International Journal of Modern Education
IJMOE
EISSN: 2637-0905
Volume: 8 Issue: 31 (September 2026) PP. 01-26

INTERNATIONAL JOURNAL OF MODERN EDUCATION (IJMOE)
www.gaexcellence.com/ijmoe

THE HUMAN DIMENSION OF NON-DESTRUCTIVE TESTING: A BIBLIOMETRIC REVIEW

Zawawi Mohamad[1]*, Affero Ismail[2], Mohd Hatta Md Hani[3], Abdul Rahim Mustafa Khalid[4]

[1]Faculty of Technical and Vocational Education, Universiti Tun Hussein Onn Malaysia, Johor, Malaysia
gb230016@student.uthm.edu.my https://orcid.org/0009-0001-1524-2446
[2]Faculty of Technical and Vocational Education, Universiti Tun Hussein Onn Malaysia, Johor, Malaysia
affero@uthm.edu.my https://orcid.org/0000-0002-2561-0417
[3]Center of Diploma Studies, Universiti Tun Hussein Onn Malaysia, Pagoh, Johor, Malaysia
hatta@uthm.edu.my https://orcid.org/0000-0002-4237-8859
[4]Competency Certification Division (NDT), Department of Skills Development, Putrajaya, Malaysia
abd.rahim@mohr.gov.my https://orcid.org/0009-0003-0178-5292
*Corresponding Author

Article Info:

Article history:
Received date: 01.07.2026
Revised date: 15.07.2026
Accepted date: 06.08.2026
Published date: 02.09.2026

To cite this document:

Mohamad, Z., Ismail, A., Hani, M. H. M., & Khalid, A. R. M. (2026). The Human Dimension of Non-Destructive Testing: A Bibliometric Review. *International Journal of Modern Education, 8*(31), 01-26.

Abstract:

Non-destructive testing (NDT) is an essential inspection and safety assurance practice in industries where structural integrity and failure prevention are critical. Although NDT research has been strongly influenced by defect detection, automation, digital inspection, and NDE 4.0, the human dimension remains less systematically mapped. This study examines how the human-dimension components of NDT practice are positioned within the broader NDT research landscape. A bibliometric analysis was conducted using 616 Scopus-indexed documents published between 1967 and 2026, refined from an initial search of 712 records. VOSviewer, Biblioshiny, biblioMagika, and Microsoft Excel were used to analyze publication trends, source productivity, author and country contributions, thematic structures, and keyword co-occurrence patterns. The findings show gradual growth in human-dimension NDT research, with stronger visibility after 2010. The dataset recorded 2,917 citations, an average of 4.74 citations per publication, and an overall h-index of 25. Thematic mapping shows that training, certification, and personnel competence occupy a central but developing position, while inspection performance appears as a basic theme, and inspection reliability, probability of detection, and human factors remain niche themes. The human dimension of NDT is visible but fragmented. The study contributes by reframing NDT research from a technology-dominant inspection perspective to a competence-assurance perspective, where personnel development, certification practice, professional competence, and reliable inspection outcomes are treated as interconnected elements of NDT reliability.

DOI: 10.35631/IJMOE.831001

Keywords:

Bibliometric Analysis, Certification, Competence Assurance, Non-Destructive Testing, Training

Introduction

Non-destructive testing (NDT) is widely used to evaluate the integrity, quality, and safety of materials, components, and structures without damaging the inspected item. It supports defect detection, maintenance decisions, and failure prevention in safety-critical sectors such as oil and gas, aerospace, nuclear, construction, transportation, manufacturing, and energy (Gupta & Khan, 2021; ICNDT, 2024; ISO, 2021). In these environments, the reliability of NDT is not determined solely by instrumentation. Reliable inspection also depends on personnel's ability to select appropriate methods, follow procedures, control inspection conditions, interpret indications, and make defensible technical decisions. This issue has become more important as NDT moves towards automation, digital inspection, and NDE 4.0. Artificial intelligence, digital twins, augmented reality, smart sensors, and automated data analysis are changing how inspections are planned, performed, and interpreted (Kanzler & Rentala, 2023; Meyendorf *et al.*, 2023). These technologies may improve inspection capability, but they also create new competence requirements. NDT personnel must understand conventional methods and be able to evaluate data quality, validate automated outputs, recognise system limitations, and exercise professional judgement in technology-supported environments.

