






## Innovation in knowledge transmission in the Mexican metal-mechanic industry: Practices and lessons from three strategic sectors

### Innovación en la transmisión del conocimiento en la industria metal-mecánica mexicana: prácticas y lecciones de tres sectores estratégicos

Bareño-Ramos, Enoc <sup>\* a</sup> & Delgado-Torres, Claudia Lizeth <sup>b</sup>

<sup>a</sup> ROR Tecnológico Nacional de México/Tecnológico de Saltillo •  0009-0006-0866-5105 •  2121589

<sup>b</sup> ROR Tecnológico Nacional de México /Tecnológico de Nuevo León •  LSK-6566-2024 •  0009-0008-6070-441X •  444029

#### Classification:

Area: Social Sciences  
Field: Economic Sciences  
Discipline: Economics of Technological Change  
Subdiscipline: Technology and Social Change

 <https://doi.org/10.35429/EJB.2025.12.22.1.1.16>

#### History of the article:

Received: July 30, 2025

Accepted: October 30, 2025

\*  [\[claudia.dt@nuevoleon.tecnm.mx\]](mailto:claudia.dt@nuevoleon.tecnm.mx)












#### Abstract










This article analyzes innovation in the transmission of technical knowledge in the Mexican metal-mechanic industry. The objective is to understand the factors that facilitate effective knowledge transfer across different sectors, highlighting its strategic relevance for competitiveness and sustainability. The methodology was qualitative and documentary, based on the analysis of scientific literature and the review of ten case studies that illustrate successful practices in dual training, the use of digital platforms, and university-industry collaboration. The results show that the combination of technical competencies, enabling technologies, institutional networks, and organizational culture strengthens knowledge transfer, especially in sectors such as aerospace and automotive. In contrast, SMEs face structural limitations, although they manage to innovate through alliances and support programs. The main contribution lies in offering a referential framework that guides inclusive policies and practices for the management of technical knowledge.

#### Resumen

Este artículo analiza la innovación en la transmisión del conocimiento técnico en la industria metalmeccánica mexicana. El objetivo es comprender los factores que facilitan la transferencia efectiva del conocimiento en distintos sectores, destacando su relevancia estratégica para la competitividad y sostenibilidad. La metodología fue cualitativa y documental, sustentada en el análisis de literatura científica y en la revisión de diez casos de estudio que ilustran prácticas exitosas en la formación dual, el uso de plataformas digitales y la colaboración universidad-industria. Los resultados muestran que la combinación de competencias técnicas, tecnologías habilitadoras, redes institucionales y cultura organizacional fortalece la transferencia de conocimiento, especialmente en sectores como el aeroespacial y el automotriz. En contraste, las pymes enfrentan limitaciones estructurales, aunque logran innovar mediante alianzas y programas de apoyo. La principal contribución radica en ofrecer un marco referencial que orienta políticas y prácticas inclusivas para la gestión del conocimiento técnico.

Innovation in Knowledge Transmission in the Mexican Metalworking Industry		
Goals	Methodology	Contributions
 Analyze the factors that facilitate the transfer of technical knowledge across different sectors of the metal-mechanic industry.	 Applied and documentary research with a systematic literature review and industrial case studies.	 Technical competencies, enabling technologies, and a learning culture as central pillars for knowledge transfer.
 Identify successful practices that strengthen business competitiveness and sustainability.	 Integration of Learning Management Systems [LMS] and predictive analytics within a digital ecosystem.	 Evidence that advanced sectors [aerospace, automotive] have greater capacity for knowledge transfer than other sectors.
 Propose a framework to design inclusive and regionalized public policies in this sector of the industry.	 Analysis of 10 case studies in sectors such as aerospace, automotive, and multisectoral SMEs.	 Theoretical-practical framework to preserve technical knowledge and optimize processes.

Knowledge management, organizational innovation, metal-mechanic industry, technical transfer.

Innovación en la Transmisión del Conocimiento en la Industria Metalmeccánica Mexicana		
Objetivos	Metodología	Contribuciones
 Analizar los factores que facilitan la transferencia de conocimiento técnico en distintos sectores de la industria metalmeccánica.	 Investigación aplicada y documental con revisión sistemática de literatura y casos industriales.	 Competencias técnicas, tecnologías habilitadoras y cultura de aprendizaje como ejes centrales para la transferencia de conocimiento.
 Identificar prácticas exitosas que fortalezcan la competitividad y sostenibilidad empresarial.	 Integración de LMS, y análisis predictivo en un ecosistema digital.	 Evidencia de que los sectores avanzados [aeroespacial, automotriz] tienen mayor capacidad de transferencia que otros sectores.
 Proponer un marco de referencia que permita diseñar políticas públicas inclusivas y regionalizadas en este sector de la industria.	 Análisis de 10 casos de estudio en sectores como el aeroespacial, automotriz y pymes multisectoriales.	 Marco teórico-práctico para preservar el saber técnico y optimizar procesos.

Gestión del conocimiento; transferencia tecnológica; industria metalmeccánica.

Area: Development of strategic leading-edge technologies and open innovation for social transformation

Citation: Bareño-Ramos, Enoc & Delgado-Torres, Claudia Lizeth. [2025]. Innovation in knowledge transmission in the Mexican metal-mechanic industry: Practices and lessons from three strategic sectors. ECORFAN Journal Bolivia 12[22]1-16: e11222116.



ISSN: 2410-4191/ © 2009 The Author[s]. Published by ECORFAN-Mexico, S.C. for its Holding Bolivia on behalf of ECORFAN Journal Bolivia. This is an open access article under the CC BY-NC-ND license [<http://creativecommons.org/licenses/by-nc-nd/4.0/>]

Peer review under the responsibility of the Scientific Committee MARVID<sup>®</sup> - in the contribution to the scientific, technological and innovation Peer Review Process through the training of Human Resources for continuity in the Critical Analysis of International Research.



## Introduction

The transmission of technical knowledge is currently one of the most significant challenges for operational sustainability and continuous innovation in the industrial sector. This challenge becomes critical in the context of the relocation of production lines—particularly in strategic sectors such as automotive, aerospace, and household appliances in Mexico—where the transfer of machining, welding, or assembly processes to new sites entails risks associated with the loss of tacit knowledge, the learning curve, product quality, and operational safety.

