Self-Organization, Technodigitalization, and Complexity in University Research Training: A Model for Developing Research Competencies

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Abstract
The article aimed to develop a methodological innovation model grounded in the principles of self-organization, complexity, and technodigitalization as applied to university research literacy. The study adopted a theoretical-conceptual approach focused on the critical integration and reorganization of existing knowledge to generate new explanations of research training processes. The methodology involved reviewing, selecting, analyzing, and integrating scientific literature on epistemology, research training, methodological innovation, complexity, and technodigital transformation. The model-building process unfolded in three stages:

epistemological delimitation, conceptual integration, and theoretical formalization of its components, relationships, and organizing principles. The proposal followed an abductive logic by generating new explanatory configurations through the articulation of concepts drawn from different fields of knowledge. The findings established that research training can be understood as a dynamic, adaptive, and relational system in which epistemological, methodological, ethical, pedagogical, and technological dimensions interact. The study concludes that the proposed model represents an epistemological reconfiguration of university research development by advancing an integrative rationale aimed at knowledge construction within complex and technodigitalized contexts.

Keywords: self-organization; complexity; university research training; methodological innovation; technodigitalization.

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Introduction

Research training currently constitutes one of the foundations of university education, as it fosters critical thinking, knowledge production, and the ability to understand and address increasingly complex challenges. However, ongoing scientific, technological, and social changes reveal the limitations of classical methodological perspectives, particularly those grounded in linear and fragmented structures of knowledge. Consequently, universities face the challenge of rethinking research training processes from perspectives capable of integrating the complexity of contemporary contexts.

Within this context, technological and digital transformation has substantially changed the ways in which scientific knowledge is accessed, organized, analyzed, and communicated. The development of artificial intelligence, intensive evidence processing, collaborative platforms, and digital research ecosystems has expanded the range of inferences and conceptual articulations that researchers can derive from their objects of study, thereby opening new possibilities for scientific production. At the same time, these developments have created new demands regarding the competencies that faculty members and researchers must develop. Thus, methodological innovation can no longer be understood merely as the incorporation of technological tools; rather, it should be conceived as a process that reorganizes the ways in which researchers investigate, learn, and construct knowledge.

In parallel, complexity sciences have contributed a perspective that moves beyond traditional explanations by recognizing educational processes as open, dynamic, and interdependent systems. From this standpoint, the development of research capacities does not follow a rigid sequence of mechanisms but rather constitutes an interactive process involving components within a pentagon of dynamic convergence and transductive integration. This framework serves as a theoretical-conceptual model for organizing the conditions required to train university researchers in contexts characterized by high complexity and technological development. Self-organization consequently assumes particular relevance by explaining the capacity of systems to reorganize, adapt, and generate new operational structures without relying on external control mechanisms.

Nevertheless, despite the developments observed in this field, the theoretical corpus of the literature continues to address complexity, self-organization, and technodigitalization predominantly as independent dimensions. Few studies have brought these three factors together within a theoretical framework that enables an understanding of their interactions and their contribution to methodological innovation in the development of university research thinking. This fragmentation constrains the construction of explanatory frameworks capable of guiding the design of training strategies aligned with the current demands of higher education.

In response to this need, this article develops an integrative theoretical model that brings together self-organization, complexity, technology, and digitalization as foundations for methodological innovation in scientific training. The proposal does not seek to replace existing research designs; rather, it offers an integrative perspective that explains the relationships among its components and contributes to strengthening and understanding training processes within university environments characterized by constant change, interdisciplinarity, and the growing digitalization of research.

In this regard, the contribution of the framework lies in articulating self-organization as the dynamic principle governing the researcher's development; complexity as the epistemological foundation for understanding the construction, deconstruction, and reconstruction of knowledge; and technodigitalization as a contemporary mediating element in the processes of scientific production, validation, and communication. This articulation makes it possible to move beyond segmented approaches to the development of research capacities and proposes an integrated understanding of the processes through which researchers develop skills to respond to scientific environments characterized by uncertainty, interconnectedness, and technological transformation.