Formal qualification and certification systems provide one mechanism for controlling competence. ISO 9712 specifies requirements for the qualification and certification of personnel performing industrial NDT, while ICNDT emphasizes that qualified and certified personnel are essential to the quality and reliability of NDT practice (ICNDT, 2024; ISO, 2026). Training is also evolving from conventional classroom and laboratory practice towards simulation, mixed reality, and digital learning environments that may support the development of practical competence (Nguyen *et al.*, 2021). However, despite the importance of personnel capability, much NDT research remains focused on inspection techniques, defect detection, structural health monitoring, condition monitoring, and data-driven inspection. Previous bibliometric reviews in NDT have mainly mapped technical and application-oriented domains, including reinforced concrete bridge defects, storage tanks, pressure vessels, corrosion detection, infrared thermography, timber evaluation, and delamination detection (Abdelkader *et al.*, 2023; Li *et al.*, 2025). These studies have improved the understanding of technological progress, but they have given limited attention to the human-performance stream of NDT. As a result, it remains unclear how training, certification, personnel competence, human factors, and inspection reliability are positioned within the wider NDT knowledge structure.

This study addresses that gap by mapping the human dimension of NDT through bibliometric evidence. It conceptualizes the human dimension as a competence-assurance pathway linking personnel development, certification practice, professional competence, and reliable inspection outcomes. The study answers four research questions:

1) What are the publication trends in the human dimension of NDT research?
2) Which sources, authors, and countries contribute to this area?
3) What thematic structures represent training, certification, personnel competence, and inspection performance?
4) What gaps and future directions emerge from the bibliometric evidence?

By addressing these questions, the study contributes to NDT research by shifting attention from a purely technology-oriented view towards a socio-technical understanding of inspection reliability.

Literature Review

This section reviews the development of the human dimension in non-destructive testing (NDT), particularly in relation to training, certification, personnel competence, inspection performance, reliability, and recent digital transformation. The review establishes the conceptual foundation of the study and explains why bibliometric mapping is needed to examine how these human-related themes are positioned within the wider NDT research landscape.

Historical Development of the Human Dimension in NDT

NDT has historically developed as a technical inspection field concerned with the detection, evaluation, and monitoring of discontinuities in materials, components, and structures without causing damage to the inspected object. Early NDT research was mainly driven by inspection technologies, defect detection, equipment capability, materials testing, and structural integrity. As NDT became more widely used in safety-critical industries such as oil and gas, aerospace, nuclear, manufacturing, transportation, construction, and pressure equipment, the role of personnel became increasingly important (Gupta & Khan, 2021). Reliable inspection outcomes depend not only on testing methods and equipment, but also on the competence of personnel who conduct the test, interpret indications, apply standards, and make technical decisions (Vasconcelos *et al.*, 2019).

The development of formal NDT personnel qualification and certification marked an important shift from technology-based inspection towards competence-based professional practice. ISO 9712:2021 specifies requirements for the qualification and certification of personnel performing industrial NDT across major methods, including ultrasonic, radiographic, magnetic, penetrant, eddy current, acoustic emission, leak, thermographic, and strain gauge testing (ISO, 2021). This indicates that NDT competence is not treated as mere informal experience, but as a structured professional capability that requires training, examination, industrial experience, qualification, and certification.

This historical development is also supported by the International Committee for Non-Destructive Testing (ICNDT), which states that qualified and certified NDT personnel are essential for ensuring quality and safety. ICNDT further explains that certification based on international standards such as ISO 9712 supports competence verification and global recognition of NDT practice (ICNDT, 2024). Therefore, the human dimension in NDT emerged from the need to control inspection reliability through competent personnel, not only through advanced inspection equipment (Bertovic, 2015).

In this study, the historical development of NDT is interpreted as a movement from inspection technology towards competence-based certification practice. This movement provides the foundation for examining the human dimension of NDT research through four connected constructs: training, certification, personnel competence, and inspection performance.