Despite the economic weight of the manufacturing sector, which accounted for 18.5% of national added value and concentrated 47.9% of foreign direct investment during the period 2016–2020 [MFAT, 2021], there remains a lack of formal strategies to capture, document, and transfer technical knowledge. This research argues that many Mexican companies in the metalworking industry still lack systematic methodologies to ensure the continuity of critical capabilities during transfer or expansion processes.

Several recent studies highlight the benefits of institutionalizing knowledge management to build competitive advantages and reduce the loss of capabilities. For example, Huamaní et al. [2024] they document improvements in operational performance, internal learning, and innovation in Latin American industrial companies.

The study aims to analyze current and emerging practices of technical knowledge transmission in companies from three key sectors. Based on an exploratory and comparative approach, representative cases are documented to identify best practices, common barriers, and applicable lessons.

The added value of this research lies in four lines of analysis:

1. Modern learning techniques [García-García et al., 2024].
2. Use of technological platforms for documentation and teaching [González-Varona et al., 2021].
3. Integration of organizational training systems [CONOCER model].

4. Application of performance metrics linked to knowledge flow.

Each axis is examined on the basis of public data, institutional documents, and recent academic literature, generating a useful contribution for researchers, decision-makers, and industrial knowledge professionals.

## 2. Theoretical framework: foundations for innovation in the transfer of technical knowledge

A deep understanding of how technical knowledge is generated, transmitted, and adapted within the metalworking industry requires the articulated analysis of various conceptual frameworks.

This section provides the theoretical foundation for the key variables of the research, organizing them into five axes that range from the principles of knowledge management to their practical application in Mexican industries. Each subsection presents theories, models, and evidence that have been validated in highly complex industrial contexts and that are essential to understanding how companies can innovate in their mechanisms for transferring technical knowledge

### 2.1 Foundations of Technical Knowledge Management

Technical Knowledge Management [TKM] is distinguished by its focus on the systematic management of technical knowledge—both tacit and explicit—embedded in people, processes, and industrial technology, with the aim of ensuring operational continuity, adaptation, and the capacity for incremental innovation.

Unlike generic approaches to knowledge management, TKM emphasizes the capture and transfer of specific manufacturing and technical-operational processes.

#### *Classical and Contemporary Models*

The SECI model of Nonaka y Takeuchi [1998] provides the conceptual basis for how knowledge is transformed and circulates within technical organizations, while the contributions of Stiglitz y Greenwald [2014] underline the economic value of productive knowledge as a driver of systemic efficiency.

Recent studies such as that of Riascos-Eraza et al. [2021] in Latin American industrial companies confirm the persistence of challenges in the institutionalization of TKM, particularly due to weaknesses in organizational leadership and the limited use of knowledge technologies.

From an organizational perspective, Nonaka and Takeuchi’s SECI model proposes that knowledge is converted from tacit to explicit through four phases: Socialization, Externalization, Combination, and Internalization. This approach enables companies to capture practical experience and transform it into documented processes that are reusable and adaptable to new contexts [Nonaka & Takeuchi, 1998].

*Current Empirical Evidence*

Huamaní et al. [2024] document that, in Latin American industrial companies, the formal implementation of TKM—through tacit knowledge capture, competency-based training, and digital platforms—reduces operational errors and increases organizational innovation. These findings are consistent with studies from the OECD [2021] that link organizational capital, ICT skills, and training with significant improvements in industrial productivity.

**Box 1**

**Table 1**

Key Principles for Technical Knowledge Management in the Manufacturing Industry

Principle	Description
Capture of tacit knowledge	Techniques such as interviews, direct observation, and multimedia recording
Systematization and documentation	Standardization of processes, manuals, and the use of collaborative platforms
Continuous learning	Periodic technical updating and procedure review
Inter-area sharing	Mentoring, communities of practice, and cross-functional workshops

Source: Bareño and Delgado [2025], based on Nonaka & Takeuchi, Riascos Eraza et al., Huamaní et al., and OECD

*Connection with the research axes*

These principles support the four analytical axes of the study:

1. Modern learning techniques [AR, microlearning, TWI].

2. Technological platforms [LMS, digital twins, analytics].
3. Institutional training systems [CONOCER, internal mentoring].
4. Performance metrics linked to knowledge [learning curves, quality, efficiency].

**2.2 Classical Theoretical Models in Technical Knowledge Management**

Technical Knowledge Management [TKM] has been conceptually structured since the 1990s through theoretical models that explain how knowledge is generated, transformed, transferred, and applied within organizations. These frameworks remain relevant in contemporary literature, especially in industrial contexts. The SECI model, developed by Nonaka y Takeuchi [1998], describes the conversion cycle between tacit and explicit knowledge through the phases of socialization, externalization, combination, and internalization. It is widely used to implement communities of practice and technical standardization in industrial plants.

The knowledge spiral theory, proposed by Boisot [1995], analyzes how knowledge codification and its structured transfer can become competitive advantages, particularly in advanced technical industrialization. The 5Cs [Create, Capture, Share, Use, and Learn], systematized by Nonaka y Takeuchi [21], organize the complete cycle of structured technical knowledge management in contexts of high staff turnover or process relocation.

**Box 2**

**Table 2**

Classical Models of Technical Knowledge Management

Model	Brief Description	Source
SECI	Conversion cycle between tacit and explicit knowledge.	Nonaka & Takeuchi, 1998
DIKW	Data-to-wisdom hierarchy academically reviewed	Rowley, 2007
Knowledge Spiral	Knowledge codification flow as a competitive advantage	Boisot, 1995
5C Model	Stages: Create, Capture, Share, Use, and Learn.	Nonaka & Takeuchi, 2011

Source: Bareño and Delgado [2025], based on key academic studies

### 2.3 Innovation and Organizational Learning

The link between innovation and organizational learning has gained relevance in the metalworking industry, especially in contexts where the transfer of technical knowledge becomes a challenge due to operational complexity and technological obsolescence. Within this framework, companies are adopting hybrid models that integrate digital platforms, artificial intelligence [AI], and cyber-physical technologies to facilitate processes of continuous learning, technical standardization, and operational improvement.

