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INTEGRATING ISO 9712-BASED CERTIFICATION INTO PUBLIC SKILLS TRAINING INSTITUTIONS: A SYSTEMATIC LITERATURE REVIEW

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Abstract:

Non-Destructive Testing (NDT) plays a critical role in ensuring the safety, reliability, and quality of industrial assets, particularly in sectors where inspection decisions directly influence operational integrity and public safety. The competence of NDT personnel is therefore a major concern, as certification based on international standards such as ISO 9712 provides a structured mechanism for qualification, assessment, and professional recognition. However, despite the increasing importance of certified NDT personnel, limited systematic evidence has examined how ISO 9712-based certification can be integrated into public skills training institutions to strengthen personnel competence, training quality, and industrial readiness. This systematic literature review aims to analyze existing research related to NDT personnel certification, training, competency development, and quality-oriented certification practices. The review was conducted using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework. An advanced search strategy was applied in Scopus and Web of Science using the keywords "non-destructive testing",

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"personnel", "training", "competency", and "certification". The search covered publications from 2016 to 2026. Following identification, screening, eligibility assessment, duplicate removal, and quality assessment, 22 primary studies were included in the final qualitative synthesis. The thematic analysis generated three major themes: NDT personnel certification, qualification, and competence assurance; NDT education, training, innovation, and competency development; and data-driven, quality-oriented NDE for certification and industrial assurance. The findings indicate that successful integration of ISO 9712-based certification into public skills training institutions requires alignment between certification standards, instructor capability, practical training resources, competency-based assessment, industrial collaboration, and emerging digital NDE practices. This review synthesizes fragmented evidence and proposes a clearer research direction to strengthen NDT certification pathways within public skills training systems.

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Keywords:

Certification, Competency, Non-Destructive Testing, Personnel, Training

Introduction

Non-destructive testing (NDT) has emerged as a cornerstone of modern industrial quality assurance, underpinning the safety, reliability, and longevity of critical infrastructure across sectors such as manufacturing, civil engineering, energy, aerospace, and transportation (Arndt *et al.*, 2025; Stephens, 2014). The global relevance of NDT is underscored by its indispensable role in detecting material defects and structural anomalies without causing damage, thereby preventing catastrophic failures and optimizing maintenance strategies (Arndt *et al.*, 2025). As industries worldwide confront increasingly stringent safety regulations and the demand for higher operational standards, the competence of NDT personnel has become a focal point for both regulatory bodies and employers (Qi-Yao, 2004; Tiwari *et al.*, 2025). In response to these imperatives, international standards, most notably ISO 9712, have been developed to harmonize qualification and certification processes for NDT practitioners. ISO 9712 establishes a rigorous framework for certifying personnel at multiple competency levels through standardized training, examination, and recertification protocols (Tiwari *et al.*, 2025; Widjanarko & Khotimah, 2021). Its adoption has facilitated cross-border recognition of qualifications, enhanced workforce mobility, and contributed to the mutual recognition of NDT certificates among nations (Feistkorn *et al.*, 2022; Gupta & Khan, 2021; Khorlo, 2018). However, despite widespread endorsement by both developed and developing countries, significant disparities persist in the implementation of ISO 9712-based certification systems. These disparities are particularly pronounced in public skills training institutions (PSTIs) and

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technical and vocational education and training (TVET) settings, where institutional readiness, curriculum alignment, resource allocation, and industry linkages vary considerably across regions (Lim *et al.*, 2017; Mohamad *et al.*, 2026). Recent scholarly discourse has highlighted the urgent need to bridge these gaps by integrating ISO 9712 requirements into PSTI curricula through systemic reforms encompassing not only technical content but also pedagogical innovation, the digitalization of training resources, and robust quality assurance mechanisms (Loutsetis, 2025).

Recent developments in the field have seen a proliferation of national adaptations of ISO 9712, such as JPK ISO 9712:2021 in Malaysia or DIN 4871 in Germany, tailored to address sector-specific needs while maintaining alignment with international best practices (Harara, 2008; Salbiah Hussein, Ilham Mukriz, 2016). Efforts toward harmonization are evident in regional initiatives across Europe, Asia, Africa, and the Arab world aimed at mutual recognition agreements for NDT certification (Gupta & Khan, 2021; Khorlo, 2018) Nonetheless, empirical studies reveal persistent gaps in theory and methodology. For instance, while ISO 9712 prescribes minimum training hours and practical experience requirements, it often lacks detailed guidance on curriculum development or integration with broader educational frameworks such as national qualification frameworks (NQFs) or competency-based education models (Mohamad *et al.*, 2026). This shortfall is particularly acute in contexts where PSTIs serve as primary pipelines for workforce development but struggle with limited access to advanced equipment, insufficiently trained instructors, or outdated pedagogical approaches (Chakravarty, 2024; Johannes & Appel, 2024). Furthermore, there is a notable lack of empirical research evaluating the effectiveness of different implementation models for ISO 9712-based certification within public institutions. Most existing literature either focuses on conceptual frameworks or reports isolated case studies without systematic comparative analysis across diverse educational environments (Ross, 2021). The issue remains unresolved due to ongoing challenges related to standardization versus contextual adaptation: while central certification schemes like ISO 9712 offer consistency and international credibility, employer-based schemes retain flexibility but risk variability in competence assurance (Chai & Yin, 2018; Mills, 2023).

Additionally, rapid technological advancements, including automation, artificial intelligence integration into NDT methods (NDE 4.0), and digital learning platforms, are outpacing current training curricula and certification schemes. This technological shift necessitates continuous curriculum updates to ensure that certified personnel remain proficient with emerging tools and methodologies (Tsougkranis, 2018).