Training, Certification, and Personnel Competence in NDT

Training, certification, and personnel competence form a competence assurance pathway in NDT (Tsougkranis, 2018). Training provides the foundation for knowledge and skill development, certification provides formal recognition of competence, and personnel competence represents the capability to apply knowledge and skills in real inspection situations. In NDT, training is not limited to theoretical learning. It involves understanding testing principles, handling equipment, applying procedures, recognizing indications, interpreting results, and developing inspection judgment.

Certification and standards provide the formal mechanism for verifying personnel competence. ISO 9712:2021 defines the qualification and certification requirements for industrial NDT personnel, while ISO/IEC 17024 provides general requirements for bodies operating certification schemes for persons. ISO/IEC 17024 also includes principles for developing and maintaining certification schemes, which are important for ensuring consistency and credibility in personnel certification (ISO, 2021; ISO, 2026).

Recent conceptual work on professional NDT certification further supports this competence assurance perspective. Mohamad *et al.* (2026) argued that professional NDT certification should not be understood merely as standards compliance or candidate examination performance, but as part of an institutional implementation system that connects standards, training structures, institutional readiness, implementation quality, governance, and professional competency outcomes. This view is relevant to the present bibliometric study because it reinforces the need to examine certification, training, personnel competence, and inspection outcomes as interconnected components of the human dimension of NDT. In NDT practice, competence cannot be measured solely by attendance at training or by possession of a certificate. Competence must be reflected in the ability to select suitable methods, follow procedures, calibrate equipment, identify relevant indications, apply acceptance criteria, and produce reliable inspection reports (Škrinjarić, 2022). This is consistent with ICNDT's position that qualification and certification are vital links in the chain of actions required to achieve quality in NDT. Therefore, certification should be viewed as a mechanism for competence assurance, not merely an administrative credential.

The need to integrate training, certification, and competence is becoming more important as NDT practice becomes more complex. NDT personnel are increasingly required to work with digital inspection systems, automated data collection, image analysis, and AI-supported interpretation (Meyendorf *et al.*, 2023). Therefore, the traditional view of competence as method-specific skill must be expanded to include digital readiness, interpretive ability, technology awareness, and professional judgment. This supports the present study's focus on mapping how training, certification, and personnel competence appear within the NDT research landscape.

Inspection Performance, Reliability, and Human Factors

Inspection performance represents the practical outcome of training, certification, and personnel competence. In NDT, the final objective is not only to produce trained or certified personnel but also to ensure reliable inspection results. Inspection performance is closely related to inspection reliability, probability of detection (POD), human factors, procedure quality, environmental conditions, and decision-making (Wall *et al.*, 2009).

POD is an important concept because it provides a quantitative measure of an NDT process's ability to detect flaws under defined conditions. However, detection reliability is not determined solely by equipment or technique. Bato *et al.* (2019) examined the impact of human and environmental factors on the probability of detection during eddy-current NDT inspections. Their study showed that POD can be affected by inspector skills, environmental conditions, defect characteristics, and inspection scenarios. This supports the argument that inspection reliability is both a technical and a human-performance issue.

Human factors are important because NDT personnel operate in real inspection environments that may involve fatigue, time pressure, poor lighting, difficult access, complex geometry, surface condition, and high responsibility for decision-making. Bertovic (2015) highlighted that human factors in NDT create risks and challenges, particularly in mechanized NDT, where personnel still need to supervise, validate, and interpret inspection outputs. Even with advanced equipment, personnel still need to validate the inspection process, interpret outputs, and decide on acceptance, rejection, repair, or further inspection. Therefore, inspection performance should be understood as a human-technical outcome.

This relationship is particularly important in safety-critical industries. In sectors such as nuclear, aerospace, oil and gas, pressure vessels, bridges, pipelines, and transportation, inspection errors may lead to serious safety, environmental, and economic consequences. Kanzler and Rentala (2023) Also connected reliability evaluation of testing systems with NDE 4.0, indicating that reliability remains an important concern as NDT systems become more digital and technology supported. Therefore, training and certification systems should be evaluated not only by whether personnel meet formal requirements, but also by whether they support reliable inspection performance. This justifies the inclusion of inspection performance and reliability as a major theme in this bibliometric study.