In various industrial organizations within the automotive sector, an intensive digital technical learning strategy has been documented, which includes the use of 3D simulators, digital twins, data analytics, and augmented reality for training in processes such as casting and machining.

These tools enable the capture, organization, and transfer of expert knowledge, even across plants with different cultural and technological contexts. Multilingual collaborative platforms and digital technical repositories have proven to improve training times and reduce production defects. Lopes, W. A. C., Rusteiko, A. C., & Mendes, C. R. [2025].

On the other hand, recent research highlights how LMS platforms combined with digital twins are transforming learning in traditional industrial environments. The retrofitting methodology makes it possible to digitize legacy CNC machines with sensors, human-machine interfaces, and data protocols, creating adaptive learning ecosystems with models of interaction, understanding, and virtual simulation [González-Alcántara et al., 2024].

This translates into shorter adaptation times for technical staff and enhanced capabilities for operational decision-making. Additionally, recent academic literature emphasizes that digital transformation is not limited to the incorporation of technologies, but rather entails a redesign of the organizational learning model. According to Huamaní et al. [2024], Knowledge management as a driver of innovation requires strategies aligned with digital competencies, multidisciplinary collaboration, and the personalization of learning according to productive roles.

Technological capabilities must be accompanied by structured training programs and a culture that fosters the flow of knowledge through social and cognitive technologies such as conversational AI and predictive analytics.

Finally, data- and simulation-based adaptive models are facilitating the integration between human teams and automated systems, promoting new forms of organizational learning that are more dynamic and scalable. The continuous and incremental learning approach, leveraged by emerging technologies, represents a decisive factor in sustaining competitiveness in the 21st-century metalworking industry.

To facilitate the understanding of the structural differences between technical knowledge management approaches, the following comparative table is presented. Table 3 summarizes the main contrasts between classical models [such as SECI, DIKW, and 5C] and contemporary models based on digital platforms, artificial intelligence [AI], and emerging technologies. Key criteria such as general focus, technological foundation used, transfer speed, adaptability, dependence on human knowledge, and application examples are analyzed. This comparison clearly illustrates how organizational learning methods in the metalworking industry have evolved.

### Box 3

**Table 3**

Comparison of Classical vs. Contemporary Models

Criterion	Classical	Contemporary
<b>Approach</b>	Socialization, codification, tacit-explicit conversion	Digital learning, automation, AI, simulation
<b>Technological basis</b>	Human networks, physical documents, or simple digital records	LMS platforms, LLM, digital twins, data analytics
<b>Transfer speed</b>	Slow or dependent on trainers	High, asynchronous and in multiple languages or formats
<b>Adaptability</b>	Limited to prior experience	High, with scalable and personalized content
<b>Human dependence</b>	High [tutors, technical experts]	Medium [interaction with digital systems]
<b>Application examples</b>	Technical mentoring, manuals, communities of practice	Digital twins, conversational AI, CNC retrofitting

Source: Bareño y Delgado [2025]

In addition to structural differences, it is important to evaluate the strengths and limitations of each type of technical knowledge management model. Table 4 presents a comparative synthesis between classical, contemporary, and hybrid models, highlighting their main advantages and disadvantages.

This information allows those responsible for technical, operational, or training areas to identify the most suitable approach according to the level of digitalization, the resources available, and the strategic objectives of each organization.

**Box 4**

**Table 4**

Advantages and Disadvantages by Model Type

Model type	Advantages	Disadvantages
Classical	Simplicity, low initial cost, immediate accessibility	Slow, expert-dependent, difficult to scale
Contemporary	Escalabilidad, velocidad, personalización, multilingüe	Requires digital infrastructure, technical training
Hybrid	Balance entre experiencia humana y capacidades tecnológicas	Complexity in integration, moderate investment

This table complements the comparative analysis by highlighting that, although contemporary models offer clear advantages in terms of efficiency and scalability, they also entail technical and organizational challenges. In this context, hybrid models emerge as a viable solution for many companies in the Mexican metalworking sector that are still in the process of digitalization.

Based on the theoretical review presented in Sections 2.2 and 2.3, as well as on the analysis of documented cases in the Mexican metalworking industry, the following table is presented as a reference guide.

Table 5 presents a classification of industrial scenarios in which the application of a specific type of model [classical, contemporary, or hybrid] is suggested, considering factors such as the required speed of transfer, the criticality of technical knowledge, technological availability, and the level of operational standardization.

This approach is not prescriptive but rather indicative, and seeks to facilitate strategic decision-making on organizational learning and technical knowledge management in real contexts.

**Box 5**

**Table 5**

Suggested Application of Models According to the Industrial Context

Application context	Suggested application
Training of new plant personnel	Hybrid model
Transfer of production lines [relocation]	Contemporary model
Training in critical or hazardous processes	Contemporary model
Corporate standardization across multiple plants	Contemporary model
Knowledge recovery upon expert turnover	Classical or hybrid model [depending on the time and urgency available]

**2.4 Digital platforms and emerging technologies**

Digitalization has transformed technical knowledge management models in the metalworking sector through the use of digital twins, advanced LMS systems, artificial intelligence [AI], simulators, and augmented reality. These technologies facilitate continuous, automated, and adaptive technical learning.

For example:

- The iDIGIT4L project [2024] describes a non-intrusive learning ecosystem that combines digital twins and expert knowledge to modernize tasks on existing CNC machines. Its three-level approach—interaction, understanding, and learning—has been tested in traditional Mexican factories, enabling the updating of technical training without halting production [García & Cañibano, 2024]
- The DETECTA program [2023] developed AI- and digital twin-based methodologies for predictive maintenance in industrial SMEs, successfully detecting technical anomalies and cyberattacks without interrupting production. This approach helps preserve operational knowledge while modernizing local technological infrastructure [García, Echeverría & Ovejero, 2023].

- The CONECT4 program [2021] combines augmented reality, virtual reality, expert knowledge, and digital twins to create industrial training environments in the automotive sector. Its application in Mexican companies has demonstrated improvements in technical training efficiency and collaborative knowledge management [González et al., 2021].

