and forming interdependent relationships. In this process, experience is considered an important dimension of symbiosis—namely, the perceptions, emotions, and reactions generated during individual interactions with intelligent technology, encompassing functional understanding, emotional responses, and satisfaction. However, existing research on experience remains human-centered, lacking clear definitions of the connotations and structure of human-machine symbiotic experience, which limits understanding of symbiosis.

Therefore, this study adopts "human-machine symbiosis" rather than "human-machine collaboration" as the research context for three reasons: first, symbiosis represents an advanced form of collaboration; second, AI has entered an accelerated development stage requiring forward-looking research; third, returning to the original intention of AI, its ultimate goal is to achieve human-machine symbiosis and harmonious development. We clarify that Human-Machine Symbiotic Experience (HSX) is not a simple sum of human experience and machine states but rather new attributes and capabilities generated during deep collaboration and evolution of a human-machine coupled system. From a perceptual perspective, it represents human subjective perception of this deep dependency and evolutionary relationship; from a functional perspective, it represents the breakthrough in capability boundaries and value leap achieved by the human-machine system through adaptive learning.

2.1.2 Conceptual Origins of Human-Machine Symbiotic Experience

1. Review of Experience-Related Concepts

Human-Machine Symbiotic Experience is both connected to and distinct from related concepts such as customer experience, customer AI experience, AI-supported customer experience, intelligent experience co-creation, online customer experience, intelligent customer experience, and technical service experience. Overall, HSX represents a deepening and extension of these various experiences. It not only includes technological support and functional applications but particularly emphasizes the long-term collaborative and reciprocal relationship between users and intelligent technology at both emotional and cognitive levels, as detailed in Table 2 .

Table 2. Distinctions and Connections Between Human-Machine Symbiotic Experience and Similar Concepts

Concept	Core Definition	Application Context	Key Characteristics	Representative Literature
Customer Experience	Overall perception and evaluation formed during user interactions with products, services, or brands	Any interaction involving products, services, or brands	Focuses on users' holistic perception, satisfaction, and expectations	Becker & Jaakkola, 2020
Customer AI Experience	AI applications in customer service primarily for improving service efficiency and quality	AI service scenarios	Focuses on functionality and effectiveness of AI technology in meeting user needs	Puntoni et al. 2021; Li et al. 2025

Concept	Core Definition	Application Context	Key Characteristics	Representative Literature
AI-Supported Customer Experience	AI-driven personalized services, recommendations, or customer interactions	AI-driven service scenarios	Emphasizes technical functionality application and service quality improvement	Ameen et al. 2020
Intelligent Experience Co-Creation	Experience process where users and intelligent technology co-create and optimize experiences; users provide feedback or data, technology optimizes based on this information	User-intelligent technology co-creation scenarios	Focuses on user participation, data feedback, and technology co-creation process	Roy et al. 2019
Online Customer Experience	User interactions with brands, products, or services in online environments, typically through websites or applications	E-commerce platforms, online service platforms	Emphasizes convenience and efficiency in virtual platform interactions, typically without deep emotional engagement	Bleier et al. 2019

Concept	Core Definition	Application Context	Key Characteristics	Representative Literature
Intelligent Customer Experience	User interactions with intelligent products, services, or systems, typically containing AI or automation technology	Smart home, intelligent customer service, etc.	Focuses on how AI or automation technology enhances user experience through functional and convenient features	任丽娜, 2021
Technical Service Experience	Experience obtained during technical support and service processes, typically including technical troubleshooting, assistance, and consulting services	Technical support environments like customer service hotlines	Focuses on efficiency of technical support and problem-solving, functional services	Prentice & Nguyen, 2020

Concept	Core Definition	Application Context	Key Characteristics	Representative Literature
Human-Machine Collaboration Experience	Cooperation between humans and machines at task level, where each leverages expertise while maintaining independence during joint task completion, emphasizing functional complementarity	Production, work scenarios, task-oriented applications like automated production lines	Emphasizes task division, cooperation efficiency, and functional complementarity	Crook, 2018
Human-Machine Symbiotic Experience	New attributes and capabilities generated through deep collaboration and co-evolution between humans and machines	Scenarios with strong emotional interaction like smart homes, service robots, intelligent medical assistants	Emphasizes emotional integration, cognitive interaction, co-evolution, and mutual dependency	This Study

In summary, although related research has begun exploring experiences resulting from human-machine interaction, it remains anchored in customer experience and centers on human-centric experiences while neglecting relationship-centered experiences. While some studies have examined human-machine collaboration experience, such experience is essentially task-oriented instrumental interaction, focusing on efficiency optimization and usability perception when humans and machines operate as independent entities under specific division of labor. This interaction is typically temporary and functional, with human and machine attributes remaining unchanged after interaction ends. In contrast, human-machine symbiotic experience is relationship-oriented systemic emergence that transcends functional coordination, emphasizing co-evolution through deep coupling and mutual dependency. In symbiotic relationships, machines change algorithmic logic by learning human preferences, while humans expand cognitive boundaries by adapting to machine capabilities, resulting in "ontological changes" for both parties during interaction. Its core lies in the "human-machine integration" enhancement and new capability leaps of the combined system that emerge after blurring subject boundaries. Furthermore, extensive marketing practice demonstrates that with the rapid development of generative AI, human-AI interactions will involve higher emotional connections and more autonomous, automatic human behavioral characteristics (Zhou et al., 2025). Particularly in the context of human-machine symbiosis, machine experience has gradually attracted scholarly attention (Hoffman & Novak, 2018; Novak & Hoffman, 2023; Balaji et al., 2025).

However, it must be emphasized that "machine experience" in this study belongs to a functional perspective. It does not refer to machines possessing human-like "subjective consciousness" or "emotional feelings," but rather to the system states, feedback logic, and adaptive evolution processes exhibited by machines during human interaction based on algorithms, sensor inputs, and model updates.

2. Human-Machine Assemblage Experience

Human-machine assemblage experience is a relatively complex concept. Compared to human-centered experience constructs, it emphasizes not only human subjective feelings but also the independent experiences of non-human objects (such as machines). Based on assemblage theory and object-oriented ontology, this concept defines consumer experience through emergent attributes, capabilities, and roles in interaction within the consumer-object assemblage context (Hoffman & Novak, 2018). It proposes four experience types: enabling experiences (self-extension and self-expansion) and constraining experiences (self-restriction and self-reduction).

Traditional human-centered experience primarily involves consumers' internal responses to non-human objects, whereas in human-machine assemblage experience, consumers can actively interact with intelligent objects (Vaccaro et al., 2024). Therefore, human-machine assemblage experience involves bidirectional human-machine interaction and distinguishes types and levels of experience.