It should be noted that this article builds upon the previously published work Research Training, Faculty Technodigitalization, and Methodological Innovation (Torres-Vela et al., 2025), which established initial foundations concerning the transformation of research processes and knowledge formation. However, the present study neither reproduces nor summarizes the content of that book; instead, it constitutes a conceptual reformulation aimed at examining a specific problem in greater depth through a new structural argument, the incorporation of updated scientific literature, and the construction of a specific theoretical model. Accordingly, the article reorganizes, expands, and articulates categories previously developed, establishing new

connections among self-organization, complexity, and technodigitalization as foundations for methodological innovation in university research training.

These considerations give rise to the following central research question: How can self-organization, complexity, and technodigitalization be articulated within a theoretical model that provides a foundation for methodological innovation in university research training? Against this backdrop, the study aims to develop a theoretical model of methodological innovation grounded in self-organization, complexity, and technodigitalization to strengthen learning for inquiry in higher education. To this end, the study undertakes an interpretive conceptual construction that reorganizes and deepens theoretical contributions from epistemology, complexity sciences, educational research, and studies on digital transformation. The study thereby seeks to provide a conceptual framework that can serve as a reference for future research, curricular innovation processes, and institutional strategies aimed at strengthening research competencies.

Theoretical Framework

Research Training as a Knowledge-Building Process

The construct of research training has moved beyond the acquisition of techniques for designing and developing research projects or applying research methods. Today, it constitutes a formative process aimed at developing skills to analyze problematic situations, construct knowledge, evaluate evidence, and formulate contextually relevant solutions in dynamic settings. From this perspective, conducting research involves integrating epistemological, methodological, ethical, technological, and social dimensions that allow research to be understood as an academic praxis in continuous flux rather than as an activity limited to the preparation of a thesis or final project (Brew, 2006).

Numerous studies indicate that strengthening research competencies requires learning environments that promote reflection, interdisciplinary collaboration, and the critical use of digital technologies. Thiem et al. (2023) pointed out that research education becomes a continuous process that contributes to intellectual autonomy and the ability to respond to complex problems from different perspectives. From this standpoint, research training can be understood as a progressive process that fosters increasingly autonomous student participation in knowledge construction.

However, a large proportion of educational designs continue to rely on linear sequences and standardized procedures that restrict interaction across disciplines, limit methodological flexibility, and hinder adaptation to contexts characterized by uncertainty and continuous change. This situation highlights the need to reconsider the principles underlying the design of research training processes.

Complexity as a Foundation for Methodological Innovation

Complexity sciences provide a theoretical approach for understanding educational processes as open, dynamic systems undergoing constant transformation. From this perspective, educational phenomena can be explained through multiple interactions that generate emergent behaviors and new forms of organization rather than through linear cause-and-effect relationships (Kenny & Cirkony, 2022).

Applying complexity to research learning entails recognizing that learning to conduct research depends on the relationships established among the institutional context, previous experiences, academic interaction, technological resources, and social conditions within which the educational process unfolds, rather than solely on the acquisition of methodological knowledge. Consequently, methodological innovation requires moving beyond fragmented approaches and incorporating perspectives that foster knowledge integration and a comprehensive understanding of scientific problems.

Universities and their research training systems constitute complex environments characterized by nonlinearity, emergent behaviors, and dynamic interactions among multiple agents, including students, faculty members, and technologies (Ariza Angarita et al., 2025; Jeladze & Pata, 2018).

From this perspective, complexity represents not merely a characteristic of the object of study but also an organizing principle for designing flexible, adaptive, and interdisciplinary training models. Addressing complexity therefore requires designs that acknowledge the unpredictable and adaptive nature of learning and innovation processes while moving beyond linear or prescriptive approaches (Dvoryatkina et al., 2021; Jeladze & Pata, 2018).

Self-Organization and Learning in Open Systems

Self-organization can be understood as a process describing a system's capacity to generate new forms of organization through interactions among its own components, without relying on external control procedures. Initially developed within the physical sciences and subsequently incorporated into the social sciences, this principle helps explain how systems continuously evolve through processes of adaptation and reorganization. In systems far from equilibrium, this process may manifest through the spontaneous formation and subsequent evolution of dissipative structures (Kerner & Osipov, 1990).