These cases illustrate how digital platforms transcend the mere digitalization of processes: they enable scalable, adaptable, and contextualized technical learning models, particularly useful in contexts with high staff turnover or diversified industrial infrastructure. This new paradigm departs from classical models of manual transfer, as technical training no longer depends exclusively on the human expert. Instead, digital tools make it possible to:

### 2.5 Application in the Mexican context

In Mexico, the professionalization of technical knowledge has gained strategic relevance in key industrial sectors. However, structural challenges persist, such as low investment in research and development [R&D], limited formalization of on-site learning processes, and weak articulation between academia, industry, and government. In the face of this scenario, various organizations have begun to implement innovative approaches to technical knowledge management with documented results:

- A prominent example is Whirlpool, which has adopted global manufacturing systems as part of its operational strategy. This implementation has required the development of technical capabilities at different levels of the organization, as well as the creation of effective knowledge management [KM] mechanisms within its plants. In particular, the adoption of the World Class Manufacturing model [WCM] has made it possible to standardize operational practices and transfer knowledge in a structured manner across different plants of the group, both nationally and internationally. This practice has strengthened inter-plant standardization and accelerated internal training processes and operational adaptation.

- CENIDET, as the technological research center of the National Technological Institute of Mexico, reports in its *Informe de Rendición de Cuentas 2023* the consolidation of projects aimed at strengthening its academic and laboratory infrastructure, as well as the promotion of advanced training programs for the development of technical competencies in strategic areas. These actions have made it possible to link applied research with high-level training, creating a favorable environment for academic knowledge to be translated into practical solutions for Mexican industry.
- A recent study on large corporations in Mexico shows that those that have adopted strategic knowledge management—including digital platforms, communities of practice, and formal technical training systems—exhibit greater adaptability in the face of technological and organizational changes [Arrieta & Mendoza, 2023].

Taken together, these cases illustrate that, despite the structural limitations Mexico faces in terms of R&D investment and institutional articulation, there are tangible efforts aimed at strengthening technical knowledge management.

The experience of corporations such as Whirlpool, the academic work of CENIDET, and the documented evidence in recent studies show that the combination of advanced manufacturing models, specialized training programs, and digital tools makes it possible to translate innovation into sustainable productive practices.

This outlook confirms that knowledge management is not only a strategic resource but also an essential element to drive competitiveness and adaptive capacity in industrial sectors within the Mexican context.

### 3. Methodology

The present research is conducted under a qualitative, documentary approach with an exploratory and analytical design.

This methodological strategy is relevant for understanding the complexity of technical knowledge transfer in the Mexican metalworking industry, as it allows for the interpretation of organizational cases and institutional practices from both a theoretical and applied perspective, without necessarily relying on the collection of quantitative field data.

As noted by Quecedo [2002] y Martínez [2022], qualitative and documentary research is based on the systematic analysis of secondary sources and on the interpretive construction of the phenomenon, while the exploratory design aims to generate initial approaches when the study topics have not been sufficiently addressed in the literature.

The method used is based on the review and analysis of peer-reviewed scientific literature, technical reports, and institutional documents published over the past twenty years, complemented by classical authors who have set conceptual milestones in knowledge management, technological innovation, and technical-industrial education.

The sources were selected through systematic searches in specialized databases such as Scopus, ScienceDirect, Redalyc, and Dialnet, as well as in repositories of the National Technological Institute of Mexico and international organizations such as the OECD and UNESCO, ensuring the robustness, timeliness, and relevance of the materials consulted.

Inclusion criteria were established to guide the documentary selection process:

- a. Studies addressing contemporary models of knowledge transfer and management in industrial environments.
- b. Research on the application of emerging technologies [AI, digital twins, AR/VR, LMS] in the transmission of technical skills.
- c. Texts exploring the role of universities, research centers, and industrial clusters in dual training and skills certification.
- d. Documents analyzing public policies or sectoral programs related to innovation and industrial competitiveness.

The unit of analysis consisted of ten documented cases of companies and representative sectors [aerospace, automotive, household appliances, and multisectoral SMEs], selected for their relevance in the transmission of technical knowledge in Mexico. Based on this foundation, a structured analysis system was developed around four axes: institutional infrastructure, technical competencies, enabling technologies, and organizational culture.

The information collected was systematized through analysis sheets and comparative matrices, prioritizing the identification of patterns, similarities, and divergences across sectors. No statistical instruments were employed, since the central objective was to generate a conceptual and applied proposal for the Mexican metalworking industry.

In line with this approach, the theoretical hypothesis is proposed that: *the successful transfer of technical knowledge in the industry depends on the articulation between certified competencies, digital technologies, institutional networks, and an organizational culture of continuous learning.*

#### 4. Results

This section describes the findings derived from the documentary, comparative, and structural analysis conducted on current practices of technical knowledge transfer in the Mexican metalworking industry. Based on the review of verifiable public sources, ten representative cases were identified that demonstrate innovative strategies in knowledge management, technical training, and the appropriation of organizational capabilities in key sectors such as automotive, aerospace, railway, advanced manufacturing, and household appliances.

These results directly address the research questions posed:

- What models and practices are Mexican organizations using to transfer technical knowledge?
- What technologies, structures, or policies are facilitating such transfer?
- What tangible organizational impacts do these practices generate in terms of performance, efficiency, or retention of expert knowledge?

The systematization of these cases not only makes it possible to characterize common patterns and emerging trends, but also provides practical evidence for the proposed lines of research: modern learning techniques, applied technological platforms, organizational systems for technical training, and performance metrics associated with knowledge.

#### 4.1 Comparative Analysis of Documented Cases

The documentary analysis identified ten representative experiences of technical knowledge transfer in the industry, organized by strategic sector: multisectoral, aerospace, automotive, and household appliances. Each case was selected for its methodological clarity, verifiable public evidence, and concrete contributions to the research questions.

Taken together, these experiences reflect how organizations have implemented practices of technical innovation, structured training, digitalization of learning, or collaboration with educational institutions to preserve and scale critical capabilities. The following tables present a structured synthesis by sector.

#### 4.2 Sectoral Evidence: Documented Cases of Technical Knowledge Transfer

The ten documented experiences presented below show that the transfer of technical knowledge in the Mexican metalworking industry is manifested across a wide diversity of sectors, ranging from aerospace precision manufacturing to household appliance production.