(1) Roles in Assemblage Experience

Within the assemblage experience framework, communal role and agentic role describe the roles consumers play in interactions with intelligent objects. These roles reflect consumers' behavioral tendencies and the nature of interactions during engagement (Hoffman & Novak, 2018).

- **Communal Role** refers to consumers' tendency to establish connections, cooperate, and share with others or objects during interaction. This role emphasizes the relationship and sense of community between consumers and interaction objects. In communal roles, consumers tend toward cooperation and sharing, relationship building, and establishing common ground.
- **Agentic Role** refers to consumers' tendency to act independently, autonomously, and with control during interaction. This role emphasizes consumers' proactivity and control in interactions. In agentic roles, consumers tend toward independent action, autonomous decision-making, and control and influence.

In actual interactions, these two roles are not oppositional but complementary. Consumers may maintain autonomy during cooperation while also considering collaboration during independent actions. Role interactions enrich the diversity of experiences and behaviors, encompassing both shared cooperation and autonomous action.

(2) Types of Assemblage Experience

Based on the roles consumers play in human-computer interaction experiences, Hoffman and Novak (2018) proposed an assemblage theory framework of enabling and constraining experiences (see Figure 2 [FIGURE:2]) to understand types of assemblage experiences. In the consumer-object assemblage context, experiences include two major categories—enabling and constraining—each further divided into subcategories: enabling includes self-extension and self-expansion, while constraining includes self-restriction and self-reduction.

Source: Adapted from Hoffman & Novak (2018)

Figure 2. Assemblage Theory Framework of Enabling and Constraining Experiences

- **Self-Extension:** Consumers inject their capabilities into intelligent objects through interaction, expanding their scope of action (agentic role).
- **Self-Expansion:** Consumers absorb the object' s capabilities, thereby expanding their identity and capabilities (communal role).
- **Self-Restriction:** Consumers constrain the object' s capabilities, narrowing its behavioral scope (agentic role).
- **Self-Reduction:** Consumers accept limitations during interaction, resulting in restricted personal action (communal role).

This framework emphasizes that human-machine symbiotic experience is not unidirectional perception but mutual shaping during interaction, with assemblage theory providing its foundation.

(3) Levels of Experience

Experience possesses three levels (Hoffman & Novak, 2018):

- **Basic Experience:** The lowest level, manifested as pattern recognition capability. Intelligent objects rely on machine learning for pattern recognition and thus possess basic experience.
- **Perceptual Experience:** The recognition, organization, and processing of inputs, serving as a filter for basic experience. Intelligent objects' perceptual experience represents their signal capture and feature extraction capabilities, reflecting strategic emergence and feedback output. Both humans and intelligent objects possess this capability.
- **Conscious Experience:** Subjective experience generated through the integration of recognition, organization, and attention, representing an emergent outcome. While intelligent objects do not possess subjective experience, their data-based feedback and adaptive processes can exhibit machine functional states analogous to human subjective experience under certain conditions.

Therefore, human-machine assemblage experience can be viewed as a dynamically emergent system. However, this research remains at the conceptual definition and principle exploration stage, lacking details on how consumer-intelligent object interactions occur, without in-depth investigation into how such interactions form experiences, and without revealing the influencing factors, formation processes, mediating mechanisms, and effects of this experience. On the other hand, the exploration of experience levels in assemblage theory provides important reference for our attention to the dynamic, emergent aspects of experience levels. Yet these studies remain at the stage of conceptual discussion and future research direction proposals. Questions remain regarding what impacts the consideration of intelligent objects and their assemblage experiences will have on consumers and other intelligent objects, how these impacts operate, what the outcomes are, and how to leverage positive results while avoiding negative ones—all requiring in-depth investigation.

(4) Distinctions and Connections Among Human, Machine, and Human-Machine Assemblage Experiences

The distinctions and connections among the three can be summarized in Table 3 :

- **Experience Subject:** Human experience centers on individuals, machine experience centers on intelligent objects, while human-machine assemblage experience results from their interaction.
- **Experience Source:** Human experience derives from senses, emotions, and cognition; machine experience originates from algorithms and sensors; human-machine assemblage experience stems from new attributes and capabilities generated through interaction.
- **Experience Nature:** Human experience is subjective feeling based on consciousness and emotion; machine experience is based on rules and logic; human-machine assemblage experience integrates both, forming composite experience.

Compared to single experiences, human-machine assemblage experience offers three advantages: (1) greater interactivity, helping reveal human-machine symbiotic relationships; (2) human-machine complementarity, combining human emotion with machine logic; and (3) real-time feedback and adaptability, involving both individual and collective experiences.

Table 3. Distinctions and Connections Among Human, Machine, and Human-Machine Assemblage Experiences

Dimension	Human Experience	Machine Experience	Human-Machine Assemblage Experience
Experience Subject	Individual	Intelligent objects	Interaction outcome
Experience Source	Senses, emotions, cognition	Algorithms, sensors	New attributes from interaction
Experience Nature	Subjective based on consciousness/emotion	Rule/logic-based response	Composite integrating both
Key References	Becker & Jaakkola, 2020; Gray & Wegner, 2012; Gray et al. 2011; 陈多闻 and 汪姿君, 2023	Hoffman & Novak, 2018; Inga et al. 2023; 邓士昌 et al., 2022	Hoffman & Novak, 2018; Inga et al. 2023; 邓士昌 et al., 2022

3. Collective Experience

With the development of service-dominant logic, scholars have begun focusing on collective experiences beyond the individual level. Hollebeek et al. (2023) propose that stakeholder journeys consist of role-related touchpoints and activity trajectories, where stakeholders shape experiences with enterprises through integration and co-creation, thereby enhancing relationship management and performance. Becker et al. (2023) note that many marketing phenomena involve collective experiences of families, teams, or corporate clients, yet existing research remains biased toward individual perspectives, inadequately explaining group-level interactions. With the rise of digital platforms, individual experiences gradually transition to collective experiences, making multi-actor platform customer experience a new focus. Mahadevan and Shainesh (2024) argue that traditional research often relies on linear business contexts, neglecting the complexity of multi-actor platforms. From a value co-creation perspective, they propose a customer experience framework in platform environments, revealing key differences between platforms and linear businesses and emerging drivers of platform touchpoints.