Recontextualizing this perspective within education makes it possible to understand that the development of research capacities strengthens when teachers, students, and institutions participate jointly in the active construction of knowledge, thereby fostering collaborative learning, self-regulation, and the collective production of knowledge. Methodological innovation consequently moves beyond responding to rigid models and instead becomes a dynamic process that continuously adapts to contextual needs.

Furthermore, the construct of self-organization explains the capacity of educational processes to incorporate new knowledge, reorganize academic practices, and formulate innovative responses to uncertain scenarios, a particularly relevant characteristic within the current context of digital transformation. In this regard, digital tools and platforms can facilitate decentralized self-organization, enabling groups to make decisions collaboratively and flexibly within academic environments.

Accordingly, digital transformation acts as a catalyst for methodological innovation by reconfiguring knowledge acquisition, research methodologies, and institutional governance (Akperov & Martynov, 2025; Kovalchuk et al., 2025).

Consequently, self-organization constitutes a relevant principle for understanding curricular and methodological innovation in universities, as it promotes adaptive and emergent processes within research training. It can also contribute to the development of autonomy and the emergence of new educational practices through dynamics that do not depend exclusively on centralized control mechanisms (Ariza Angarita et al., 2025; Odintsova et al., 2023).

Technodigitalization and the Transformation of University Research

The incorporation of digital technologies holds significant potential, yet its impact depends on how these tools integrate into educational processes and contribute to strengthening analytical skills, critical thinking, collaborative work, and responsible scientific production; therefore, technology adoption alone does not constitute methodological innovation (Castro Benavides et al., 2020). In this sense, technodigitalization functions as an articulating factor within the research process rather than merely as a collection of technological resources. This perspective moves beyond instrumental views of digitalization by recognizing its role in transforming research training models. Technologies supported by artificial intelligence and learning analytics, for example, have expanded opportunities for information management and analysis, as well as forms of interaction among researchers, faculty members, students, and technologies throughout academic processes (Molenaar, 2022).

Technodigitalization, consequently, enables the creation of personalized, adaptive, and feedback-rich learning environments, thereby fostering self-organization and the management of complexity within research training (Dvoryatkina et al., 2021; Akperov & Martynov, 2025).

Conceptual Integration of the Proposed Model

The analysis developed in this study indicates that research competency development, self-organization, complexity, and technodigitalization do not constitute independent dimensions but rather interacting components within a single system. While complexity provides the epistemological premises for understanding the dynamic nature of the construct, self-organization explains the processes through which educational systems reorganize their

practices, and technodigitalization expands the possibilities for creating and circulating scientific knowledge.

This articulation gives rise to the theoretical model proposed in this study, which aims to provide a conceptual structure capable of integrating these components into a university-level methodological innovation framework. The development of this model appears in the following section.

Metodology

The present study adopted a theoretical-conceptual approach aimed at developing a methodological innovation model grounded in the principles of self-organization, complexity, and technodigitalization as applied to university research training. In this type of research, the primary objective involves generating new theoretical explanations through the integration, reorganization, and critical development of existing knowledge rather than subjecting hypotheses to empirical data falsification (Jaakkola, 2020).

The methodological process involved identifying, selecting, and critically analyzing scientific literature consistent with the epistemological and methodological foundations associated with the development of research skills, methodological innovation, complexity, and technodigital transformation. This sequence made it possible to examine convergences, divergences, and conceptual gaps, thereby supporting the development of a theoretically coherent proposal with explanatory capacity (Post et al., 2020).

The model configuration proceeded through conceptual synthesis, understood as a strategy for reorganizing knowledge that enables relationships to emerge among concepts previously developed across different disciplinary fields. From this perspective, conceptual research seeks to generate new explanatory configurations by integrating categories, principles, and emerging relationships rather than merely describing existing theories (Gilson & Goldberg, 2015).

The theoretical development process followed three complementary stages. The first stage involved epistemological delimitation aimed at identifying the philosophical and scientific foundations underpinning the transformation of traditional models of research-oriented educational training toward dynamic, systemic, and adaptive approaches. The second stage involved conceptual integration through the articulation of theoretical contributions from complexity theory, adaptive systems, educational innovation, and technodigital ecosystems. The third stage involved formalizing the proposed model by defining its components, relationships, and organizing principles.