The motivation for this systematic review arises from these unresolved challenges at the intersection of global standardization efforts and local implementation realities. By synthesizing recent scholarship on integrating ISO 9712-based certification into public skills training institutions worldwide, including empirical findings from Malaysia's TVET sector (Mohamad *et al.*, 2026; Salbiah Hussein, Ilham Mukriz, 2016), South Africa's NQF-aligned programs (Johannes & Appel, 2024), UK apprenticeship models (Jovanović, 2024), as well as digital innovations in Russia's VR-based radiography training (Loutsetis, 2025), this study aims to advance understanding beyond existing fragmented accounts. The review seeks to identify best practices for aligning institutional processes with international standards while accommodating contextual constraints such as resource limitations or sector-specific requirements. It also addresses critical gaps by systematically comparing theoretical models with real-world outcomes documented in diverse settings. In doing so, this work offers original

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insights into how PSTIs can operationalize ISO 9712 not merely as a compliance exercise but as an integrated system that fosters sustainable professional competence among NDT personnel. The necessity of this study is further justified by the growing demand for qualified NDT practitioners amid global infrastructure expansion and industrial modernization initiatives; failure to address competence gaps risks undermining both public safety and economic competitiveness (Kuvshinnikov & Kovshov, 2024). By providing a comprehensive synthesis grounded in recent empirical evidence and conceptual advances including governance structures for quality assurance (Mohamad et al., 2026), modular certification frameworks for civil engineering applications (Stephen, 2024), and strategies for digital transformation, the present review offers actionable recommendations for policymakers, educators, accreditation bodies, and industry stakeholders seeking to elevate NDT personnel competence through effective integration of ISO 9712-based certification within public skills training ecosystems.

Literature Review

Non-Destructive Testing (NDT) is a critical field in industrial quality assurance, safety, and maintenance, with applications spanning construction, transportation, and manufacturing. The integration of NDT certification into public skills training institutions is a promising approach to address the growing demand for skilled professionals while ensuring standardized practices. This review explores the current state of NDT certification, its integration into educational frameworks, and the challenges and opportunities it presents.

NDT certification systems, such as those based on ISO 9712, play a pivotal role in ensuring practitioners' competence. These certifications assess both theoretical knowledge and practical skills, with sector-specific training often required to address unique challenges in fields like in-service inspections and corrosion monitoring (Milligan, 2015). The distinction between employer-based (second-party) and independent (third-party) certifications highlights the need for impartiality and standardization in training and assessment (Milligan, 2015). However, gaps in sector-specific competencies, particularly in in-service inspections, have led to the introduction of supplementary training programs by certification bodies (Tsougkranis, 2018). These frameworks underscore the importance of aligning certification processes with industry needs to enhance workforce readiness.

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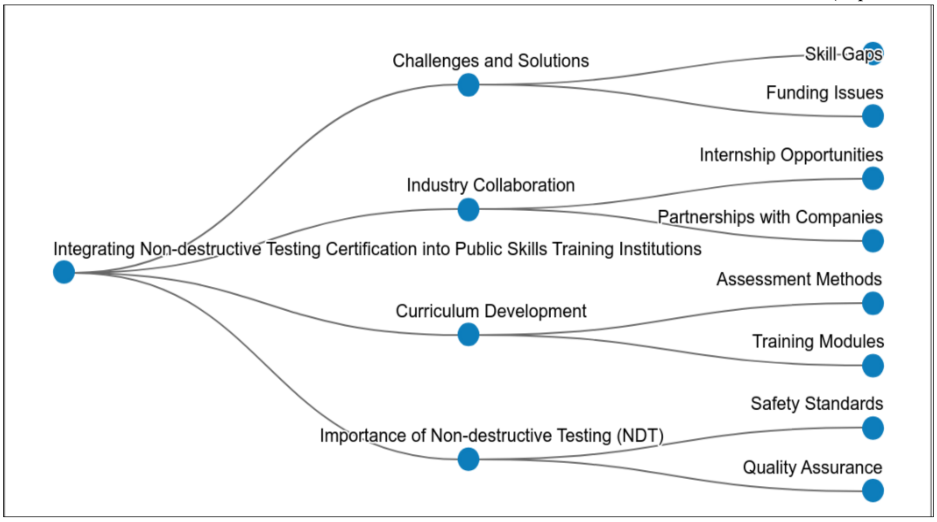

Figure 1: Concept Map of Literature Review Themes for Integrating ISO 9712-Based NDT Certification into Public Skills Training Institutions.

Figure 1 illustrates the key themes of the literature review on integrating ISO 9712-based Non-Destructive Testing certification into public skills training institutions. The concept map shows that successful integration requires attention to four major areas: the importance of NDT, curriculum development, industry collaboration, and challenges and solutions. The importance of NDT is linked to safety standards and quality assurance, underscoring the need for certification to produce competent personnel who can support reliable inspection practices. Curriculum development focuses on training modules and assessment methods, suggesting the need for structured learning content aligned with ISO 9712 requirements. Industry collaboration highlights partnerships with companies and internship opportunities, which are important for strengthening practical exposure and workplace readiness. Meanwhile, challenges such as skill gaps and funding issues indicate that institutional support, resources, and strategic planning are necessary for effective implementation. Overall, the concept map concludes that integrating ISO 9712-based certification into public skills training institutions is not only a curriculum issue, but also a broader institutional and industry-driven process that requires alignment between training standards, assessment practices, industrial needs, and sustainable support mechanisms.

Efforts to integrate NDT training into educational institutions have been explored globally. For instance, modular NDT programs have been implemented in Germany, Singapore, and Ukraine, focusing on embedding foundational NDT concepts into university curricula (Gilbert, 2023; Sulaiman & Eldy, 2023). These programs emphasize the development of advanced techniques and research-driven applications, bridging the gap between academic knowledge and industry requirements. Similarly, apprenticeship schemes, such as those offered by the British Institute of Non-Destructive Testing (BINDT), combine theoretical instruction with practical experience, providing a comprehensive pathway for skill development (Lyon, 2007). These initiatives demonstrate the potential of structured educational programs to produce a skilled and certified NDT workforce.

Despite these advancements, challenges remain in scaling NDT training within public institutions. The scarcity of high-quality defect samples for training, as well as the need for standardized curricula, poses significant barriers (Martinez-Trejo & Pavlakovic, 2025).

Innovative approaches, such as the use of synthetic defect data and advanced simulation tools, have been developed to address these limitations, enhancing the quality and consistency of training (Martinez-Trejo & Pavlakovic, 2025). Additionally, the integration of emerging technologies like artificial intelligence (AI) into NDT workflows offers opportunities to modernize training and improve inspection accuracy (Topp et al., 2025). However, the lack of established standards for AI applications in NDT highlights the need for further research and regulatory development (Topp et al., 2025).

Integrating NDT certification into public skills training institutions offers a strategic solution to meet the growing demand for qualified professionals while promoting standardized practices. Successful implementation requires collaboration between industry, certification bodies, and educational institutions to develop comprehensive training programs that address sector-specific needs. By leveraging technological advancements and adopting innovative training methodologies, public institutions can play a pivotal role in shaping the future of NDT. However, addressing challenges such as resource limitations and the need for standardized curricula will be essential to realize the full potential of this integration.