Recent Digital Development: NDE 4.0, Digital Literacy, and Technology-Supported Inspection

Recent developments in NDT are strongly influenced by digitalization, automation, artificial intelligence, image analysis, robotics, sensors, augmented reality, and NDE 4.0. NDE 4.0 represents the integration of NDT/NDE with Industry 4.0 technologies. Meyendorf *et al.* (2023) explain that NDE 4.0 involves digital technologies such as artificial intelligence, augmented reality, digital twins, smart inspection systems, and automated data analysis. This development aims to improve inspection capability and support a new inspection paradigm for Industry 4.0 environments.

This digital transition has direct implications for NDT training and competence development. NDT personnel must not only understand conventional methods, but also digital inspection workflows, automated systems, data quality, AI-supported outputs, and system limitations. Nguyen *et al.* (2021) introduced a mixed-reality system for NDE training that enables trainees to interact with simulated objects and probes in a mixed environment. This shows that technology-supported training can enhance practical learning and prepare personnel for complex inspection tasks.

The relevance of digital literacy is also supported by recent bibliometric research in education and computer science. Rayendra *et al.*(2026) conducted a systematic literature network and bibliometric review on deep learning and digital literacy to find a shift from technical exploration towards more human-centric and pedagogical deep learning frameworks. This finding is relevant to NDT because advanced technologies such as AI, automation, and digital inspection require personnel to develop new forms of digital and interpretive competence.

Recent digital developments show that the human dimension of NDT is becoming more, not less, important. Automation and AI may improve inspection capability, but they also change the competence required of personnel. NDT personnel need to understand, supervise, validate, and interpret technology-supported inspection systems. Therefore, future NDT research should integrate technical development with human competence, digital literacy, certification practice, and inspection reliability.

Previous Studies on Bibliometric Analysis of NDT

Previous bibliometric studies have contributed significantly to understanding the development of NDT technologies and applications. As summarized in Table 1, existing studies have mainly examined technical and application-oriented areas, including infrared thermography for concrete bridge inspection, delamination detection, timber mechanical evaluation, steel corrosion detection, storage tanks and pressure vessels, and reinforced concrete bridge defect assessment. These studies commonly analyzed publication trends, citation patterns, keyword co-occurrence, country contributions, thematic clusters, and technology evolution. Their findings show that NDT research has increasingly moved towards image processing, deep learning, machine vision, infrared thermography, ultrasonic testing, acoustic emission, IoT, and data-driven inspection.

Although these studies provide useful bibliometric evidence on the technical advancement of NDT, they mainly map technology- and application-oriented domains, leaving the human-performance stream of NDT research underrepresented. Limited bibliometric attention has been given to NDT personnel development and performance assurance, particularly how competence-related themes are structured within the wider NDT literature. This gap is important because reliable NDT practice depends not only on advanced inspection technologies, but also on competent personnel who can conduct inspections, interpret results, comply with standards, and make reliable decisions. Therefore, the present study addresses this gap by mapping the human dimension of NDT research within the broader bibliometric landscape.

Table 1: Previous studies on Bibliometric Analysis of NDT

Author	Objective of the Study	Total Document and Data Source	Attributes Examined	Main Findings
Ibrahim *et al.* (2026)	To examine current practices, challenges, and future needs in the use of infrared thermography for concrete bridge deck inspection.	110 documents from Scopus and Web of Science. The study reports a notable increase in publications after 2017.	Publication trends, country contribution, defect types, IRT data analysis approaches, environmental factors, physical factors, technical factors, image processing, deep learning, and machine learning.	IRT research on concrete bridge decks has grown since 2017. IRT is effective for shallow defects but is limited for deeper defect characterization, requiring standardized protocols and automated analysis.
Abdulwahd *et al.* (2025)	To analyze advances in NDT techniques for delamination detection using bibliometric methods.	4,382 publications indexed in Scopus, covering 2021–2025.	Annual scientific production, citation trends, thematic focus, collaboration patterns, core themes, leading journals, authors, institutions, and country contributions.	Delamination-related NDT research is rapidly growing and dominated by composites, ultrasonic testing, and infrared thermography, with increasing emphasis on advanced imaging and data-driven inspection.
Brougui *et al.* (2025)	To map research trends on the evaluation of timber mechanical properties using NDT, especially	129 Scopus-indexed publications. The coverage period is not fully stated in the metadata, but the study reports growth	Research trends, keyword co-occurrence, thematic clusters, ultrasonic testing, modulus of elasticity, timber structures, standardization,	NDT for timber mechanical evaluation is expanding, especially ultrasonic methods, but lacks standardized procedures, in-