The methodological logic followed a theory-building approach based on abductive reasoning, whereby explanations emerge interactively from existing concepts and the identification of new theoretical relationships capable of interpreting contemporary phenomena. From this perspective, the model does not seek to constitute a definitive representation of educational reality but rather an open conceptual architecture amenable to further development, academic debate, and subsequent exploration in applied contexts (Locke et al., 2008).

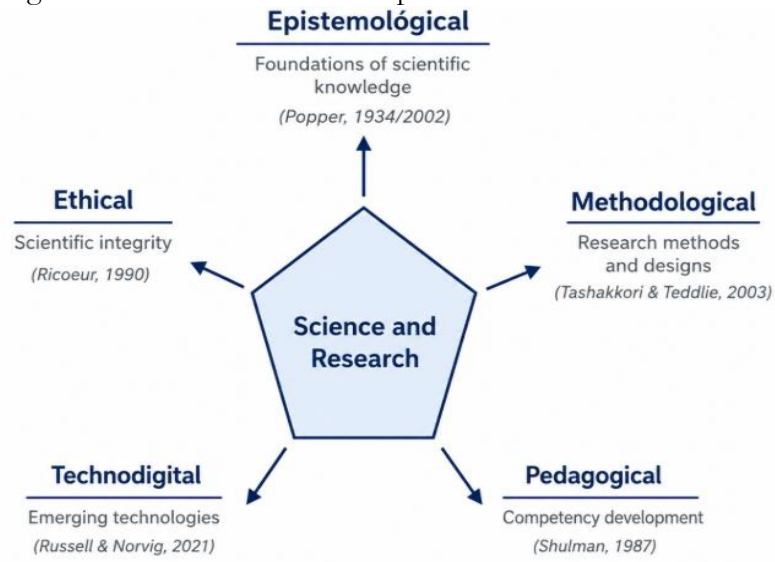
The proposal rests on an integrative approach to knowledge, through which methodological innovation emerges from interactions among subjects, technologies, information, and institutional contexts. Accordingly, the theoretical construction considers educational processes as complex systems characterized by interdependencies, feedback mechanisms, and continuous adaptive capacities rather than as linear structures (Morin, 2005; Holland, 2014).

Consequently, the methodology employed enabled the development of a conceptual model aimed at explaining how self-organization, technodigital intelligence, and complexity can contribute to redefining university research training processes. The validity of the proposal rests on its argumentative consistency, epistemological articulation, and capacity to generate new research questions, in accordance with established criteria for the construction and development of theoretical contributions in the social sciences and education (Jaakkola, 2020; Post et al., 2020).

Results

Building upon the integration of the epistemological, methodological, pedagogical, ethical, and technodigital foundations represented in the preceding pentagon, the study developed the Research Training Model Based on Self-Organization and Technodigitalization. This design proposes a reorganization of training processes through dynamic interactions among the researcher, knowledge, intelligent technologies, and the academic environment. Although these interactions already occur within university research training, they generally operate implicitly, without explicit articulation or systematic organization.

Figure 1. Multidimensional Perspective on Science and Research



Note. Relational framework of the integrative dimensions of scientific knowledge and practice. Author's own elaboration based on Popper (1934/2002), Ricoeur (1990), Russell and Norvig (2021), Shulman (1987), and Tashakkori and Teddlie (2003).

Building upon the integration of the epistemological, methodological, pedagogical, ethical, and technodigital foundations represented in the preceding pentagon, the Research Training Model Based on Self-Organization and Technodigitalization was developed. This design proposes a reorganization of training processes through dynamic interactions among the researcher, knowledge, intelligent technologies, and the academic environment. Although these interactions already occur, they generally operate implicitly, without explicit articulation or systematic organization.

Research Training Model Based on Self-Organization and Technodigitalization

To conceptually structure the components, dimensions, subdimensions, and indicators of the proposed model, Table 1 was developed. The epistemological and methodological dimensions integrate classical analytical frameworks for research design, while the self-organization axis operationalizes the capacity for self-regulation throughout the research process.