Research Question

Research questions play a fundamental role in a systematic literature review (SLR) by establishing the scope, direction, and methodological focus of the review. Clearly formulated research questions guide the identification, selection, and exclusion of studies, thereby ensuring the review remains aligned with the study's topic and objectives. They also support the development of a systematic search strategy by defining the key concepts to be examined and ensuring that relevant evidence is captured comprehensively. In addition, research questions provide an analytical structure for organizing, categorizing, and synthesizing findings from the included studies. This helps reduce ambiguity, improve transparency, and strengthen the relevance of the review outcomes. Well-developed research questions also enhance the reproducibility of the review by allowing other researchers to understand the basis for study selection, data extraction, and thematic synthesis. As emphasized by Kitchenham (2007), specifying research questions is one of the most important activities during the planning stage of an SLR because it drives the overall review methodology.

In this study, the PICo framework proposed by Lockwood et al. (2015) was adopted to formulate the research questions. PICo is a mnemonic framework commonly used in qualitative and evidence-based reviews to structure research questions according to three key components: Population, Interest, and Context. The Population in this review refers to Non-Destructive Testing personnel, including trainees, inspectors, technicians, instructors, and NDE/NDT engineers. The Interest focuses on certification, qualification, competence assurance, training innovation, competency development, data-driven NDE, and quality-oriented certification. The Context refers to public skills training institutions, TVET systems, industrial certification environments, and safety-critical industrial settings. The use of the PICo framework ensured that the research questions were systematically developed, conceptually focused, and aligned with the review's overall aim: to examine the integration of Non-Destructive Testing certification into public skills training institutions. Based on this framework, the study was guided by the following three research questions:

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RQ1. How are certification, qualification, and competence assurance processes structured to support the development of competent Non-Destructive Testing personnel in public skills training and industrial certification contexts?

RQ2. What education, training, and competency development approaches are used to enhance the readiness of Non-Destructive Testing personnel for certification and professional practice?

RQ3. How do data-driven and quality-oriented NDE approaches contribute to certification, competence development, and industrial assurance in Non-Destructive Testing?

Materials and Methods

The present systematic literature review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework developed by Page et al. (2021). PRISMA is widely recognized as a rigorous and transparent reporting standard for systematic reviews, as it provides a structured procedure for identifying, screening, assessing, and including relevant studies. By adhering to PRISMA guidelines, this review sought to enhance methodological transparency, minimize selection bias, and ensure the consistency and reproducibility of the review process. The use of PRISMA also strengthens the credibility of the synthesis by requiring explicit reporting of search strategies, eligibility criteria, study selection procedures, and data extraction processes. In this study, two major bibliographic databases, Scopus and Web of Science, were selected for their extensive multidisciplinary coverage, high-quality indexing, and relevance to engineering, technical education, certification, and workforce development research.

The PRISMA process was implemented through four main stages: identification, screening, eligibility assessment, and inclusion. During the identification stage, relevant records were retrieved from Scopus and Web of Science using predefined keywords and Boolean search strings aligned with the scope of the review. The screening stage involved removing duplicates and assessing titles and abstracts against the established inclusion and exclusion criteria. Subsequently, the eligibility stage required a full-text assessment of potentially relevant studies to determine their suitability for inclusion in the final synthesis. Finally, studies that met all eligibility criteria were included for data extraction, thematic analysis, and evidence synthesis. This systematic and transparent procedure ensured that the review was conducted with methodological rigor and produced reliable findings to inform future research, policy development, and practice related to ISO 9712-based certification, non-destructive testing personnel competence, and public skills training institutions.

Identification

According to the PRISMA framework, the identification phase is the initial stage of the systematic literature review process, during which potentially relevant records are retrieved from selected databases. In this review, Scopus and Web of Science were chosen as the primary databases due to their broad multidisciplinary coverage, strong indexing standards, and relevance to engineering, technical education, personnel competence, and certification-related research. The search was conducted using predefined keywords related to non-destructive testing, personnel, training, competency, and certification (as shown in Table 1). The initial search yielded 179 records from Scopus and 44 from Web of Science, totalling 223 records for

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further review. The higher number of records retrieved from Scopus indicates broader coverage of applied engineering, vocational training, and industry-oriented publications, whereas Web of Science yielded a more selective set of records from high-quality journals and proceedings. The combined use of both databases strengthens the comprehensiveness of the review by reducing database selection bias and increasing the likelihood of capturing relevant studies across technical, educational, and certification domains. These 223 records formed the initial evidence base for subsequent duplicate removal, screening, eligibility assessment, and final inclusion.

Screening

Following the identification phase, the screening process was conducted to refine the initial pool of records and ensure only studies within the review scope were retained. A total of 165 records were excluded based on predefined criteria, including non-English publications, studies published before 2016, books, review articles, in-press documents, and records outside the selected subject areas of Engineering, Computer Science, Materials Science, and Social Sciences (refer to Table 2). In addition, documents outside the gold access category were also removed to ensure accessibility and consistency in full-text retrieval. After applying these screening criteria, 58 records remained, comprising 32 records from Scopus and 26 records from Web of Science. This reduction indicates that the review adopted a rigorous, targeted selection process to retain studies most relevant to non-destructive testing, personnel competence, training, and certification. Subsequently, duplicate records were checked across databases to avoid duplicates, resulting in the removal of 11 records. Consequently, 47 unique records were retained for the eligibility assessment stage.

Table 1: The Search String.