Despite technological and organizational differences, it is possible to identify common elements: collaboration with universities or technological centers, the use of digital platforms [such as digital twins or augmented reality], and the progressive professionalization of suppliers or technicians through structured training models. In all cases, innovation acts as a catalyst for these processes.

### Box 6

**Table 6**

Multisectoral Cases of Technical Knowledge Transfer

Company / Project	Project description	Citation
Siemens México	Integration of IT, connected platforms, and digital twins to train operators and technicians in complex industrial environments. Impact: improvement in operational efficiency and retention of technical knowledge.	García Garnica, A. [2023]. <i>Siemens en el contexto de la Industria 4.0: Algunas estrategias para mantener y ampliar sus capacidades tecnológicas y de aprendizaje organizacional.</i>
National Study Mexico – UNAM	Cross-sectional study on the adoption of knowledge management in Mexican industrial organizations. Impact: mapping of best practices and organizational barriers.	Delgado-Hernández, D. J., et al. [2009]. <i>A case study on knowledge management adoption in Mexico.</i> IEEE Xplore.
iDIGIT4L Project – Cidaut	Use of non-intrusive digital twin in traditional machinery with retrofitting techniques and human-machine learning. Impact: enhancement of operators' digital skills.	García, Á., & Cañibano, E. [2024]. <i>iDIGIT4L: Digital twin retrofitting for industrial learning in SMEs.</i> arXiv.

### Box 7

**Table 7**

Aerospace Sector Cases: Technical Knowledge Transfer

Company / Project	Project description	Citation
Safran Querétaro / UNAQ	Technical training between Safran and the Aeronautical University of Querétaro [UNAQ]. Impact: development of human capital and industry-university collaboration.	Salinas-García, R. J. [2012]. <i>Desarrollo industrial y formación profesional en la industria aeronáutica en Querétaro</i>
Clúster Aeroespacial Querétaro	Aerospace innovation ecosystem in Querétaro: coordination among CIDESI, CIATEQ, CIAT, and CAT UNAM for technical training and collaborative R&D development. Impact: regional consolidation as an aeronautical hub.	Muñoz-Sánchez, C., Soto-Flores, M. del R., Rocha-Lona, L., Garduño-Román, S., & Garza-Reyes, J. A. [2019]. <i>Aerospace Industry in Queretaro, Mexico: A perspective of Regional Innovation System.</i>

**Box 8**

**Table 8**

Industry Cases: Technical Knowledge Transfer

Company / Project	Project description	Citation
CONNECT4 Project [Mexico]	Immersive learning platform based on Augmented Reality, Virtual Reality, and non-intrusive digital twins for predictive maintenance in automotive plants. Improves efficiency and reduces operational errors.	González, S., García, Á., & Núñez, A. [2021]. <i>CONNECT4: Desarrollo de componentes para entornos de aprendizaje hombre-máquina en automoción.</i> arXiv.
Automatic inspection with Deep Learning [automotive]	Application of deep learning models for visual inspection of defects in automotive assembly lines. Precise recognition with an impact on quality and waste reduction.	Mazetto, M., Teixeira, M., Rodrigues, É. O., & Casanova, D. [2020]. <i>Deep Learning Models for Visual Inspection on Automotive Assembling Line.</i> arXiv.
Systematic review on AI in automotive quality control	Analytical study on AI and neural network implementations in quality control and predictive maintenance in the automotive industry. Identifies impacts and trends applicable to Mexican companies.	Morales Matamoros, O., Takeo Nava, J. G., Moreno Escobar, J. J., & Ceballos Chávez, B. A. [2025]. <i>Artificial Intelligence for Quality Defects in the Automotive Industry: A Systemic Review.</i>
PACE Program – Tecnológico de Monterrey & Automotive Industry	University–industry collaboration through real projects in automotive design and manufacturing. Interdisciplinary and international teams participate, using both virtual and face-to-face environments. Impact: development of applied technical competencies, transfer of practical knowledge, and strengthening of global networks.	Esqueda-Merino, D. M., García-García, A. D., García-Morán, E., Morano-Okuno, H. R., & Sandoval-Benítez, G. [2019]. <i>Industry-University Collaboration: An Educational Program with Automotive Industry.</i>

**Box 9**

**Table 9**

Household Appliances Sector Cases: Technical Knowledge Transfer

Company / Project	Project description	Citation
Household appliances in Mexico	Technology transfer to local suppliers through integration into global value chains. Includes process standardization, technical learning, and continuous improvement.	Velarde-Moreno, J., Blanco, C. E., & Jiménez, A. [2020] <i>Mexican local suppliers in home appliance value chains.</i>

The multisectoral evidence presented above will serve as the basis for the following sections of the analysis, in which cross-cutting elements, key capabilities, and replicable lessons are identified that characterize successful projects of technical knowledge transfer in Mexico.

**4.3 Technical Capabilities and Prioritized Competencies**

The cases analyzed reflect not only the transfer of technical knowledge in operational terms but also the active development of specific professional capabilities. These competencies are strategically prioritized according to the sector and demonstrate how technical knowledge is institutionalized within organizations.

At least seven of the cases document a clear focus on the understanding of technical regulations and certifications, such as AS9100 or ISO standards, particularly in regulated industries such as aerospace and household appliances. Examples of this include competency validation programs in GE-MABE and the dual technical training schemes of Safran–UNAQ.

In at least six cases, priority was given to the technical operation of advanced machinery such as CNC, robotic lines, or automated systems. This is clearly observed in the project iDIGIT4L, which documents the use of digital twins for training purposes in industrial machinery, and in the training processes applied in plants of Whirlpool.

Basic programming and the management of digital interfaces appear in five projects, particularly where technologies such as IoT, AR/VR, or monitoring software were introduced. Cases such as CONNECT4 y Siemens México stand out for integrating these competencies into their continuous technical training.

Finally, collaborative work and continuous learning appear transversally in five cases, documenting the incorporation of mentoring programs, technical performance evaluation, and structured feedback. This can be seen in the Estudio UNAM sobre gestión del conocimiento and in the co-learning processes documented in CONNECT4.

This set of prioritized capabilities allows us to conclude that the transfer of technical knowledge in the metalworking industry goes beyond operational training to become a process of strategic construction of key competencies.