Table 1. Conceptual Structuring Matrix of the Research Training Model

Component	Dimension / Axis	Subdimensions	Indicators	Evidence / Application
Central Axis	**Self-Organization** (Wiener, 1948)	**Self-regulation** (Zimmerman, 2000)	Structures research processes	Field journals
		Adaptability (Savickas, 1997)	Adjusts action plans	Reflective portfolio
		Autonomous learning (Knowles, 1975)	Makes decisions autonomously	Autonomous project design
Structural	**Epistemological** (Popper, 1934/2002)	**Paradigms** (Kuhn, 1962)	Identifies epistemological milestones	Critical essays
		Knowledge construction (Bunge, 1980)	Provides arguments supported by scientific evidence	Epistemological matrices
		Critical thinking (Paul & Elder, 2006)	Analyzes the validity of knowledge	Rationale for the study
	Methodological (Hernández-Sampieri & Mendoza, 2018)	**Research designs** (Creswell & Creswell, 2018)	Selects appropriate methods	Research proposals
		Methods (Tashakkori & Teddlie, 2003)	Designs coherent research studies	Validated instruments
		Techniques and instruments (Arias, 2012)	Applies analytical techniques	Data analysis
	Ethical (Ricoeur, 1990)	**Scientific integrity** (Resnik, 2015)	Applies ethical research principles	Ethical statements

Component	Dimension / Axis	Subdimensions	Indicators	Evidence / Application
		Social responsibility (Vallaeys, 2014)	Prevents and avoids academic plagiarism	Plagiarism-detection software reports
		Digital ethics (Floridi, 2013)	Uses data responsibly	Research protocols
	Pedagogical (Shulman, 1987)	**Research competencies** (Restrepo, 2003)	Develops research skills	Assessment rubrics
		Research pedagogy (Stenhouse, 1998)	Applies active methodologies	Research-Based Learning (RBL) projects
		Inquiry-based learning (Barrows, 1986)	Critically analyzes one's own practice	Reflective journals

Component	Dimension / Axis	Subdimensions	Indicators	Evidence / Application
Structural	**Technodigital** (Russell & Norvig, 2021)	**Applied Artificial Intelligence** (Luckin et al., 2016)	Uses AI-assisted tools	Analytical software (SPSS, R, NVivo, ATLAS.ti)
		Big Data (Mayer-Schönberger & Cukier, 2013)	Analyzes large volumes of data	Data mining and predictive analytics
		Digital environments (Siemens, 2005)	Integrates technologies into research	Academic platforms and management systems
Dynamic	**Evolutionary capacity** (Vygotsky, 1978)	**Learning progression** (Biggs & Collis, 1982)	Demonstrates progressive improvement	Sequential assessments
		Cognitive complexity (Hayes et al., 2021)	Integrates complex knowledge	Evidence portfolio
	Traceability (Kaiya et al., 2017)	**Process monitoring** (Abran, 2010)	Documents research processes	Records or research logs
		Reproducibility (Peng, 2011)	Justifies methodological decisions	Protocols and open-data repositories

Note. Author's own elaboration (2026). The matrix draws upon the articulation of the epistemological, methodological, and systemic dimensions of research training.

Integration of the Model: Toward a New Rationale for Research Training

The integration of the proposed model constitutes a contribution that extends beyond the pedagogical dimension, as it advances an emergent approach through which students can understand the processes involved in acquiring research skills for studies at any level and with varying degrees of theoretical depth within the university. Rather than merely organizing strategies to develop competencies for methodological applications, the model seeks to reconsider the foundations underlying the construction of scientific knowledge.

For decades, pedagogical processes aimed at training researchers in university contexts have centered on mastering methods, techniques, and instruments designed to produce verifiable

results. Although this approach has yielded significant advances in the consolidation of modern science, it presents limitations when explaining phenomena characterized by complexity, the interaction of multiple variables, and the sustained dynamics of social, educational, and technological contexts.

In response to this reality, the framework advances an integrative research rationale in which conducting research involves more than applying predefined procedures; it entails understanding, interpreting, and configuring new approaches to knowledge. The researcher consequently moves beyond the role of a mere implementer of methods, techniques, and procedures and instead emerges as a knowledge builder through a dynamic relationship among theory, experience, context, and critical reflection.

This perspective aligns with an understanding of learning to conduct research grounded in the integration of being, knowing, doing, and understanding, conceived as complementary spheres of scientific development. Researchers require not only technical competencies but also the capacity to formulate meaningful questions, interpret complex realities, establish conceptual connections, and assume an ethical position toward the knowledge they produce.