Scopus	(TITLE-ABS-KEY ("non-destructive testing" OR "nondestructive testing" OR "non destructive testing" OR "non-destructive evaluation" OR "nondestructive evaluation" OR NDT OR NDE) AND TITLE-ABS-KEY (training OR education OR learning OR teaching OR instruction OR "practical training" OR "industrial training" OR "skills training") AND TITLE-ABS-KEY (certification OR "professional certification" OR competence OR competency OR "skills development" OR "workforce development")) **Date of Access: June 2026**
WoS	("non-destructive testing" OR "nondestructive testing" OR "non destructive testing" OR "non-destructive evaluation" OR "nondestructive evaluation" OR NDT OR NDE) (Topic) AND (training OR education OR learning OR teaching OR instruction OR "practical training" OR "industrial training" OR "skills training") (Topic) AND (certification OR "professional certification" OR "personnel certification" OR "skills certification" OR qualification OR "qualification system" OR "certification system") (Topic) **Date of Access: June 2026**

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Table 2: The Selection Criterion Is Searching

Criterion	Inclusion	Exclusion
Language	English	Non-English
Timeline	2016 – 2026	< 2016
Literature type	Journal, Conference	Book, Review
Publication Stage	Final	In Press
Subject Area	Engineering, Computer Science, Material Science, Social Science	Besides Engineering, Computer Science, Material Science, Social Science
Open Access	Gold	Besides Gold

Eligibility

During the eligibility phase, the remaining 47 full-text articles were assessed in greater detail to determine their relevance to the objectives of the review. This stage involved a more rigorous evaluation of the content beyond the title and abstract screening, with particular attention given to the alignment of each study with the core focus areas of non-destructive testing, personnel competence, training, competency development, and certification. A total of 25 articles were excluded because they were considered out of field, had titles that were not sufficiently significant to the review scope, or presented abstracts that were not directly related to the objectives of the study. This exclusion process was necessary to ensure that only conceptually and methodologically relevant studies were retained for synthesis. As a result, 22 studies met the eligibility criteria and were included in the qualitative analysis. These studies formed the final evidence base for identifying key themes, research patterns, and knowledge gaps related to NDT personnel competence and certification.

Data Abstraction and Analysis

An integrative analysis was employed in this study to systematically examine, interpret, and synthesize evidence from the 22 studies included in the qualitative analysis. This approach was considered appropriate because the selected studies comprised diverse research designs, methodological orientations, and disciplinary perspectives related to non-destructive testing certification, personnel competence, and public skills training institutions, as shown in Table 3. The analysis began with a comprehensive data extraction process, in which each publication was carefully reviewed to identify key concepts, methodological characteristics, empirical findings, and arguments relevant to the objectives of the review. As illustrated in Figure 2, the authors systematically examined the included studies to identify recurring themes and subthemes associated with the integration of non-destructive testing certification into public skills training institutions.

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Following the initial extraction, the authors compared the findings across studies to identify patterns, similarities, and conceptual relationships. Attention was given to how previous studies discussed certification systems, training practices, competence development, institutional readiness, and workforce outcomes. The methodological approaches and main findings of each study were also analyzed to determine the strength and relevance of the evidence. To enhance analytical rigor, the authors maintained an audit log throughout the analysis to document emerging interpretations, analytical decisions, uncertainties, and reflections on theme development. The preliminary themes were then reviewed collaboratively by the authors to ensure consistency, coherence, and alignment with the study objectives. Any differences in interpretation were resolved through discussion and consensus. This iterative process strengthened the credibility of the thematic synthesis and ensured that the final themes were grounded in the evidence extracted from the included studies.

Identification Quality of Appraisal

In accordance with the guidelines proposed by Kitchenham (2007), the quality assessment stage was conducted after the selection of primary studies to evaluate the methodological rigor, relevance, and reliability of the evidence included in the review. This step is essential in systematic literature reviews because it allows researchers to assess the strength of the selected studies and compare them in a structured, transparent manner. In the present study, the quality assessment framework was adapted from Abouzahra et al. (2020) was employed, comprising six quality assessment criteria specifically aligned with the objectives of this review. Each selected study was evaluated against these criteria using a three-point scoring system. A score of 1 was assigned when the criterion was fully met and rated as “Yes” (Y), a score of 0.5 was assigned when the criterion was partially met and rated as “Partly” (P), and a score of 0 was assigned when the criterion was not met and rated as “No” (N). This scoring approach enabled a more systematic and consistent evaluation of study quality, ensuring that only studies with sufficient methodological and contextual relevance contributed meaningfully to the final synthesis.

QA1. Is the purpose of the study clearly stated?
QA2. Is the interest and the usefulness of the work clearly presented?
QA3. Is the study methodology clearly established?
QA4. Are the concepts of the approach clearly defined?
QA5. Is the work compared and measured with other similar work?
QA6. Are the limitations of the work clearly mentioned?

The table presents the quality assessment (QA) procedure used to evaluate the methodological quality and relevance of the selected studies based on predefined criteria. Three experts independently assessed each study by assigning a rating of “Yes” (Y), “Partly” (P), or “No” (N) for each criterion. These ratings were then converted to numerical scores, with “Yes” indicating full compliance, “Partly” partial compliance, and “No” non-compliance with the criterion. The scores provided by all three experts were subsequently summed to generate an overall quality score for each study. To ensure that only studies of sufficient quality and relevance were retained for the subsequent analysis, a minimum acceptance threshold was established. Studies with a total score exceeding 3.0 were accepted for further review, while those falling below the threshold were excluded. This procedure strengthened the transparency, consistency, and rigour of the study selection process by ensuring that the final synthesis was based on evidence that met an acceptable quality standard.

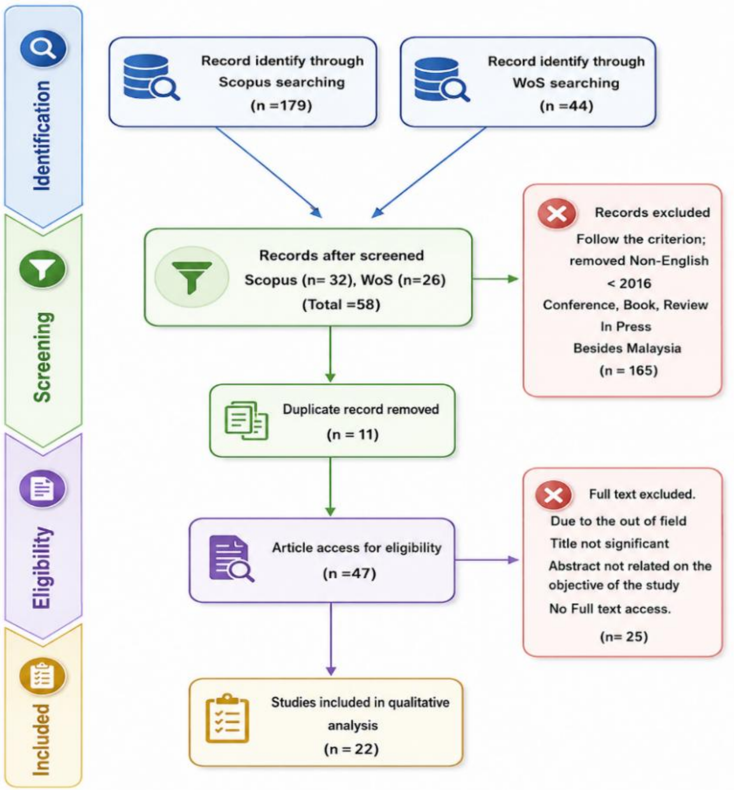

Figure 2: Flow Diagram of the Proposed Searching Study

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Table 3: Number and details of Primary Studies Database