International Journal of Modern Education IJMOE
EISSN: 2637-0905
Volume: 8 Issue: 31 (September 2026) PP. 01-26

	ultrasonic-based methods.	since the early 2000s.	and in-service assessment.	service validation, and integration with machine learning.
Chen *et al.* (2025)	To map the knowledge structure and thematic trends in steel corrosion detection research.	1,484 papers indexed in Web of Science, covering 2001–2024.	Publication trends, knowledge structure, collaboration pattern, research quality, corrosion detection methods, electrochemical techniques, NDT, image processing, machine vision, deep learning, IoT, and 5G.	Research on steel corrosion detection has grown rapidly since 2015, with a growing focus on image processing, machine vision, deep learning, IoT, and real-time monitoring.
Li *et al.* (2025)	To analyze the application and development of NDT techniques for storage tanks and pressure vessels over the last two decades.	Web of Science database, covering January 2004 to July 2024.	Descriptive statistics, keyword co-occurrence, burst word analysis, co-citation analysis, major journals, highly cited literature, highly cited journals, and technology evolution.	NDT for storage tanks and pressure vessels has matured, with acoustic emission as a prominent technique and strong contributions from Chinese researchers.
Abdelkader *et al.* (2023)	To synthesize research on reinforced concrete bridge defects, NDT methods, and analysis techniques through systematic review and bibliometric analysis.	505 peer-reviewed journal articles and book chapters from Scopus and Web of Science, covering 1991 to September 2022.	Bridge defect types, NDT techniques, data processing methods, public datasets, keyword networks, scientometric mapping, VOSviewer analysis, Bibliometric analysis, and future research directions.	NDT is widely used for reinforced concrete bridge defect assessment, with growing integration of computer vision, fuzzy logic, AI, and decision-support methods.

Methodology

This study employed a bibliometric analysis to map the human dimension of non-destructive testing (NDT) research, with specific attention to human-dimension themes. Bibliometric analysis is suitable for this study because it enables the systematic examination of publication

International Journal of Modern Education IJMOE EISSN: 2637-0905
Volume: 8 Issue: 31 (September 2026) PP. 01-26
growth, influential documents, leading contributors, keyword structures, and thematic patterns within a specific research domain (Donthu *et al.*, 2021; Vardari *et al.*, 2025).

Search Strategy

The search strategy was developed to retrieve publications that explicitly connect NDT with personnel-related and human-dimension themes. The Scopus advanced search string was organized into three keyword blocks: NDT/NDE terminology, competence- and certification-related terminology, and personnel- or human-related terminology. This structure was used to ensure that the dataset captured studies related to NDT personnel development, training, certification, qualification, competence, human factors, and inspection performance, while retaining the broader technical context of NDT research.

The specific procedure is described in Figure 1. The data for this study were collected on 04 April 2026 from the Scopus database using an advanced search strategy. Publications from 2026 were included only up to the extraction date and should therefore be interpreted as partial-year data. The search was conducted across the title, abstract, and keywords fields to retrieve publications related to the human dimension of non-destructive testing (NDT), particularly training, certification, personnel competence, and inspection performance. The search query was designed using three main keyword blocks: NDT/NDE terminology, certification- and competence-related terminology, and personnel- or human-related terminology. The final search query used in Scopus was TITLE-ABS-KEY ("non-destructive testing" OR "nondestructive testing" OR "non destructive testing" OR NDT OR "non-destructive evaluation" OR "nondestructive evaluation" OR NDE) AND TITLE-ABS-KEY (certification OR qualification OR "personnel certification" OR "personnel qualification" OR "competence assurance" OR "competency assurance" OR "certified personnel" OR "qualified personnel" OR training OR education OR competence OR competency OR "technical competence") AND TITLE-ABS-KEY (personnel OR inspector OR inspectors OR technician OR technicians OR practitioner OR practitioners OR workforce OR operator OR operators OR "human factors" OR "human performance").