From this perspective, research acquires a self-organizing character because the knowledge-construction process neither remains fixed nor follows a single predetermined methodological path. Instead, research problems require the continuous reorganization of concepts, approaches, and procedures according to the characteristics of the phenomenon under investigation. Research training must therefore prepare researchers to navigate the uncertainty and complexity inherent in the scientific process.

Technodigitalization constitutes another component that transforms traditional approaches to research. New digital tools expand opportunities to access, analyze, and represent knowledge; however, their value depends on researchers' ability to employ them from a critical and reflective standpoint. Consequently, technology functions as a factor that enhances research without replacing the human capacity to interpret, formulate arguments, and generate meaning.

In this regard, the theoretical construction proposes moving beyond the boundaries of a research rationale centered on the instrumental dimension of method toward a configurative rationale in which scientific rigor intertwines with epistemological coherence, methodological consistency, the relevance of the knowledge generated, and its contribution to understanding and transforming reality.

Therefore, university research training requires a profound transformation: moving from preparing researchers who focus primarily on complying with methodological protocols toward developing individuals and collectives capable of constructing knowledge within complex contexts. Contemporary researchers must generate new ways of asking questions, establish connections among different forms of knowledge, and formulate interpretations that expand the boundaries of knowledge rather than merely answer existing questions.

Finally, the integrated model represents an epistemological reconfiguration of university research by conceiving scientific knowledge as a dynamic, relational, and open process. Its central

contribution lies in proposing a perspective that moves beyond reducing research to a technical activity and instead recognizes it as an intellectual and social practice through which the university actively participates in constructing new understandings of reality.

Discussion

The conceptual analysis supports an understanding of research training as a multidimensional construct that extends beyond mastery of methodological procedures and instead takes shape through the interaction of epistemological, pedagogical, methodological, ethical, and technodigital dimensions. This interpretation aligns with Morin (2001), who argues that complex phenomena acquire meaning through the relationships and interactions among their components rather than through the isolated analysis of their constituent elements. Similarly, it relates to Tobón's (2016) competency-based approach, which views training as an integrated process in which abilities, knowledge, values, and performance converge in response to concrete situations.

The findings further extend these approaches by incorporating technodigitalization as a structural dimension of contemporary research training. This incorporation recognizes that digital technologies function not merely as support resources for researchers but also transform the ways in which scientific knowledge is produced, organized, validated, and communicated. Consequently, research training requires new capacities related to the interpretation of digital information, the critical use of technological tools, and decision-making within increasingly complex environments.

Within this framework of intelligibility, conducting research entails a continuous process of epistemological reflection, conceptual construction, and ethical responsibility. The contributions of Bunge (2004) and Schön (1983) help explain that scientific activity requires both a logical structure of knowledge and researchers' capacity to reflect critically on their own practice. Nevertheless, the findings support a shift toward a dynamic perspective in which researchers apply previously established knowledge to reconstruct and generate new knowledge through continuous interaction with the reality under investigation.

Regarding the technodigital dimension, the results indicate that the incorporation of artificial intelligence, data analysis, collaborative platforms, and practices associated with open science continually transforms traditional research processes.

These findings correspond with the studies by Zawacki-Richter et al. (2019) and Holmes et al. (2019), who highlight the growing impact of artificial intelligence on educational and scientific processes. Likewise, Floridi (2019) argues that digital transformation creates new forms of knowledge organization through processes of interaction between humans and technology.

Along these lines, the proposal extends Castells' (2010) ideas concerning the network society by recognizing that contemporary research circulates through information networks, thereby enabling new forms of epistemological construction mediated by digital environments. In this

context, technodigitalization represents a transition in the conditions under which scientific knowledge undergoes production, communication, and legitimation.

Within this context, principles such as open science, traceability, and reproducibility acquire particular relevance because they strengthen the transparency and quality of research processes by promoting the documentation, verifiability, and replicability of the procedures and outcomes obtained (Nosek et al., 2015; Vicente-Saez & Martinez-Fuentes, 2018). From this perspective, scientific transparency also entails making the processes, responsibilities, and procedures involved in knowledge production visible, thereby promoting accountability and governance within scientific communities (Kosmarski et al., 2019).