No	Authors	Title	Year	Source title	Scopus	WoS
1	Cramer *et al.* (2017)	Significance of personnel qualification and quality management for thermal spray plants	2017	Proceedings of the International Thermal Spray Conference	√	
2	Bayar *et al.* (2026)	Intelligent Non-Destructive Evaluation of Additively Manufactured Metal Parts: From Advanced Inspections to Data-Driven Quality Predictions	2026	Journal of Manufacturing and Materials Processing	√	
3	Zavadil and Zavadil (2018)	Quality factors affecting NDT personnel qualification and certification process	2018	NDT 2018 - 57th Annual Conference of the British Institute of Non-Destructive Testing	√	
4	Martinez-Trejo and Pavlakovic (2025)	Enhancing Inspector Training Through the Integration of Artificial Defect Data in Guided Wave Testing	2025	62nd Annual Conference of the British Institute of Non-Destructive Testing, NDT 2025	√	
5	Pacana *et al.* (2023)	Method for Analysing Quality Problems of Automotive Castings	2023	Materials Research Proceedings	√	
6	O'Brien (2019)	Development and qualification of additively manufactured parts for space	2019	Optical Engineering	√	
7	Rastegaev *et al.* (2017)	Universal Educational and Research Facility for the Study of the Processes of Generation and Propagation of Acoustic Emission Waves	2017	Inorganic Materials	√	
8	Holland (2017)	Preparing the NDE engineers of the future: Education, training, and diversity	2017	AIP Conference Proceedings	√	
9	Lindgren & Jolley (2020)	Perspective on nondestructive evaluation of additive manufactured components	2020	ASTM Special Technical Publication	√	

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10	Ilia and Zemzyulina (2024)	PLS-SEM multigroup analysis of industry 5.0 specific human capital performance in manufacturing companies	2024	Proceedings - European Council for Modelling and Simulation, ECMS	√	
11	Aldrin & Lindgren (2018)	The need and approach for characterization - U.S. air force perspectives on materials state awareness	2018	AIP Conference Proceedings	√	
12	Neumann *et al.*(2025)	A data-based certification approach for additively manufactured metal aircraft components	2025	Progress in Additive Manufacturing	√	√
13	Gbadamosi-Adeniyi *et al.* (2024)	ML-Based Analysis of In-Situ Backscatter Electron Detection for Quality Assurance during Additive Manufacturing	2024	2024 Joint International Vacuum Electronics Conference and International Vacuum Electron Sources Conference, IVEC + IVESC 2024	√	
14	Crespo *et al.* (2023)	A Challenge-Based Specialization Diploma on Structural Health Monitoring for Civil Engineering and Architecture Programs	2023	ASEE Annual Conference and Exposition, Conference Proceedings	√	
15	Rodriguez-Martin and Rodriguez-Gonzalvez, (2018)	Learning based on 3D photogrammetry models to evaluate the competences in visual testing of welds	2018	IEEE Global Engineering Education Conference, EDUCON	√	
16	Murav'ev *et al.* (2024)	Analysis of Test Results and Test Quality during Certification of Non-Destructive Testing Specialists	2024	Russian Journal of Nondestructive Testing	√	
17	Tsougkranis (2018)	In-service inspection; training and certification aspects	2018	NDT 2018 - 57th Annual Conference of the British Institute of Non-Destructive Testing	√	
18	Prakash *et al.* (2023)	Learning defects from aircraft NDT data	2023	NDT and E International	√	√

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19	Hall (2020)	Competencies, Self-awareness, and Practice: Notes on My Reading of Chapters 5–7	2020	New Directions for Evaluation	√	
20	Kolokolnikov and Dubov (2017)	Training of NDT personnel in the field of condition monitoring and technical diagnostics based on the metal magnetic memory method	2017	WCCM 2017 - 1st World Congress on Condition Monitoring 2017	√	
21	Virkkunen *et al.* (2021)	Augmented Ultrasonic Data for Machine Learning	2021	Journal Of Nondestructive Evaluation		√
22	Snow *et al.* (2023)	Scalable in situ non-destructive evaluation of additively manufactured components using process monitoring, sensor fusion, and machine learning	2021	Additive Manufacturing		√

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Result and Finding

Quality Assessment Analysis

The quality assessment indicates that the selected studies demonstrate an acceptable to high level of methodological and contextual relevance for inclusion in the systematic literature review. Most studies scored above the minimum acceptance threshold of 3.0, suggesting that they sufficiently addressed the core assessment criteria, including clarity of research purpose, relevance and usefulness of the work, methodological transparency, conceptual clarity, comparison with related studies, and acknowledgment of limitations (shown in Table 4). Several studies achieved very high scores, reflecting strong alignment with the review objectives and a well-established contribution to non-destructive testing, personnel competence, certification, training, and quality assurance. However, some studies received lower scores due to limited methodological detail, insufficient discussion of limitations, or weaker comparison with similar work. These variations are expected given the diversity of research designs, publication types, and disciplinary orientations represented in the selected literature. Nevertheless, the overall assessment confirms that the final set of studies provides a credible and sufficiently robust evidence base for qualitative synthesis and thematic analysis.