Therefore, this study posits that beyond micro-level individual experiences, HSX also encompasses enterprise-level and societal-level collective experiences. At the enterprise level, we examine experience hierarchies during individual interactions with multiple machines or machine systems, such as in smart home environments. Through system model construction, we analyze how synergistic effects among different devices influence experience. For example, in smart home environments, the interactive coordination among smart speakers, lighting systems, and temperature control systems affects users' comprehensive experience. Research can analyze how device coordination enhances or diminishes user experience through system models. By constructing integrated experience models, we analyze whether individual experiences exhibit new levels or patterns when multiple devices or systems work together. At the macro societal level, we examine collective interactions with machine systems, focusing on how collective behavior influences machine system operations and, conversely, how machine systems shape collective behavior. Social Network Analysis (SNA) can be employed to explore how collective behavior affects machine system interactions. By constructing collective behavior models, we study behavioral patterns of individuals interacting with machine systems in collective environments (such as communities or enterprises). For instance, in smart cities or industrial internet contexts, we investigate how communities or enterprises collectively participate in intelligent systems through shared data and collaborative platforms.

In summary, this study treats machines as systems with functional agency. Therefore, machine experience does not refer to subjective consciousness but rather to the feedback loop states presented by systems through recursive computation during complex interactions, serving as the digital-intelligent foundation for realizing human-machine symbiotic emergence. Related concepts of experience establish the research foundation for clarifying connotations and structures at the individual level. Stakeholder/participant-centered customer experience provides reference for transitioning from single individual experience research to collective experience research (such as community experience) composed of multiple individuals, laying theoretical groundwork for this study' s investigation of HSX formation from a digital ecosystem perspective and understanding how interactions among participants influence user experience. However, such research remains at the conceptual discussion stage and has not considered machine and human-machine assemblage experiences.

2.2 Relevant Theories on HSX Formation

Three major theoretical perspectives for studying customer experience are relevant to this research: assemblage theory, emergence theory, and spiral theory, each discussed below.

2.2.1 Assemblage Theory Assemblage theory originates from speculative realist philosophy, emphasizing that objects possess ontological properties and challenging human-centered perspectives. This theory posits that human and non-human actors form stable or unstable structures during interaction, whose attributes and capabilities cannot be reduced to the sum of parts or relationships but represent emergent holistic functions (Bogost, 2012; Bryant, 2011). In this study, assemblage theory provides the theoretical foundation for understanding the roles, capabilities, and emergent attributes of consumers and intelligent objects in human-machine interaction.

2.2.2 Emergence Theory Emergence theory describes how holistic properties in complex systems arise through interactions among constituent elements (Vargo & Peters, 2023). Its core arguments include three aspects:

- **Concept:** Emergence refers to new wholes generated through element interactions that transcend the sum of parts (Capra & Luisi, 2014). In marketing systems, customer experience can be reduced to measurable variables or viewed as an emergent process requiring observation of system logic to reveal new attributes of HSX.
- **Hierarchy:** Emergence involves upward causation (higher-order properties depend on lower-order elements) and downward causation (higher-order properties react upon lower-order elements) (McLaughlin, 2008). In human-machine symbiosis, individual behavior, system structure, and technological innovation all reflect this self-organizing and adaptive process (Arthur, 1999).
- **Marketing Application:** As markets shift from value chain-oriented to system-oriented perspectives, marketing systems are viewed as complex adaptive systems (Barile & Polese, 2010; Vargo & Lusch, 2016). Core phenomena such as customer experience, innovation, value, and brand meaning are emergent results of dynamic interactions. Emergence theory can explain the multi-level formation of HSX and its expansion from individual to collective experience.

Hoffman and Novak (2018) note that experience is emergent, involving multiple levels from basic experience to perceptual experience to conscious experience. However, they do not explain how experience emerges or the relationship between experience levels and emergence stages. The concept of emergence and the emergent process based on multi-actor service ecosystems in emergence theory demonstrate a process from singular to plural, from unconscious to conscious change. This provides theoretical foundation for studying HSX' s multi-level formation as a dynamic, interactive emergent process, opening the dynamic formation mechanism of HSX, revealing correspondences between emergence stages and experience levels, and extending experience from individual to collective levels.

2.2.3 Spiral Theory Spiral theory examines dynamic relationships of mutual causation between variables (Kraemer et al., 2020), suitable for analyzing long-term interactions between HSX and outcomes. Its three principles are:

- **Feedback Loops:** Variables form positive or negative causal cycles that produce dynamic impacts over time.
- **Change Precedes Absolute Level:** The rate and direction of variable change have greater impact on downstream variables than absolute levels (Chen et al., 2011).
- **Upper and Lower Boundaries:** Spiral changes are controlled by upper and lower limits, preventing infinite growth or decline.

Based on spiral theory, we can explore positive or negative cycles of HSX over time, such as experience gain spirals or loss spirals, and investigate how moderating mechanisms (such as human-machine harmonious relationships) influence spiral direction. Additionally, new technologies (AI, virtual/augmented reality, IoT) may trigger new experience types, with experience types, object characteristics, service categories, and customer personality all potentially influencing spiral mechanisms and their effects.

In summary, assemblage theory provides the foundation for understanding multi-actor, multi-attribute emergence in human-machine interaction; emergence theory explains the dynamic formation of experience from individual to system levels; and spiral theory reveals the interactive cycles between experience and outcomes over time. The combination of these three theories provides theoretical support for studying HSX' s formation mechanisms, experience levels, and effects.

2.3 Research on HSX Mechanisms and Effects

With the proliferation of digital platforms and artificial intelligence, customer experience research exhibits three major trends: transformation from traditional marketing to digital-intelligent marketing; shift from single-individual experience to multi-actor collective experience; and transition from single-type experience to multi-type experience combinations. Existing research primarily draws upon social exchange theory, situated cognition theory, service-dominant logic, value co-creation theory, and information processing theory. With the development of intelligent technology, scholars have begun employing anthropomorphism theory, interaction experience theory, and assemblage theory to study customer experience formation mechanisms, providing theoretical foundations for systematic HSX research.

Influencing factors of customer experience primarily include service quality, brand and retail stimuli, customer expected experience, marketing agility, platform and technological stimuli, and environmental and organizational factors (Becker & Jaakkola, 2020; Mahadevan & Shainesh, 2024). Previous research typically focused on single factors, while emerging studies indicate that combined effects of multi-source stimuli better reflect real experiences. Particularly in intelligent contexts, customer experience is influenced by interactive effects of technological, organizational, and environmental factors, moderated by customer characteristics, contexts, and cultural environments.