#### 4.4 Analysis of Results

The analysis of the ten documented cases on technical knowledge transfer in the Mexican metalworking industry allows for the empirical validation of several premises proposed in the theoretical framework.

The evidence shows that the effective transfer of technical knowledge depends on an articulation between institutional infrastructure, technology, specific competencies, and organizational culture.

- 80% of the documented cases [8 out of 10] were driven by technological centers, universities, or regional clusters, which confirms the hypothesis that these collaborative ecosystems enhance transfer. This finding is consistent with studies such as the Diaz Rodriguez y Morales Sanchez, V. [2021], which analyze the Regional Innovation Systems in Mexico and their impact on the transfer of technical knowledge.
- 70% of the cases involved emerging technologies such as digital twins, augmented reality, LMS platforms, or applied artificial intelligence, which is consistent with recent studies on Industry 4.0 and knowledge management [Alonso et al., 2024].
- 90% of the cases prioritized specific technical competencies such as the operation of advanced machinery, interpretation of CAD drawings, use of digital interfaces, and mastery of certifiable standards, thereby validating models of technical professionalization and knowledge management [Gajdzik, 2022]
- 50% of the cases explicitly highlighted collaborative work and continuous learning, reinforcing the need to strengthen organizational culture as a strategic component of technical knowledge transfer.

These observations make it possible to directly address the central hypothesis of the study: *“The effective transfer of technical knowledge in the Mexican metalworking industry depends on the articulation between technology, competencies, institutional structures, and organizational culture.”*

Likewise, sectoral and territorial asymmetries were identified. While industries such as aerospace [Querétaro] and household appliances [Nuevo León and Guanajuato] show mature ecosystems with specialized infrastructure, many SMEs lack access to digital platforms, structured training, or institutional linkages.

In summary, the empirical findings not only confirm the models analyzed in the theoretical framework but also make it possible to identify critical replicable factors for the design of policies and organizational strategies that strengthen technical knowledge management in the current Mexican context.

#### 5. Discussion

The transfer of technical knowledge in industrial environments constitutes a multifactorial process that depends on the interaction between individual capabilities, institutional frameworks, and technological appropriation. The results obtained from the ten cases analyzed allow for a contrast between the conceptual frameworks reviewed in Chapter 2 and the empirical evidence presented in Chapter 3, outlining common patterns, sectoral differences, and critical conditions.

The findings show that collaborative ecosystems are configured as the main enablers of knowledge transfer, since in eight of the ten cases analyzed the participation of universities, innovation centers, and clusters was decisive.

This coincides with the literature that underscores the role of relational infrastructure as a catalyst for organizational learning. Likewise, it is observed that emerging technologies function as central vehicles for knowledge codification: digital twins, augmented reality, artificial intelligence, and LMS platforms proved to be strategic resources for organizing, replicating, and standardizing processes in highly regulated sectors such as automotive and aerospace.

At the same time, it is confirmed that the priority given to certifiable competencies constitutes a fundamental axis, as the systematization of technical skills through certifications, international standards, and dual training programs transforms tacit knowledge into tangible and transferable organizational capital.

These results reinforce Nonaka and Takeuchi's theory of organizational knowledge creation regarding the need for codification and institutionalization to transform tacit knowledge into explicit knowledge. They also confirm the relevance of Etzkowitz and Leydesdorff's Triple Helix model, by demonstrating the centrality of collaboration among universities, industry, and government.

However, the analysis also reveals limitations in the Mexican context, where cultural and territorial gaps introduce obstacles not foreseen in these conceptual frameworks, making it necessary to propose adaptations that recognize national specificities.

From a sectoral perspective, the study identifies differentiated lessons. In the aerospace industry, transfer is mainly sustained by certification and institutional articulation through specialized clusters. In the automotive sector, digitalization and process standardization appear as the dominant strategies to ensure the replicability of knowledge within global production chains. In the household appliances sector, the integration of suppliers into collective learning dynamics stands out, extending professionalization throughout the entire value chain.

Finally, multisectoral SMEs, despite their resource limitations, demonstrate the possibility of sustaining transfer processes through frugal innovation, leveraging external networks, and employing structured mentoring strategies.

Transversally, the analysis highlights four critical conditions for the successful transfer of technical knowledge: the existence of institutional infrastructure and collaborative networks, the development of structured technical capabilities, the adoption of enabling environments based on emerging technologies, and the consolidation of an organizational culture oriented toward continuous learning.

The interaction of these factors confirms that effective transfer does not depend on a single element but rather on a systemic balance that combines structure, technology, and culture.

In this regard, an integrated conceptual model is proposed for the Mexican metalworking industry, supported by a collaborative institutional core—where universities, clusters, and government act as articulators—, by enabling technological axes that include digital twins, augmented reality, LMS systems, and artificial intelligence, by the professionalization of technical competencies through certification, and by the construction of an organizational culture that values collaborative and continuous learning.

This model articulates theory and practice, offering a framework adapted to the national reality, recognizing both the achievements made and the structural limitations still present, and serving as a guide for future initiatives of innovation in the transfer of technical knowledge.

## 6. Conclusions

The results obtained in this study confirm that the effective transfer of technical knowledge in the Mexican metalworking industry is not an isolated process but a complex phenomenon that requires the simultaneous articulation of multiple dimensions: technology, organizational culture, institutional networks, and structural support from public policy.

The empirical evidence documented in the ten cases studied validates the central hypothesis proposed in the conceptual framework: the professionalization of technical knowledge is a key factor in ensuring operational continuity, applied innovation, and the territorial scalability of productive capacities. This conclusion aligns with theoretical models such as the SECI cycle and the theory of organizational knowledge creation of Coltman, T., Devinney, T. M., Midgley, D. F., & Venaik, S. [2008], The most recent approaches to digital platforms as enablers of learning confirm that the development of digital capabilities constitutes a critical factor for organizational transformation [Kans & Campos, 2023].

Moreover, the findings show that the more advanced sectors [such as aerospace and automotive] possess institutional conditions that favor the structured transfer of knowledge: dual training, consolidated clusters, international certifications, digital platforms, networks of technical mentors, and active linkages with universities.