Table 4: Quality Assessment Analysis

Paper	QA1	QA2	QA3	QA4	QA5	QA6	Total Mark	Percentage (%)
PS1	Y	Y	N	P	P	N	4.5	75.0
PS2	Y	Y	Y	Y	Y	Y	6.0	100.0
PS3	Y	Y	P	Y	Y	P	5.0	83.3
PS4	Y	Y	Y	Y	P	P	5.0	83.3
PS5	Y	Y	Y	Y	Y	N	5.0	83.3
PS6	Y	Y	Y	Y	P	Y	5.5	91.7
PS7	Y	Y	Y	Y	P	N	4.5	75.0
PS8	Y	Y	P	Y	P	Y	5.0	83.3
PS9	Y	Y	P	Y	P	Y	5.0	83.3
PS10	Y	P	Y	Y	Y	P	5.0	83.3
PS11	Y	Y	Y	Y	P	P	5.0	83.3
PS12	Y	Y	Y	Y	P	Y	5.5	91.7
PS13	Y	Y	Y	Y	P	P	5.0	83.3
PS14	Y	Y	Y	Y	Y	N	5.0	83.3
PS15	Y	Y	Y	Y	P	N	4.5	75.0
PS16	Y	Y	Y	Y	Y	Y	6.0	100.0
PS17	Y	Y	P	Y	Y	Y	5.5	91.7
PS18	Y	Y	Y	Y	Y	P	5.5	91.7
PS19	P	P	P	Y	P	Y	4.5	75.0
PS20	Y	Y	P	Y	P	P	4.5	75.0
PS21	Y	Y	Y	Y	Y	Y	6.0	100.0
PS22	Y	Y	Y	Y	Y	Y	6.0	100.0

Note: Note: Y=1, P=0.5, N=0

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Thematic Analysis

The thematic development in this review was conducted through an interpretive synthesis of the titles and abstracts of the 22 selected studies. The analysis focused on identifying recurring concepts, dominant research objectives, methodological orientations, practical contributions, and emerging gaps related to non-destructive testing, personnel competence, training, certification, and quality assurance (shown in Table 5). Based on the evidence available from the titles and abstracts, the literature can be organized into three major themes. The first theme captures studies that directly address personnel qualification, certification, competence assurance, examination quality, and professional requirements for NDT personnel. The second theme focuses on education, training innovation, and competency development, including virtual learning, artificial defect data, educational facilities, challenge-based learning, and competence evaluation. The third theme reflects the growing transformation of NDT and NDE through digitalization, machine learning, data-driven quality prediction, additive manufacturing, and certification-oriented quality assurance. This three-theme structure provides a coherent basis for discussing how NDT personnel competence is shaped by certification systems, training practices, and emerging digital technologies within safety-critical and industry-oriented contexts.

Table 5: Theme Development Summary

Theme	Focus Area	Main Research Direction
Theme 1: NDT Personnel Certification, Qualification and Competence Assurance	Personnel certification, ISO-based qualification, examination quality, training requirements, professional competence, sector-specific certification	Examines how NDT personnel competence is developed, assessed, certified, and assured through structured qualification systems, certification processes, examination quality, and professional standards.
Theme 2: NDT Education, Training Innovation, and Competency Development	Inspector training, virtual learning, educational facilities, challenge-based learning, competency evaluation, professional learning, training resources	Explores how educational models, training technologies, learning resources, and competency-based approaches support the development of NDT inspectors, technicians, engineers, and related professionals.
Theme 3: Data-Driven and Quality-Oriented NDE for Certification and Industrial Assurance	Machine learning, digital twins, sensor fusion, additive manufacturing, predictive quality assurance, NDE-based qualification, quality management, human capital	Investigates the use of advanced NDT/NDE technologies, data-driven systems, quality management approaches, and digital tools to support certification, industrial quality assurance, and workforce capability.

NDT Personnel Certification, Qualification, and Competence Assurance

The selected studies indicate that NDT personnel certification and qualification are strongly positioned as mechanisms for ensuring competence, reliability, and responsibility in safety-critical industrial work. Across the reviewed abstracts, personnel competence is not treated as an isolated individual attribute but as part of a broader assurance system encompassing training, qualifications, certification, employer responsibility, and quality management. Cramer et al. (2017) emphasized that internationally recognized qualifications and certifications are increasingly required in industrial sectors where process outcomes cannot be fully verified through final inspection alone. Zavadil and Zavadil (2018) similarly argued that NDT personnel qualification is essential for responsible task execution, particularly because certification must demonstrate readiness to perform inspection activities correctly. Tsougkranis (2018) extended this concern to in-service inspection, where degradation mechanisms such as corrosion, stress corrosion cracking, and fatigue damage demand sector-specific competence beyond general NDT knowledge. Murav'ev et al. (2024) further strengthened this theme by showing that certification quality depends not only on candidate performance, but also on the alignment between examination difficulty and candidate training level.

A major finding across the theme is that certification effectiveness depends heavily on the quality and structure of training before assessment. The abstracts suggest that training should not function merely as a formal requirement before certification, but as a systematic process for developing theoretical understanding, practical capability, sector-specific judgement, and readiness for examination. Zavadil and Zavadil (2018) highlighted several quality factors in NDT training, including lecturer requirements, course design, theoretical and practical balance, training materials, equipment, and test samples. Tsougkranis (2018) identified a gap in the standard certification route under ISO 9712, particularly where sector-specific competence for in-service inspection is not sufficiently embedded in training and examination processes. Cramer et al. (2017) also linked effective personnel qualification with monitored installations, controlled parameters, and structured training in special processes. Murav'ev et al. (2024) provided additional evidence that test outcomes can reveal mismatches between candidate preparation and task difficulty, suggesting that training programmes should be adjusted based on examination evidence rather than maintained as fixed instructional routines.

The findings also show that competence assurance requires stronger integration between certification standards, assessment design, and workplace requirements. Certification is presented not only as proof of individual achievement, but also as a quality assurance mechanism that supports industrial confidence, contractual compliance, and safe inspection performance. Cramer et al. (2017) connected personnel certification with quality management systems and industrial certification requirements, particularly in sectors such as aviation, rail vehicles, power engineering, and thermal spraying. Zavadil and Zavadil (2018) discussed the distinction between employer-based and independent qualification and certification, indicating that responsibility for personnel competence must be shared between certification systems and employing organizations. Tsougkranis (2018) proposed ISO 9712-compliant employer-specific schemes governed by accredited third-party certification bodies as a possible solution for sector-specific competence assurance. Murav'ev et al. (2024) contributed an assessment-based perspective by applying Rasch analysis to examine examination quality, task difficulty, candidate training level, and distribution of test items. Together, these studies indicate that reliable certification systems require alignment among standards, training delivery, examination validity, employer needs, and industrial risk contexts.