Mediators of customer experience include cognition, emotion, social interaction, behavior, senses, intelligence, spirit, brand attitude, and service capability, such as experiential value, service capability enhancement, and social rapport with anthropomorphized robots (Ameen et al., 2020; Bleier et al., 2019; 牟宇鹏 et al., 2019; 滕乐法 et al., 2020; 沈鹏熠 et al., 2021). Moderators involve product types, service contexts, relationship types, customer characteristics, participation levels, brand interaction, perceived costs, customer orientation, economic conditions, and moral identity (Becker & Jaakkola, 2020; Liu-Thompkins & Okazaki, 2022). Experience outcomes mainly include satisfaction, loyalty, word-of-mouth, purchase behavior, customer lifetime value, perceived quality, and service performance (Brakus et al., 2009; Chandler & Lusch, 2015; De Keyser et al., 2020; Cova, 2021). Different types of customer experiences produce different attitudinal and behavioral outcomes through mediating and moderating mechanisms, such as Benetton' s "No Hate" campaign influencing customer reactions through emotional and cognitive stimuli.

Based on this, this study will systematically explore HSX formation mechanisms, differential effects, and boundary conditions by integrating user, machine, and environmental factors within the intelligent context, providing guidance for practice.

2.4 Summary

Through the above analysis of research status and development trends, three major questions regarding HSX remain: Question 1: What is the origin of HSX? Including issues of connotation, type, structure, and measurement; Question 2: How is HSX formed? Including sub-questions of whether HSX is emergent, what levels it possesses, and what its formation mechanisms are; Question 3: What are the mechanisms and effects of HSX? Including influencing factors, differential outcomes, and mediating mechanisms.

3. Research Framework

Considering new problems arising from incorporating non-human actors and their assemblage experiences, this research will first clarify the origin of the Human-Machine Symbiotic Experience (HSX) concept (including connotation, structure, type, dimensions, and measurement). Building upon this foundation, we will concentrate on exploring HSX' s influencing factors and formation processes, as well as its effects and mechanisms. To this end, we design three progressive studies, as illustrated in Figure 3 [FIGURE:3], specifically:

Study 1: Based on comprehensive analysis of HSX' s connotation, structure, and measurement, this study clarifies HSX' s core characteristics, experiential structure, and feasible measurement approaches.

Study 2: Building upon clarified connotation, structure, and measurement, this study employs emergence theory to elucidate the multi-level, multi-stage, multi-mode formation mechanisms of HSX.

Study 3: This study reveals HSX' s mechanisms and effects by (1) uncovering mediating mechanisms underlying differential HSX formation; (2) analyzing different valence outcomes produced by different HSX types; and (3) exploring potential boundaries of HSX mechanisms to provide systematic solutions for achieving optimal HSX.

Figure 3. Research Framework for HSX Formation Mechanisms and Effects

3.1 Study 1: Origin of Human-Machine Symbiotic Experience (HSX) from an Assemblage Perspective

Study 1 focuses on in-depth research into HSX' s core characteristics and measurement, specifically including: (1) HSX's connotation and its distinctions from and connections with similar concepts; (2) HSX' s connotation and structure; and (3) HSX measurement, as detailed in Figure 4 [FIGURE:4].

Figure 4. Origin of Human-Machine Symbiotic Experience (HSX) from an Assemblage Perspective

3.1.1 HSX Connotation and Distinctions from Similar Concepts

Building upon clarified HSX connotation, this study identifies distinctions and connections between HSX and related concepts including customer experience, customer AI experience, AI-supported customer experience, intelligent experience co-creation, online customer experience, intelligent customer experience, and technical service experience (see left side of Figure 4). For example, regarding customer experience versus HSX: traditional customer experience involves users evaluating functions and usage experiences of smart home devices after purchase; HSX emerges from long-term user-device interactions where intelligent systems gradually learn user preferences and provide personalized services, forming emotional connections and cognitive feedback. Regarding customer AI experience versus HSX: customer AI experience focuses on functional interactions between users and AI, such as AI recommendation systems providing personalized suggestions based on user behavior; HSX involves deeper interactions where AI systems not only provide recommendations but also establish continuous emotional interactions with users, forming partnership-like collaborations. Regarding intelligent experience co-creation versus HSX: in intelligent experience co-creation, users and intelligent systems jointly create and optimize experiences, such as user feedback helping AI continuously improve service in AI customer service; in HSX, user-intelligent system interactions extend beyond feedback to include emotional and cognitive symbiosis.

3.1.2 Structural Presuppositions of HSX Based on the literature review, unlike previous research emphasizing humans as active "actors" and machines as passive "assistants," this study will discuss HSX based on assemblage theory from a "human-machine assemblage-centered" perspective. This approach emphasizes that humans and machines possess equal agency, interacting and shaping each other within networks without absolute dominance. This indicates that human-machine interactions can be complementary or mutually influential. Human experience originates from subjective judgment, including five dimensions: cognition, emotion, body, senses, and social interaction. Machine experience does not refer to human-like "subjective consciousness" or "emotional feelings" but rather to system states, feedback logic, and adaptive evolution processes exhibited by machines during human interaction based on algorithms, sensor inputs, and model updates—representing machine operational states and responses rather than subjective conscious experience.

To further solidify the analytical foundation of human-machine interaction, this study introduces Actor-Network Theory (ANT) as core theoretical support. Its central principle of "generalized symmetry" demonstrates high compatibility with this HSX research. Specifically, ANT' s generalized symmetry principle breaks the traditional binary opposition of "humans as dominant, non-humans as objects," 主张 that human and non-human actors possess equal agency within networks, mutually shaping and co-constructing network forms and operational logic through interaction (Latour, 1987; 1996). This principle precisely aligns with this study' s core presupposition of "equal human-machine interaction" —in HSX scenarios, humans are not sole dominants, nor are machines passive tools, but rather equal actors participating in interaction processes. Machines' operational states and response logic directly influence the generation of human experience, while human behavioral feedback conversely drives machines' adaptive evolution, forming a bidirectional shaping interaction relationship.

From the ANT perspective, the "experience" of machines defined in this study essentially represents the core agency manifestation of machines as symmetrical actors, specifically expressed as data flow and processing trajectories (Hoffman & Novak, 2018): machines capture human behavioral data (such as actions, voice, physiological signals) through sensors, generate response strategies through algorithmic processing, and feedback to humans through actuators. This complete data processing and feedback loop constitutes the "action path" of machines participating in human-machine interaction, representing the "experience" manifestation at the machine level. Based on this, HSX is not a simple superposition of human subjective experience and machine functional states but rather the result of deep coupling between the two as symmetrical actors—human subjective experience (cognition, emotion, etc.) adjusts based on machine responsive behaviors, while machine operational states and response logic optimize based on human feedback data. This bidirectional interaction ultimately generates symbiotic experiences with deeply coupled attributes between "human subjective experience" and "machine functional state." In conclusion, unlike individual human experience or separate machine operational states, HSX originates from human-machine interaction and its generated new attributes and capabilities, representing human subjective experience of human-machine symbiotic relationships, roughly divisible into extension experiences and expansion experiences.