As shown in Figure 1, this study retrieved 712 documents related to the human dimension of NDT. After screening the records and excluding literature not directly related to the human dimension of NDT, 616 documents were retained for further analysis. This process establishes the foundation for subsequent bibliometric analyses in this area. Since the dataset was purposively constructed around human-dimension search terms, the study does not estimate the absolute proportion of human-related studies within the entire NDT literature. Instead, it examines the internal structure and conceptual positioning of human-dimension themes within the selected NDT dataset.

Data Cleaning and Harmonization

In bibliometric analysis, data cleaning and harmonization were conducted to ensure the relevance, consistency, and reliability of the bibliometric dataset. This procedure is important because bibliometric studies commonly require removing duplicate records, standardizing inconsistent data, excluding irrelevant fields, and transforming metadata into a consistent format for analysis (Vardari *et al.*, 2025). This study employed biblioMagika and OpenRefine to clean and standardize inconsistent data, including author names, affiliations, and keywords (Punj *et al.*, 2023). The initial Scopus search produced 712 records, which were manually

International Journal of Modern Education
EISSN: 2637-0905
Volume: 8 Issue: 31 (September 2026) PP. 01-26
screened based on titles, abstracts, author keywords, index keywords, source titles, and document types. Records were excluded if the terms NDT or NDE were used in unrelated contexts, or if the term training referred only to machine learning model training without any link to personnel training, competence development, inspection practice, or NDT performance. After this refinement process, 616 records were retained as the final dataset for analysis. Keyword harmonization was then performed to reduce inconsistencies caused by spelling variations, abbreviations, plural forms, and synonymous terms. For example, terms such as NDT, non-destructive testing, nondestructive testing, and non-destructive testing were standardized. Related terms such as training and education, certification and standards, personnel competence, personnel qualification, probability of detection, inspection reliability, and inspection performance were also harmonized using a VOSviewer thesaurus file. Microsoft Excel and biblioMagika were used to inspect and verify the dataset, while VOSviewer and Biblioshiny supported keyword standardization and bibliometric mapping (Aria & Cuccurullo, 2017). This harmonization process did not alter the original dataset but improved the clarity and interpretability of the bibliometric results, particularly for mapping the human dimension of NDT research.

Data Analysis Method

The final dataset was analyzed using VOSviewer, biblioMagika, Biblioshiny and Microsoft Excel. VOSviewer was used to conduct keyword co-occurrence analysis and to generate network and focused keyword maps. VOSviewer is widely used for constructing and visualizing bibliometric networks, including citation, co-authorship, co-citation, bibliographic coupling, and keyword co-occurrence networks (van Eck & Waltman, 2010). biblioMagika and Biblioshiny were used to support descriptive bibliometric analysis, including publication productivity, citation indicators, source analysis, author contribution, and related bibliometric metrics (Aria & Cuccurullo, 2017). biblioMagika is an Excel-based bibliometric tool designed to support publication productivity analysis, scholarly impact assessment, and dataset cleaning before further analysis in VOSviewer (Ahmi, 2024). Microsoft Excel was used for manual screening, data checking, keyword tagging, and preparation of summary tables. The combination of these tools enabled the study to examine publication trends, identify influential contributions, and map the conceptual structure of the human dimension in NDT research, particularly in relation to competence development, formal recognition, and inspection outcomes.

International Journal of Modern Education
IJMOE
EISSN: 2637-0905
Volume: 8 Issue: 31 (September 2026) PP. 01-26