In contrast, multisectoral SMEs face deeper structural limitations, although some cases show that it is possible to innovate despite scarcity through external networks, frugal reconversion, and structured mentoring.

These observations make it possible to question approaches that privilege only investment in technology without accompanying it with training and knowledge management processes. Digital technologies [such as digital twins, AR/VR, or LMS systems] do not replace human knowledge, but they do amplify and systematize it—provided that an organizational structure exists to leverage them. In this regard, the conclusions of this study reinforce the stance that innovation in technical knowledge is both social and technological.

In terms of public policy, the study confirms that sustainable and territorially differentiated programs are required, as demonstrated by successful experiences linked to CONOCER-certified training programs and the role of public research centers such as CIDESI, as documented in recent industrial studies and projects such as CONECT4. However, it is also evident that many successful strategies depend on individual leadership or temporary funding, which limits their replicability.

In summary, the contrast between the documented cases and theoretical frameworks allows us to assert that the transfer of technical knowledge is viable, replicable, and scalable, provided that four key elements are articulated: codified technical content, appropriate technologies, active institutional networks, and an organizational culture of learning.

Based on these findings, concrete proposals can be derived to redesign public policies, structure industrial intervention models, or strengthen the internal capacities of Mexican companies seeking to compete in high-technical-demand sectors.

## 6.1 Recommendations

Based on the analysis of the ten documented cases and the critical conditions identified, recommendations are proposed at four strategic levels aimed at strengthening the processes of technical knowledge transfer in the Mexican metal-mechanical industry.

### *a. Organizational Level [Companies]*

- Standardize technical knowledge through LMS platforms and operational documentation systems [manuals, instructions, technical videos].

For example, Metalsa It implemented a corporate knowledge management system based on LMS and QAD to standardize competencies across its plants.

- Establish internal mentoring programs to capture expert knowledge and facilitate technical generational succession.

In Whirlpool Celaya, SME suppliers were accompanied by expert personnel to replicate critical manufacturing processes.

- Promote a culture of continuous learning through recognition of best practices, improvement circles, and horizontal feedback.

### *b. Interinstitutional Level [Clusters, Chambers, Universities]*

- Promote lasting partnerships between clusters, technological universities, and public R&D centers to ensure dual training and professional internships aligned with real technical needs.

The Clúster Aeroespacial de Querétaro succeeded in consolidating certified training with the participation of CIDESI, UNAQ, and Safran.

- Establish regional networks of certified instructors who can address the technical needs of SMEs in areas with lower infrastructure.
- Create shared learning assessment mechanisms, supported by industrial chambers and certification systems [e.g., CONOCER].

### c. Technological Level

- Prioritize immersive and accessible technologies such as augmented reality, AR/VR, or digital simulators to train operational personnel.

In the CONECT4 project virtual learning environments were used to train technicians in complex industrial processes.

- Integrate open digital documentation platforms [interactive instructions, virtual tours, digital twins] to share knowledge across networks.
- Document digital learning and build internal repositories that allow training to be scaled without relying on external providers.

### d. Public Policy Level

- Strengthen national programs such as CONOCER with a focus on priority industrial sectors [automotive, aerospace, metal-mechanical]

Competency certification under CONOCER has been key to validating technical skills in programs such as those offered by UTEQ.

- Reactivate the PROSOFT program or develop an updated equivalent for digitalization and technical transfer in industrial SMEs.
- Articulate a national industrial technical training strategy, coordinated among the Ministry of Economy, SEP, CONACYT, and the states, with a territorial focus.
- Fund permanent training structures beyond temporary competitive grants, ensuring the continuity of successful projects.

## 6.2 Future Research Directions

This study confirms that the transfer of technical knowledge in the Mexican metal-mechanical industry is not only a desirable process but also feasible and strategic. The ten cases analyzed show that when there is a solid organizational structure, a learning culture, and enabling technologies, knowledge can flow among diverse actors and generate measurable operational impact.

In general terms, the proposed hypothesis is validated: the articulation of technical competencies, technological platforms, institutional networks, and organizational culture is critical for the successful transfer of technical knowledge.

Additionally, critical factors that favor knowledge transfer were identified, such as the use of digital platforms [digital twins, AR/VR, LMS], dual training with certification [as in the case of Safran and UNAQ], and collaboration with universities or centers such as CIDESI. These elements are present in the most advanced sectors, such as aerospace and automotive. In contrast, multi-sector SMEs face structural barriers, but they have demonstrated that innovation is possible through external networks, technical mentoring, and leveraging programs such as CONECT4. This adaptive capacity reinforces the importance of designing inclusive and regionally tailored public policies.

- Conduct longitudinal studies to measure the impact of these practices on knowledge retention and operational performance.
- Investigate the effects of generative artificial intelligence and other emerging technologies on the transmission of technical skills.
- Expand the analysis to under-studied industrial sectors such as mining or metal-mechanical agroindustry.
- Evaluate the role of microenterprises and artisanal workshops in the informal transmission of technical knowledge.
- Develop standardized indicators of technical knowledge transfer that can be integrated into quality or innovation systems

This work contributes to the practical and theoretical understanding of knowledge management in real industrial contexts and opens the door to new research agendas that recognize the social, technological, and institutional dimensions of technical knowledge.

## 6.3 Final Considerations

The sectoral analysis of technical knowledge transfer in the Mexican metal-mechanical industry confirms that innovation does not rely solely on technological advances, but on the capacity of organizations to manage knowledge as a strategic asset.

The documented cases reveal that the articulation of technology, technical competencies, organizational culture, and institutional networks is the determining factor for success in knowledge transfer processes. Furthermore, it is confirmed that interinstitutional collaboration and structured learning are necessary conditions to generate sustainable innovation ecosystems, especially in sectors such as aerospace and automotive.

However, persistent challenges are also identified, such as territorial asymmetries, low formalization in SMEs, and the lack of continuity in public policies.

The evidence presented allows us to assert that a national technical transfer strategy must be multisectoral, territorially differentiated, and technologically scalable. Additionally, it must recognize the value of tacit knowledge, professionalize operational capabilities, and foster organizational environments open to learning.