This component primarily involves qualitative research: using qualitative methods to preliminarily explore (a) HSX' s core characteristics and (b) HSX' s structure, then developing corresponding interview protocols and conducting in-depth interviews based on these research objectives.

3.1.3 Development of HSX Measurement Scales Based on the above qualitative research, quantitative research is needed to supplement qualitative findings and avoid 偶然性和不稳定性 from small interview samples. The quantitative component will further advance empirical research on HSX, particularly measurement of the machine dimension. Specifically, machine dimension measurement indicators will focus on "algorithmic response consistency," "interaction feedback precision," and "system learning evolution speed," rather than measuring machine emotions. This design will help better capture machines' functional performance during interaction, providing more stable and reliable empirical support for comprehensive HSX understanding.

(a) By combining reference to existing scales with self-developed scales, we will create HSX questionnaires to survey more participants and further explore HSX' s structure. This research component involves exploring and validating the HSX structure derived in section (2), specifically including two parts (see lower middle portion of Figure 4):

- **Exploratory Factor Analysis:** Employing principal component factor analysis to derive several ideal factor models composed of HSX measurement factors and corresponding items.
- **Confirmatory Factor Analysis:** Conducting confirmatory factor analysis on the derived ideal models and selecting the optimal model through comparison.

(b) Since assemblage experience constitutes a spatiotemporal network of interacting experiential factors, network analysis methods can be employed to assess HSX intensity or density through indicators such as network centrality, density, and connectivity (Tononi & Koch, 2015; Novak & Hoffman, 2023).

(c) Machine learning approaches can also be used to engineer HSX, combining multiple data types and algorithmic models to analyze and model multidimensional data including user behavior, emotional responses, and cognitive evaluations. This helps quantify and understand different layers of HSX. Machine learning can not only provide precise measurement of existing experiences but also predict future experience trends, offering theoretical support and practical guidance for further optimizing human-computer interaction design.

3.2 Study 2: Formation Mechanisms of HSX Based on Emergence Theory

Study 2 investigates how HSX is formed. Existing research suggests user experience is emergent (e.g., Thompson et al., 1989), distinct from products and other components interacting with participants (Lemon & Verhoef, 2016). Emergent user experience is both holistic (Verhoef et al., 2009) and multidimensional. However, we remain unclear about how HSX emerges, with emergence processes and mechanisms still ambiguous. Additionally, research has found that experience possesses multiple levels. For example, Hoffman and Novak (2018) divide experience into three distinct levels from basic to perceptual to conscious experience. Therefore, this research component primarily includes three aspects (see Figure 5 [FIGURE:5]).

Figure 5. Formation Mechanisms of Human-Machine Symbiotic Experience

3.2.1 Value Emergence Cycle Process of Human-Machine Symbiotic Systems This component aims to reveal the experiential value emergence cycle process of human-machine symbiotic systems. Integrating emergence theory, we reveal how HSX emerges from interactions in complex and dynamic environments. Drawing upon Inga et al. (2023) and considering that IQ determines cognitive and technical effectiveness in human-machine collaboration while EQ promotes emotional connection and interaction depth (张小军, 2023), jointly influencing experience quality and sustainability, we explore HSX emergence processes along IQ dimensions (symbiotic understanding, prediction, and execution) and EQ dimensions (symbiotic understanding, prediction, and negotiation). This involves not only single-stage emergence but also a progressive, spiral ascent from quantitative change (emergence stage) to qualitative change (emergence node) to new quantitative change (new emergence starting point).

Specifically, this process involves a logic shift from value co-creation to value emergence, representing a new evolution of value creation in the AI era with human-machine symbiotic systems as carriers. We argue that human-machine symbiotic complex adaptive systems constitute emergent phenomena based on human-machine equal participation, featuring self-organization, self-adaptation, non-linearity, and participant-generated institutional logic (Vargo & Lusch, 2016; 许晖 et al., 2024). The focus is on the complexity of value creation in human-machine symbiotic systems. On one hand, as a complex adaptive system, the value of human-machine symbiotic ecosystems emerges from nonlinear interactions among equal-participation subsystems (human actors and machine actors), enabling dynamic selection and adaptation of resources and participants within the system. Second, the emergent nature of human-machine system value creation. Existing value co-creation theory posits that value is a unique phenomenological experience determined by beneficiaries during product or service "use" (Vargo & Lusch, 2016), a concept consistently human-centered. However, the emergent value in this component represents a system-level new resource where value becomes a system-level emergent property jointly determined by both human and machine, heralding the emergence of new capabilities in human-machine assemblages.

3.2.2 Actor Expansion and Scope Evolution of HSX Beyond single-user experiences, millions of household-level consumer assemblages interacting with their respective intelligent objects collectively define macro-users, macro-objects, and macro-user-object assemblages that cannot be reduced to their individual parts. For example, through cloud-based machine learning, Cloud Alexa tightly integrates experiences from millions of users. While individual users have their own experiences, do millions of users possess corresponding collective experiences? Therefore, this research component investigates the actor expansion from individual experience to collective experience and the scope evolution process of human-machine assemblages. We correspond emergence stages with emergent experience levels, then expand HSX from individual experience to collective experience based on experience actors (such as macro-experiences generated by macro-users or macro-machines and macro-user-machine assemblages, or experience networks formed based on user collectives or user-object collectives). The focus is on experience actor expansion.

This includes three aspects:

- **Micro Level:** Examining experience levels when individuals interact with single machines, such as perception, cognition, emotion, and behavior. Constructing a multi-level model from perception to behavior to analyze emergence characteristics at each level.
- **Meso Level:** Examining experience levels when individuals interact with multiple machines or machine systems, such as in smart home environments. Through system model construction, analyzing how synergistic effects among different devices influence experience.
- **Macro Level:** Examining experience levels when collectives (such as communities or enterprises) interact with machine systems, such as in smart cities or industrial internet contexts (Li et al., 2025). Constructing macro models to analyze interactive relationships between collective behavior and machine systems.

3.2.3 HSX Pattern Development Paths and Experience Gaps This component addresses two aspects: pattern matching of HSX and exploration of experience gaps.