Overall, the evidence under this theme suggests that integrating NDT certification into public skills training institutions requires more than adopting international standards at the curriculum level. The reviewed studies imply that effective integration should include competent instructors, sufficient practical resources, valid assessment instruments, sector-specific training content, employer engagement, and quality management procedures. Cramer et al. (2017) showed that certification and quality management are closely connected in special industrial processes, while Zavadil and Zavadil (2018) demonstrated that course quality, lecturer competence, and practical resources influence certification outcomes. Tsougkranis (2018) highlighted the need for additional sector-specific preparation where conventional ISO 9712 certification routes may not fully address in-service inspection demands. Murav'ev et al. (2024) further indicated that examination data can support evidence-based improvement of training and certification systems. For public skills training institutions, this synthesis suggests that ISO 9712-based certification should be institutionalized through a complete competence assurance pathway involving training design, practical exposure, examination readiness, certification governance, and continuous quality improvement.

NDT Education, Training, Innovation, and Competency Development

The findings under the theme of NDT education, training innovation, and competency development show that effective competence formation in non-destructive testing requires more than conventional classroom instruction. The selected abstracts indicate a strong movement toward practical, simulation-based, technology-supported, and competency-oriented learning approaches. Martinez-Trejo and Pavlakovic (2025) highlighted the limitation of inspector training caused by the lack of high-quality defect samples and proposed artificial defect data as a method to strengthen guided wave testing training and assessment. Rastegaev et al. (2017) demonstrated a similar concern by developing an educational and research facility capable of simulating acoustic emission sources, industrial objects, and repeatable diagnostic situations for training and certification purposes. Holland (2017) broadened this discussion by arguing that future NDE engineers require strong interdisciplinary preparation across measurement physics, engineering knowledge, and practical shop-floor exposure. Crespo et al. (2023) also showed that challenge-based learning can develop competencies in structural health monitoring, instrumentation, and non-destructive testing through real structural testing and industry collaboration.

A recurring finding across the abstracts is that competency development in NDT is strengthened when learners are exposed to realistic defect conditions, practical equipment, and structured assessment situations. Martinez-Trejo and Pavlakovic (2025) reported that artificial defect data can provide diverse and standardized scenarios for guided wave training, allowing more consistent interpretation exercises and examination materials. Rodriguez-Martin and Rodriguez-Gonzalvez, (2018) presented another form of training innovation through three-dimensional photogrammetry models of welds, enabling competence acquisition and evaluation in visual testing without requiring direct access to physical laboratories. Rastegaev et al. (2017) Similarly, repeated simulation of cracks, corrosion damage, leaks, and other acoustic emission sources is a low-cost method for education and personnel certification. Kolokolnikov and Dubov (2017) added a sector-specific training perspective by focusing on condition monitoring and technical diagnostics using the metal magnetic memory method, in which stress-strain state assessment is a central component of expert preparation.

The reviewed studies also suggest that NDT education should align with broader professional and industrial competence requirements. Holland (2017) noted that NDE engineering requires broad knowledge across multiple physics domains, engineering principles, NDE methods, and industrial practices, and identified a shortage of education programs designed specifically for NDE engineers. Crespo et al. (2023) showed that a challenge-based specialization diploma can produce positive competency outcomes when theoretical learning is combined with laboratory work, field instrumentation, structural testing, and participation from industry specialists. Hall (2020) contributed a broader competence perspective by linking evaluator competencies with professional self-knowledge, education, in-service training, and practice-based development. Kolokolnikov and Dubov (2017) further indicated that training for condition monitoring and technical diagnostics must address complex industrial problems beyond simple flaw detection, especially when lifetime assessment and stress evaluation are involved.

The synthesis indicates that NDT education and training innovation are increasingly moving toward experiential, digital, simulated, and industry-connected learning environments. The abstracts collectively show that competency development can be improved through artificial defect datasets, virtual models, educational test facilities, challenge-based programs, and specialized training linked to certification needs. Martinez-Trejo and Pavlakovic (2025), Rodriguez-Martin and Rodriguez-Gonzalvez, (2018), and Rastegaev *et al.* (2017) demonstrated that simulation and digital resources can reduce dependence on limited physical defect samples while improving assessment consistency. Holland (2017), Crespo et al. (2023), and Hall (2020) emphasized the need for broader educational structures that support professional competence, interdisciplinary learning, and continuous development. For public skills training institutions, these findings suggest that integrating NDT certification should include not only formal training hours but also realistic practice environments, competency-based assessment tools, industry participation, and flexible learning resources suitable for different NDT methods and occupational levels.

Data-Driven and Quality-Oriented NDE for Certification and Industrial Assurance

The findings under the theme of data-driven, quality-oriented NDE for certification and industrial assurance indicate a clear transition from a conventional inspection-centred practice toward integrated, digital, and evidence-based quality assurance systems. Bayar et al. (2026) conceptualized advanced NDT in additive manufacturing as a “quality intelligence layer”, where inspection data, machine learning, digital twins, and cyber-physical systems are connected to support predictive quality decisions. O’Brien (2019) similarly emphasized that qualification of additively manufactured parts, particularly for space applications, requires certification standards, predictive models, shared data, and closed-loop process control to manage process variability. Lindgren and Jolley (2020) added that NDE capability in additive manufacturing must be validated through probability of detection, defect characterization, process knowledge, and systematic evaluation of structural performance. Neumann et al. (2025) further advanced this direction by proposing a data-driven certification process for aircraft components, integrating design, manufacturing, post-treatment, NDT, destructive testing, and machine learning-based prediction.

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A consistent issue across the selected studies is the need to connect NDE data with certification and industrial decision-making. Additive manufacturing introduces complex defects, geometry-related challenges, residual stresses, anisotropic microstructures, and process-dependent variability, making traditional post-process inspection insufficient for high-risk applications. Bayar et al. (2026), O'Brien (2019), and Lindgren and Jolley (2020) each highlighted that certification in advanced manufacturing cannot depend solely on final inspection but must also consider process control, material behaviour, defect detectability, and validated inspection capability. Snow et al. (2023) demonstrated this shift through an in situ NDE system that used process monitoring, sensor fusion, machine learning, and probability-of-detection curves to evaluate subsurface flaws in laser powder bed fusion components. Gbadamosi-Adeniyi et al. (2024) also addressed certification challenges by applying in situ sensing and machine learning during electron beam powder bed fusion for real-time qualification, showing the relevance of embedded monitoring for quality assurance before final product evaluation.