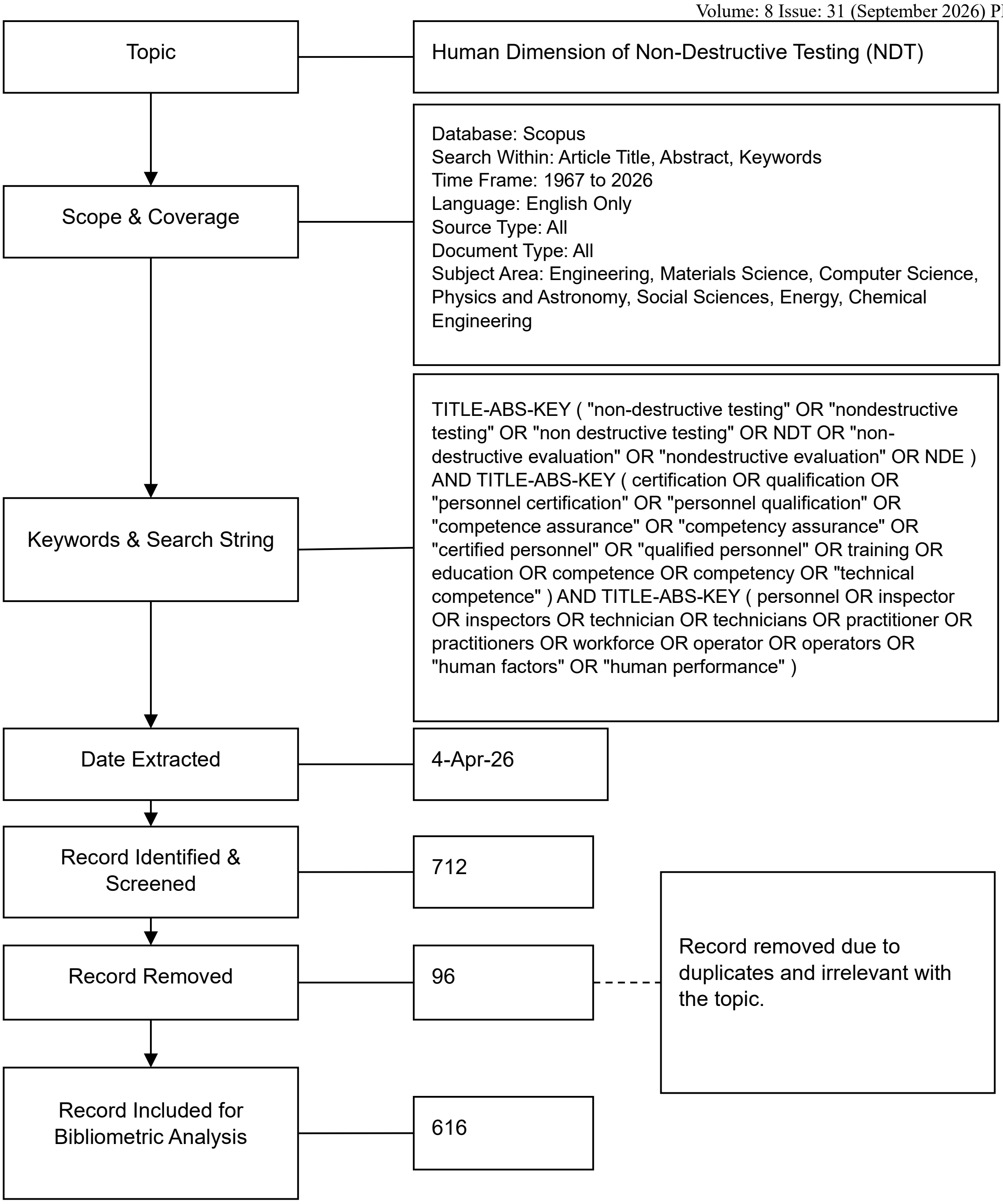

Figure 1: Search Strategy Flow Chart

Source: Punj *et al.* (2023) Page *et al.* (2021), Moher *et al.* (2009)

Results

Publication Trends

To address the first research question, "What are the publication trends in the human dimension of NDT research?", this study analyzed the annual research output and citation metrics of publications related to the human dimension of NDT research from 1967 to 2026. As shown in Table 2, the final dataset comprised 616 Scopus-indexed documents, totaling 2,917 citations, with an average of 4.74 citations per publication and 12.21 citations per cited publication. The overall h-index and g-index were 25 and 48, respectively. The publication trend indicates that research output was relatively limited and inconsistent during the early period from 1967 to 1979, with most years producing fewer than five publications. In 1998, 27 publications and 53 citations were recorded, indicating an early phase of stronger scholarly activity.