1. HSX Patterns

From an assemblage theory perspective, pattern matching corresponds to the paired capacities through which two entities mutually influence and interact (DeLanda, 2011; 2016). As emergent results of exercising paired capacities, HSX involves not only humans but also non-human machines. Only when both achieve relatively balanced matching can HSX emerge; imbalance may reveal the dark side of HSX, such as self-restriction or self-reduction. According to the three emergence stages of HSX, three human-machine symbiotic patterns can be distinguished.

- **Pattern One Stage:** No interaction process exists in human-machine symbiotic patterns, possibly following a unidirectional-passive symbiotic model.
- **Pattern Two Stage:** Interactive behaviors begin to emerge in human-machine symbiotic patterns, following a bidirectional-passive symbiotic interaction model.
- **Pattern Three Stage:** Interaction evolution enters autonomous fusion stage, following bidirectional-active symbiotic logic. In this advanced form, HSX no longer relies on explicit command transmission but is built upon deep 契合 of bidirectional functional agency between human and machine. At this stage, the machine side achieves deep prediction of environment and user intentions through high-level adaptive algorithms, while the human side expands cognitive boundaries through internalization of technological capabilities. This pattern represents the advanced level of HSX in terms of system integration and co-evolution, demonstrating the deep resonance state achieved by human-machine systems through intention alignment and functional coupling in complex contexts. In this form, the human-machine assemblage exhibits strong emergent characteristics, achieving a substantive leap from tool assistance to actor symbiosis. Therefore, we argue that HSX formation process research should also include human-machine matching as an important component.

2. Experience Gap

Experience Gap refers to discontinuities or mismatches in HSX during the transition from human-centered to human-machine assemblage-centered perspectives. This gap primarily manifests during the transition from Pattern Two (bidirectional-passive symbiotic interaction) to Pattern Three (bidirectional-active symbiotic model). During this stage, machines gradually transform from simple executors to learners with functional adaptive systems, while human users need to adapt to this new interaction mode. Components of the experience gap include:

- **Cognitive Gap:** As machine autonomy and complexity increase, users may face increased cognitive load when interacting with machines, particularly during machine adaptive adjustments, leading to confusion or maladaptation regarding machine responses and behaviors.
- **Emotional Gap:** When machines become more anthropomorphized or possess higher adaptability, users may feel emotional mismatch or discomfort, particularly when machine behaviors deviate from user expectations, potentially leading to distrust or emotional rejection.
- **Behavioral Gap:** Users' understanding and adaptation of machine behaviors may lag behind machine self-learning and behavioral evolution, resulting in decreased interaction efficiency.

Therefore, this research component is divided into three sub-components: (1) matching and evolution of human-machine symbiotic patterns; (2) in-depth exploration of experience gap formation factors and impacts; (3) exploration of strategies and methods for bridging experience gaps.

3.3 Study 3: Mechanisms and Effects of HSX

This component empirically examines HSX formation mechanisms to validate measurement tools provided in Study 1 and dynamic emergence processes discovered in Study 2, and further explores its effects on users, enterprises, and society as well as potential boundary conditions. It can be divided into four aspects: HSX influencing factors, HSX mechanisms, HSX effects, and HSX moderation (see Figure 6 [FIGURE:6]), primarily addressing three components: HSX influencing factors, HSX mechanisms, and HSX boundaries.

Figure 6. Mechanisms and Effects of Human-Machine Symbiotic Experience

3.3.1 Influencing Factors of HSX Extensive customer experience research indicates that environmental factors (such as social and market environments) and organization-related factors (such as social interaction and institutions) influence experience (Mahadevan & Shainesh, 2024; Becker et al., 2023). Based on literature review and considering the importance of technological factors in HSX contexts, we argue that differences in roles played by technology (e.g., mechanical AI, thinking AI, or feeling AI) and acceptance of machines (Huang & Rust, 2021; Inga et al., 2023) affect experiential outcomes. Therefore, this component will identify three categories of drivers for HSX (technological conditions, organizational conditions, and environmental conditions) based on the TOE Framework (Technology-Organization-Environment Framework) and investigate behavioral outcomes of these structures. We can adopt the method from Wolter & Cronin (2016), using cross-sectional surveys. Following relevant protocols, survey respondents will be asked to recall a memorable HSX episode, which will then be incorporated into subsequent questions. This approach enables investigation of correspondences between HSX stimuli, HSX dimensions, and behavioral outcomes, extending HSX results from individual to collective experience through two research paths:

- **Path 1:** Construct relevant theoretical models using single-type conditional variables for structural equation modeling to examine how specific influencing factors affect HSX types and dimensions. Based on this, we propose:

  Research Proposition 1a: User, machine, and contextual factors positively/negatively influence HSX.

- **Path 2:** Employ fsQCA (fuzzy-set Qualitative Comparative Analysis) to identify differentiated configurational paths that facilitate HSX by examining configurational effects of all types of influencing factors on HSX types and dimensions. Based on this, we propose:

Research Proposition 1b: Different combinations of user, machine, and contextual factors help shape satisfactory HSX.

- **Path 3:** Based on spiral theory, explore cyclical effects between influencing factors and HSX outcomes through longitudinal research to identify upper and lower thresholds of influence ranges, thereby more finely 刻画ing impact effects. Based on this, we propose:

  Research Proposition 1c: User, machine, and contextual factors positively/negatively influence HSX, which in turn positively/negatively influences users, machines, and environmental factors over longer periods, forming positive/negative spirals.

3.3.2 HSX Mechanisms This component primarily examines HSX formation mechanisms and effects. Given differential experience outcomes (positive/negative) in existing research, this study combines dual-system decision theory and cognitive-affective dual pathways to explore mediating mechanisms producing differential outcomes. According to dual-system decision theory (Metcalfe & Mischel, 1999; Kahneman, 2011), systems can be divided into the associative, impulsive, and autonomous "hot system," corresponding to the "flocking toward" phenomenon generated by HSX, and the rule-based, reflective, and controlled "cold system," corresponding to the "shying away" phenomenon caused by machine-related concerns. Dual-system processing better understands the cognitive and emotional mechanisms underlying differential HSX outcomes.

(1) HSX Formation Mechanism I. The "hot system" is an intuitive heuristic system that relies on intuition, operates quickly, automatically generates solutions, extracts partial information during processing, and follows associative thinking. Therefore, novel and positive HSX may promote individuals or collectives to follow associative thinking, activating the "hot system" for rapid information processing and problem-solving, gradually forming positive psychological fascination such as digital technology trust and emotional attachment, as well as positive cognitive fascination such as high technology acceptance and self-efficacy during human-machine interaction, ultimately producing positive experience outcomes. Identifying mediating mechanisms that activate the hot system to cause actor fascination is the focus of this component. Based on this, we propose:

Research Proposition 2a: Experience cues in human-machine interaction positively influence HSX through the "hot system" that causes fascination.