Interpreting research training through the lens of complexity makes it possible to move beyond linear frameworks based on the transmission of content and procedures. Following Morin (2001), complex systems exhibit interaction, adaptation, and continuous reorganization, thereby requiring ongoing dialogue. Under this understanding, the construct emerges as a process in which relationships among individuals, knowledge, technologies, and contexts generate new configurations of learning and scientific production.

This perspective relates to Prigogine's (1996) work on systems far from equilibrium, instability, and the emergence of new forms of organization, insofar as such systems can generate new orders through dynamic processes of transformation. Complementarily, the theory of autopoiesis proposed by Maturana and Varela (1980) provides a basis for interpreting research and training processes systemically: such processes maintain their identity while simultaneously reorganizing themselves through interactions with reality. Likewise, Luhmann's (1995) contributions support an understanding of research training as a social system developed through communicative, reflective, and meaning-making processes.

From this systemic perspective, research training emerges as a dynamic structure that continuously reorganizes itself through interactions between researchers' internal capacities and the external conditions of scientific and educational environments. This interpretation complements Habermas (1984), who emphasizes that knowledge construction and validation require processes of intersubjective communication and rational argumentation. Ultimately, research training constitutes a space in which personal knowledge construction, social interaction, and scientific legitimation converge.

These interpretations also support the need to approach research training through complexity and transdisciplinarity. This position coincides with Morin (2007), who argues that educational phenomena should be approached through relationships of interdependence, and with Nicolescu (1996), who advocates moving beyond traditional disciplinary boundaries to foster new forms of understanding knowledge.

Within this interpretive horizon, the study's principal contribution lies in proposing a configurational understanding of research training that transcends perspectives centered exclusively on methodological competencies or the instrumental use of technologies. The training of university researchers requires the integration of cognitive, epistemological, ethical, and technological layers capable of addressing contemporary challenges in scientific knowledge

production. Accordingly, the proposed model provides foundations for guiding adaptive, flexible, and context-sensitive training processes in which research emerges as a complex practice of knowledge construction, transformation, and evolution.

Conclusions

Research training in universities requires a broader understanding that moves beyond hegemonic paradigms centered on the mastery of methods, techniques, and instruments. The analytical findings support the conclusion that research training constitutes a multidimensional construct involving interacting epistemological, pedagogical, methodological, ethical, and technodigital components. Their articulation enables new ways of understanding and developing scientific research in higher education.

The proposed model facilitates the interpretation of research and training as a dynamic and configurational process in which the researcher constructs knowledge through interactions among individual skills, theoretical foundations, contextual conditions, and available technological tools. From this framework of intelligibility, research moves beyond a practice limited to the application of established procedures and instead emerges as a reflective, critical, and transformative practice.

The findings further demonstrate that technodigitalization constitutes a structural dimension of contemporary research. The incorporation of artificial intelligence, data analysis, collaborative platforms, and open science principles represents more than an instrumental modernization; these elements transform the ways in which scientific knowledge undergoes production, validation, and communication. Consequently, research training must foster new capacities that enable researchers to engage critically with these technological environments.

From a complexity perspective, research training can be understood as an open, adaptive, and self-organizing system in which interactions among its components generate new configurations of learning and scientific production. This interpretation makes it possible to move beyond linear training models and recognize researcher development as a continuous process involving reorganization, reflection, and meaning-making.

The core contribution of the study lies in proposing an integrative rationale for research training that brings together the dimensions of being, knowing, doing, and understanding as foundations for preparing researchers capable of interpreting complex phenomena and generating relevant knowledge. The proposal extends canonical frameworks by incorporating a perspective in which research develops through dialectical dynamics involving epistemological interaction, scientific communication, and technological mediation.

Finally, universities face the challenge of transforming their research training designs toward flexible, interdisciplinary, transdisciplinary, and context-sensitive approaches. Twenty-first-century researcher training requires methodological competencies, critical capacity, ethical responsibility, complex thinking, and reflective mastery of emerging technologies. In this regard, the proposed model constitutes a theoretical contribution aimed at strengthening ways of

understanding research as an evolutionary process of knowledge construction and transformation.

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