The abstracts also show that machine learning and data analytics are increasingly used to improve defect detection, classification, and certification confidence. Prakash et al. (2023) developed machine learning models for ultrasonic aircraft inspection data and linked algorithmic detection performance with an industry-based certification process using probability of detection. Virkkunen et al. (2021) reported that augmented ultrasonic data and deep convolutional networks can support flaw detection performance comparable with trained human inspectors, while also showing that limited representative flaw data remains a key barrier for field implementation. Aldrin and Lindgren (2018) discussed model-assisted inversion, physics-based models, deep learning, and heuristic approaches as pathways for quantitative NDE characterisation and probabilistic life management. Bayar et al. (2026) also identified image processing, signal processing, supervised learning, deep learning, and multi-sensor data fusion as important enablers of automated defect classification and predictive quality assessment. Taken together, these studies suggest that future certification practices will increasingly require digital evidence, traceable data pipelines, validated algorithms, and performance metrics that are acceptable for industrial assurance.

Quality-oriented NDE also appears closely linked to organizational capability, human competence, and continuous improvement. Pacana et al. (2023) showed that quality problems in automotive castings can be analyzed through methodological triangulation involving NDT tests and quality management tools, where gas porosity was linked to outdated work instructions and low employee competence. Ilia and Zemzyulina (2024) demonstrated that digital competencies and Industry 5.0-specific human capital have a positive relationship with production system performance, suggesting that digital transformation in quality assurance also depends on workforce capability. Neumann et al. (2025) and Gbadamosi-Adeniyi et al. (2024) indicated that data-based certification platforms and real-time qualification methods still require reliable training data, production data, and quality assurance procedures. Snow et al. (2023) further argued that conventional machine learning metrics may be insufficient for NDE flaw detection performance, making POD and false-alarm evaluation more suitable for qualification contexts. For public skills training institutions, these findings indicate that future NDT certification integration should include not only conventional method training, but also digital NDE literacy, data interpretation, machine learning awareness, quality management, and evidence-based certification readiness.

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Conclusion

This systematic literature review aimed to examine the integration of ISO 9712-based certification into public skills training institutions, with particular attention to the competence, training readiness, certification processes, and industrial assurance of Non-Destructive Testing personnel. The review covered studies published between 2016 and 2026 and was conducted using the PRISMA framework to ensure a transparent, structured, and reproducible review process. Scopus and Web of Science were selected as the primary databases due to their relevance to engineering, technical education, certification, and workforce development research. Based on the inclusion and exclusion criteria, only studies published within the selected timeframe and written in English, and focused on NDT, personnel, training, competency, and certification, were retained. The review was guided by three research questions: certification and competence assurance processes; education and training approaches; and the role of data-driven NDE in supporting certification and industrial assurance.

The findings show that the literature on ISO 9712-based NDT certification is distributed across three major themes. The first theme, NDT personnel certification, qualification, and competence assurance, indicates that certification is not only a formal recognition mechanism but also an essential system for assuring inspection reliability, professional responsibility, and sector-specific competence. The second theme, NDT education, training innovation, and competency development, highlights the importance of practical training, simulation-based learning, artificial defect data, virtual models, challenge-based learning, and industry-connected learning environments. The third theme, data-driven and quality-oriented NDE for certification and industrial assurance, reflects the increasing role of machine learning, digitalization, sensor fusion, probability of detection, quality management, and data-based certification in modern NDT practice. Together, these themes show that the successful integration of ISO 9712-based certification into public skills training institutions requires alignment between standards, curriculum, instructors, facilities, assessment systems, industry collaboration, and digital transformation.

This review contributes to the field by synthesizing fragmented knowledge across NDT certification, training systems, competence development, and quality assurance. Previous studies often discussed these areas separately, such as personnel certification, inspector training, advanced NDE technologies, or industrial quality systems. This review brings these areas together and provides a broader understanding of ISO 9712-based certification as an institutional competence-assurance pathway. The thematic classification provides a useful framework for understanding how public skills-training institutions can strengthen NDT training by integrating certification standards, competency-based education, practical assessment, and emerging digital NDE practices. This synthesis also extends the discussion beyond technical NDT performance to the wider institutional conditions required to produce competent, certification-ready NDT personnel.

The practical implications of this review are relevant to public skills training institutions, TVET providers, certification bodies, policymakers, instructors, and industry stakeholders. For public skills training institutions, the findings suggest that ISO 9712-based certification should not be implemented only as an additional examination requirement. Instead, certification should be embedded into curriculum design, instructor development, training facilities, practical

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exposure, assessment planning, and industry partnership. Training providers need to ensure that learners receive sufficient theoretical knowledge, hands-on experience, practice in defect interpretation, and preparation for certification. Certification bodies and policymakers may use these findings to support more structured pathways for instructor certification, equipment upgrading, sector-specific training, and quality assurance. Industry collaboration is also important to ensure that training outcomes reflect workplace requirements, inspection risks, and current technological developments.

Several limitations should be acknowledged. The review was limited to Scopus and Web of Science, potentially excluding relevant studies from other databases, professional bodies, technical reports, certification documents, or grey literature. The use of English-language publications and the selected publication period from 2016 to 2026 may also have limited the range of evidence included. In addition, the review relied mainly on titles and abstracts for thematic classification, potentially missing some methodological details or deeper findings. Another important gap identified from the review is the limited number of studies specifically addressing NDT training programs that integrate artificial intelligence, digital NDE tools, and AI-related curriculum components into certification-based training. Future research should therefore examine how AI, machine learning, digital twins, simulation tools, and data analytics can be formally embedded into ISO 9712-aligned training curricula. Empirical studies are also needed to evaluate implementation models in public skills training institutions, including instructor readiness, trainee certification outcomes, institutional capability, and industry acceptance.

In conclusion, this systematic literature review demonstrates that integrating ISO 9712-based certification into public skills training institutions is a strategic approach for strengthening NDT personnel competence, improving certification readiness, and supporting industrial quality assurance. The review highlights that effective integration requires more than adopting an international standard; it requires a complete institutional system involving curriculum alignment, competent instructors, adequate resources, valid assessment, industry linkage, and continuous quality improvement. Systematic reviews in this field are important because they provide evidence-based synthesis for a research area that remains fragmented across certification, education, technology, and industrial practice. Such synthesis can guide future empirical research, support policy development, and assist public skills-training institutions in preparing competent, certified, and responsive NDT personnel.

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