(2) HSX Formation Mechanism II. The "cold system" is a rational analytical processing system that results from conscious effort, relies on systematic information processing, employs algorithmic rules, operates slowly, and follows logical thinking. Therefore, fearful and concerning HSX may promote individuals or collectives to follow logical thinking for rational information processing and problem-solving, gradually forming psychological fear such as technology anxiety and emotional rumination, as well as cognitive fear caused by cognitive overload and cognitive bias, ultimately producing negative experience outcomes (Rapp et al., 2025). Identifying mediating mechanisms that activate the cold system to cause avoidance or fear is the focus of this component. Based on this, we propose:

Research Proposition 2b: Experience cues in human-machine interaction negatively influence HSX through the "cold system" that causes fear.

(3) HSX Formation Mechanism III. This component examines long-term lagged effects of HSX based on (1) and (2), investigating whether HSX will 反向作用于 mediating mechanisms and influencing factors over longer periods, forming positive or negative spirals, and exploring the upper and lower boundaries of these spirals. According to Conservation of Resources theory, for individuals with balanced resources, further resource addition may generate resource gains, forming upward resource gain spirals; for individuals experiencing resource loss, further loss may generate additional losses, forming downward resource loss spirals. Based on this, we propose:

Research Proposition 2c: Over longer periods, HSX will 反向作用于 its mediating mechanisms and influencing factors, forming positive "gain spirals" in the "hot system" and negative "loss spirals" in the "cold system."

3.3.3 HSX Effects This component aims to test the predictive validity of HSX and examine whether this complex hybrid effectively influences relevant individual and social outcomes. Over time, these influences may further affect HSX, forming spiral effects that demonstrate interactive relationships between HSX and related outcomes. Although HSX may produce numerous positive effects such as improved decision quality and enhanced emotional well-being, negative voices also exist, becoming louder as AI rapidly enters daily life. For instance, previous research reveals that regarding privacy perception, participants prefer moderate levels of linguistic anthropomorphism, while preferring high levels for emotion and functionality. This suggests that optimal anthropomorphism levels for social robots may vary depending on whether privacy information is involved (Liu et al., 2024). Accompanying moral decision-making issues also represent challenges for HSX. Research indicates that people generally reject allowing machines to make moral decisions in important domains involving life safety, law, medical care, and military affairs (Berkeley et al., 2015). Therefore, whether HSX produces differential outcomes for users or society constitutes this component's research focus. Based on this, we propose:

Research Proposition 3a: HSX produces differential outcomes for users/enterprises/society.

Furthermore, as a resource for individuals or collectives, does HSX also lead to further gains or losses due to differential outcomes in (2)? Where are the boundaries of gains or losses? Therefore, this component must also combine spiral theory with mixed-effects growth curve models to explore spiral lower boundaries. Based on this, we propose:

Research Proposition 3b: Gain spirals and loss spirals exist between HSX and differential user/enterprise/society outcomes.

We predict how initial HSX levels affect changes in positive and negative outcomes during initial periods, then add interaction terms between initial HSX and HSX changes in stage 2 models predicting positive or negative outcome changes, conducting floodlight analysis for relevant exploration.

3.3.4 HSX Boundaries This component empirically explores potential moderating variables between HSX and related outcomes, aiming to discover boundary conditions that enhance positive effects and mitigate negative impacts. Through systematic analysis of these boundary conditions, we hope to reveal dynamic variation patterns of HSX across different contexts, providing scientific foundations for optimizing AI system design and enhancing user experience. This will not only help maximize positive HSX effects but also effectively mitigate potential negative risks, promoting sustainable development of human-machine symbiosis technology. It includes two main components:

(1) Moderation of HSX Formation and Activation

Based on relevant research, we preliminarily propose a moderation mechanism research framework for HSX, as shown in the lower left of Figure 6. The moderation mechanisms for HSX formation and activation include three aspects:

- **User Internal States.** Including individual personality traits, emotional needs, cultural backgrounds, etc., these factors directly influence users' perception and response to HSX, causing differential experience outcomes. For example, user personality traits—extraversion, openness, neuroticism —affect their interaction styles and emotional investment with machines. Extraverted users may more easily establish emotional connections with machines, while introverted users may focus more on machine accuracy and efficiency in task execution.
- **Machine External Manifestations.** Referring to machines' specific physical and functional characteristics, such as appearance types, system performance, and interaction modes, these factors influence users' initial impressions and interaction experiences. Appearance types include machine form design, color schemes, interface styles, etc., which can affect users' emotional responses and identification. Anthropomorphized appearances may make users feel closer, enhancing emotional interaction quality. System performance factors such as task execution capability, response speed, and stability are crucial for user satisfaction. Efficient, stable, and responsive machines can enhance users' trust and dependence on assemblage experience. Additionally, machine interaction modes (e.g., voice recognition, haptic feedback, visual interface) significantly impact interaction fluency and acceptance of emotional feedback. Good interaction design can reduce users' cognitive load and improve assemblage experience quality.

- **Contextual Differences.** Referring to how users' cognitive and emotional responses to machines vary across different social and usage contexts, 主要包括 trust contexts and experience contexts. For example, in trust-critical domains like medical or financial contexts, machine behaviors face higher ethical and trust requirements, with users' trust in machine decisions directly affecting assemblage experience depth. Changes in trust contexts may prompt users to more cautiously evaluate machine task execution and emotional feedback (Yin et al., 2024). Experience contexts refer to varying emotional needs and task requirements in specific usage scenarios. In different contexts such as home, work, or public spaces, users' dependence on and usage patterns of machines differ, directly affecting assemblage experience outcomes. For instance, in home environments, users may focus more on emotional support and interaction provided by machines, while in work scenarios, task execution efficiency and functionality may become priorities. Different contexts require machines to flexibly adjust functions and feedback to adapt to user needs.

Based on this, we propose:

Research Proposition 4a: User internal states moderate the relationship between experience cues and emotional/cognitive processes toward machines and HSX.

Research Proposition 4b: Machine external manifestations moderate the relationship between experience cues and emotional/cognitive processes toward machines and HSX.

Research Proposition 4c: Contextual orientation differences moderate the relationship between experience cues and emotional/cognitive processes toward machines and HSX.