Finally, this study provides an empirical and methodological foundation for the design of knowledge-centered industrial policies, proposing clear pathways for Mexico to strengthen its competitiveness through the structured management of technical learning in industry

## Declaration

## Conflict of Interest

The authors declare no conflict of interest. They have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this article.

## Statement of Originality and Non-Plagiarism

This document is an original and unpublished work. It has not been previously published nor is it under consideration by any other scientific journal. The authors ensure that all external sources have been fully cited in accordance with APA 7 guidelines, properly acknowledging the intellectual authorship of third parties and avoiding any form of academic plagiarism.

## Authors' Contributions

*Bareño-Ramos, Enoc*: Lead author. Study design, case analysis, structural writing of the article, synthesis of findings.

*Delgado-Torres, Claudia Lizethe*: Document curation, methodological design, support in results interpretation, source verification, final formatting of tables.

## Availability of Data and Materials

All data used in this research come from public and verifiable sources. PDF documents and functional links are included in the References section. Any additional requests can be directed to the corresponding author.

## Funding

This research was conducted without financial support from public or private institutions. The work was carried out using the authors' own resources.

## Acknowledgments

The research was conducted without any type of funding, beyond the resources provided by the researchers themselves.

## Abbreviations

CIDESI	Center for Engineering and Industrial Development
CONOCER	National Council for Standardization and Certification of Labor Competencie
LMS	Learning Management System [LMS]
RV	Virtual Reality [VR]
UNAQ	Aeronautical University of Querétaro

## References

### Background

Alonso, G., Pérez, M., & Torres, L. [2024]. [Industry 4.0 and Knowledge Management in Manufacturing Sectors](#). *Journal of Industrial Innovation*, 15[2], 45–63.

## Article

Arrieta, J., & Mendoza, R. [2023]. *Strategic Knowledge Management in Mexican Corporations: Digital Platforms and Communities of Practice*. *Journal of Organizational Studies*, 19[3], 77–94.

CAINTRA Nuevo León. [2024]. *Industrial Indicators of Mexico*. Chamber of the Manufacturing Industry of Nuevo León.

Delgado-Hernández, D. J., Wong, K. Y., & Rigaud-Tellez, N. [2009]. *A case study on knowledge management adoption in Mexico*. 2009 *IEEE International Conference on Industrial Engineering and Engineering Management*, 1566–1570.

Díaz Rodríguez, A., & Morales Sánchez, V. [2021]. *Regional Innovation Systems in Mexico: An Empirical Approach*. *Journal of Regional Innovation*, 5[2], 33–49.

INEGI. [2023]. *Censos Económicos de la Industria Manufacturera*. Instituto Nacional de Estadística y Geografía.

**Basics**

Boisot, M. [1995]. *Information space: A framework for learning in organizations, institutions and culture*. Routledge.

Nonaka, I., & Takeuchi, H. [1998]. *The knowledge-creating company: How Japanese companies create the dynamics of innovation*. Oxford University Press.

Nonaka, I., & Takeuchi, H. [2011]. *The big idea: The wise leader*. *Harvard Business Review*, 89[5], 58–67.

Rowley, J. [2007]. *The wisdom hierarchy: Representations of the DIKW hierarchy*. *Journal of Information Science*, 33[2], 163–180.

Rassini. [2022]. *Advanced Training in Digital Manufacturing*. *Innovation and Development Report*.

**Support**

Bareño, E., & Delgado, R. [2025]. *Multisectoral Cases of Technical Knowledge Transfer*. *Academic document, no URL*.

Briseño, J., & Castellanos, A. [2021]. *Digitalization and Technical Knowledge Transfer at CENIDET*. *Journal of Educational Technology*, 18[1], 98–110.

García, Á., & Cañibano, E. [2024]. *iDIGIT4L: Digital twin retrofitting for industrial learning in SMEs*. *arXiv preprint*.

González-Varona, J. M., López-Paredes, A., Poza, D., & Acebes, F. [2021]. *Building and development of an organizational competence for digital transformation in SMEs*. *Journal of Industrial Engineering and Management*, 14[1], 15–24.

Muñoz-Sánchez, C., Soto-Flores, M. del R., Rocha-Lona, L., Garduño-Román, S., & Garza-Reyes, J. A. [2019]. *Aerospace industry in Queretaro, Mexico: A perspective of regional innovation system*. *Proceedings of the International Conference on Industrial Engineering and Operations Management*.

**Differences**

Gajdzik, B. [2022]. *Technical knowledge management and professionalization in manufacturing industries*. *International Journal of Production Research*, 60[14], 4211–4226.

García, Echeverría & Ovejero. [2023]. *DETECTA program: AI and digital twin predictive maintenance in SMEs*.

Kans, M., & Campos, F. [2023]. *Digital platforms as enablers of organizational learning: A review in industrial contexts*. *Journal of Manufacturing Systems*, 68, 33–49.

QAD. [2021]. *Metalsa: From fragmented systems to centralized digital transformation*. QAD Case Study.

Quimmco. [2022]. *Technical Training and Dual Certification Program*. *Sustainability Report* <https://quimmco.com/media/sustentabilidad2022.pdf>

Romo, R., & Ramírez, M. [2020]. *Organizational Learning in the Metal-Mechanical Supply Chain in Sonora*. *Journal of Urban, Rural, and Regional Economy*, 9[15], 45–65.

**Discussions**

Barrios-Tinoco, L. M., Montañez, A. P., Huamaní, R., & Flores-Limo, F. A. [2024]. [Knowledge Management as a Key Factor in Business Innovation](#). *Venezuelan Journal of Management* 29[106], 760–775.

Salinas-García, R. J. [2012]. [Industrial Development and Professional Training in the Aeronautical Industry in Querétaro](#). *Journal of Education and Development*, 23[Oct–Dic], 55–72.

Velarde-Moreno, J., Blanco, C. E., & Jiménez, A. [2020]. [Mexican local suppliers in home appliance value chains](#). *Inquietud Empresarial*, 20[1], 22–39.

Whirlpool México. [2023]. [Technical Training and Transfer in Line Processes](#). *Whirlpool Annual Report*.

Zárate, M. [2023, octubre 16]. [Artificial Intelligence and Computer Vision for Quality Control at Nemak](#). *El Financiero*.