(2) Moderation for Promoting HSX Effectiveness

Moderation for promoting HSX effectiveness is shown in the lower right of Figure 6. In the moderation mechanisms for promoting HSX effectiveness, we primarily consider two types: enhancing experiential value and reducing experiential threat. In the moderation mechanisms between HSX and related positive/negative outcomes, enhancing experiential value and reducing experiential threat are two key moderating factors that directly influence users' overall evaluation and outcomes of HSX. These two moderating factors interact to jointly determine the effects and impacts of human-machine interaction.

- **Enhancing Experiential Value.** Aims to improve positive HSX effects, enabling users to obtain more benefits and satisfaction from experiences. Such factors can enhance overall experiential value and usage motivation by optimizing users' emotional, cognitive, and behavioral outcomes. For example, enhancing group interaction by promoting social interaction and group collaboration can not only improve individual experiential value but also drive overall social benefit enhancement, thereby strengthening positive HSX impacts and increasing social identity and participation.

- **Reducing Experiential Threat.** Aims to eliminate or mitigate negative emotions, anxiety, or distrust users may face during machine interaction, thereby reducing potential negative outcomes and avoiding negative impacts on experience. For example, as technology advances, machines increasingly collect and use personal data. Users' concerns about privacy and data security may become negative factors affecting symbiotic experience. Strengthening privacy protection and data security measures can reduce users' concerns about personal information leakage during usage, lowering emotional and cognitive threats and thereby enhancing positive assemblage experience effects. Additionally, beyond value-cost perspectives on boundary factors, whether other moderating mechanisms exist represents future research extension, such as considering experience itself (e.g., temporality and spatiality of experience). Based on this, we propose:

Research Proposition 5a: Factors enhancing experiential value moderate the relationship between HSX and relevant user/enterprise/society outcomes.

Research Proposition 5b: Factors reducing experiential threat moderate the relationship between HSX and relevant user/enterprise/society outcomes.

(3) Moderated Mediation and Mediated Moderation

Beyond the above (1) and (2), whether moderation precedes mediation or vice versa may also create differences in system operation. Therefore, this component additionally tests moderated mediation (considering moderation first, then whether moderators operate through mediators) and mediated moderation (considering mediation first, then whether mediation processes are moderated), ensuring whether system operation sequence affects mechanism functioning.

4. Theoretical Construction and Innovation

Against the backdrop of rapid AI development and the "AI+" strategy' s deepening advancement, human-machine interaction patterns are evolving from traditional human-machine collaboration to more complex Human-Machine Symbiosis (HMS) stages. In this process, the relationship between humans and intelligent agents extends beyond unidirectional "tool-user" dependency to form dynamic symbiotic relationships through deep collaboration and mutual adaptation, with Human-Machine Symbiotic Experience (HSX) as its core manifestation. While existing research has recognized AI' s application effectiveness in healthcare, manufacturing, finance, and other domains, it generally remains at the tool attribute or collaboration level, lacking systematic exploration of HSX as an emerging phenomenon. This study attempts to break through previous perspectives, conducting theoretical construction and innovation across three levels: conceptual connotation, formation mechanisms, and functional effects. The main theoretical contributions are as follows:

First, regarding research objects, unlike previous studies focusing primarily on individual user experiences, this study treats "Human-Machine Symbiotic Experience" as an independent research object, exploring its unique attributes and multidimensional connotations. Previous experience research emphasized human perception and value creation during consumption and usage processes (Pine & Gilmore, 2019) or focused on customer experience' s role in economic value (De Keyser & Kunz, 2022). However, in HSX contexts, machines not only function as tools but also exhibit autonomous attributes (Hoffman & Novak, 2018), continuously evolving through active learning and self-adaptation during interaction, thereby influencing the overall experience system' s trajectory. This study expands HSX from human-centered unidirectional perception to "human-machine-collective" multi-actor interaction, extending from individual to collective experience and from economic to social value, breaking the object boundaries of existing experience research.

Second, regarding research content, unlike previous studies focusing on AI' s impact on individual psychology or behavior (such as overcoming mental sets or improving efficiency), this study examines HSX' s emergent mechanisms and evolutionary patterns during dynamic interaction. Based on emergence theory and complex systems theory, we propose that HSX is not static but gradually emerges through dynamic synergy between intelligence quotient (information processing, logical reasoning, etc.) and emotional quotient (emotional response, social integration, etc.). Specifically, HSX exhibits "real-time-emergent-interactive-iterative" evolutionary characteristics during interaction, not only shaping human perception and behavior but also driving machines to generate new capabilities through learning and feedback. This perspective breaks traditional experience research' s linear causality assumptions, revealing HSX' s self-organizing and evolutionary characteristics, providing new pathways for understanding bidirectional empowerment in human-machine interaction.

Third, regarding research perspectives, unlike existing research focusing on one-human-one-machine scenarios, this study constructs a "multi-actor-multi-machine" collective symbiotic perspective to explore HSX' s mechanisms and boundary conditions. With the proliferation and interconnection of intelligent agents, HSX has extended from individual-single-machine interactions to collective-multi-machine complex scenarios. In this process, HSX may promote capability spiral enhancement through value co-creation and emotional coordination, but may also bring negative effects due to over-dependence or ethical risks (Madhavaram & Appan, 2025). This study proposes that the relationship between HSX and outcome variables is not unidirectional causality but exhibits double-helix effects: positive experiences can iteratively enhance interaction quality and value creation, while negative experiences may lead to trust crises and decision biases. Through longitudinal tracking and dynamic modeling, this study will theoretically deepen spiral theory' s applicability in intelligent interaction scenarios and practically reveal HSX's boundary conditions and moderating mechanisms.

Overall, this study focuses on HSX as the research object, concentrating on its conceptual construction, formation mechanisms, and functional dynamics, attempting to achieve theoretical innovation in three aspects: first, clarifying HSX's connotation and structure through multidimensional deconstruction, promoting cross-disciplinary integration between customer experience theory and assemblage theory; second, revealing HSX' s dynamic emergence and evolutionary patterns, constructing its staged evolutionary model, enriching emergence theory' s application in intelligent interaction research; third, by verifying HSX' s double-helix effects and boundary conditions, promoting cross-fusion among spiral theory, dual-system decision theory, and regulatory focus theory, ultimately constructing a theoretical system of HSX encompassing connotation, mechanisms, and boundaries. This not only responds to the practical challenges of human-machine relationship reshaping in the digital-intelligent era but also provides important theoretical support for the "AI+" strategy and enterprise intelligent transformation.

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