The strongest citation impact occurred after 2010, particularly between 2015 and 2023. The year 2015 recorded the highest total citation count, with 474 citations from 12 publications, while 2021 recorded 423 citations, the highest h-index of 9, and the highest g-index of 19. These results suggest that recent influential publications are strongly associated with digital inspection, machine learning, automated defect detection, NDE 4.0 and inspection performance. In terms of publication volume, 2025 recorded the highest annual output with 25 publications, although its citation count remained low because of the citation time lag. The results show that the human dimension of NDT research has gradually developed over time, with stronger visibility in recent years. However, the citation pattern also indicates that the most influential publications remain largely technology oriented. These findings indicate that human-dimension NDT research has gradually become more visible, although the citation structure remains strongly influenced by technology-oriented publications.

International Journal of Modern Education
IJMOE
EISSN: 2637-0905
Volume: 8 Issue: 31 (September 2026) PP. 01-26

Table 2 : Annual Research Output and Citation Metrics
Source: Generated by the author(s) using biblioMagika® (Ahmi, 2024)

Year	TP	NCA	NCP	TC	C/P	C/CP	h	g	m
1967	3	3	0	0	0.00	0.00	0	0	0.000
1968	1	1	0	0	0.00	0.00	0	0	0.000
1969	2	2	2	2	1.00	1.00	1	1	0.017
1970	2	2	0	0	0.00	0.00	0	0	0.000
1971	1	1	1	1	1.00	1.00	1	1	0.018
1972	3	3	0	0	0.00	0.00	0	0	0.000
1973	2	2	0	0	0.00	0.00	0	0	0.000
1974	3	3	0	0	0.00	0.00	0	0	0.000
1976	5	5	2	4	0.80	2.00	2	2	0.039
1977	10	10	2	6	0.60	3.00	1	2	0.020
1978	2	2	0	0	0.00	0.00	0	0	0.000
1979	5	5	1	2	0.40	2.00	1	1	0.021
1980	2	2	0	0	0.00	0.00	0	0	0.000
1981	5	5	1	1	0.20	1.00	1	1	0.022
1982	18	18	1	1	0.06	1.00	1	1	0.022
1983	15	15	1	1	0.07	1.00	1	1	0.023
1984	12	12	3	9	0.75	3.00	2	3	0.047
1985	20	20	1	1	0.05	1.00	1	1	0.024
1986	12	12	4	4	0.33	1.00	1	1	0.024
1987	5	5	0	0	0.00	0.00	0	0	0.000
1988	9	9	2	4	0.44	2.00	2	2	0.051
1989	12	12	5	12	1.00	2.40	1	3	0.026
1990	2	2	0	0	0.00	0.00	0	0	0.000
1991	3	3	1	7	2.33	7.00	1	2	0.028
1992	16	16	6	12	0.75	2.00	2	3	0.057
1993	4	4	1	1	0.25	1.00	1	1	0.029
1994	7	7	1	1	0.14	1.00	1	1	0.030
1995	8	8	5	13	1.63	2.60	2	3	0.063
1996	14	14	5	25	1.79	5.00	2	5	0.065
1997	14	14	5	8	0.57	1.60	1	2	0.033
1998	27	27	9	53	1.96	5.89	3	7	0.103
1999	8	8	3	8	1.00	2.67	1	2	0.036
2000	8	8	1	1	0.13	1.00	1	1	0.037
2001	6	6	2	37	6.17	18.50	2	6	0.077
2002	18	18	2	5	0.28	2.50	1	2	0.040
2003	9	9	3	3	0.33	1.00	1	1	0.042
2004	13	13	3	6	0.46	2.00	2	2	0.087
2005	10	10	1	17	1.70	17.00	1	4	0.045
2006	14	14	3	10	0.71	3.33	1	3	0.048
2007	12	12	5	36	3.00	7.20	3	6	0.150
2008	12	12	7	22	1.83	3.14	3	4	0.158
2009	12	12	8	101	8.42	12.63	5	10	0.278
2010	16	16	6	25	1.56	4.17	3	4	0.176
2011	10	10	5	54	5.40	10.80	2	7	0.125
2012	9	9	7	36	4.00	5.14	3	5	0.200
2013	15	15	7	56	3.73	8.00	4	7	0.286
2014	14	14	9	68	4.86	7.56	4	8	0.308
2015	12	12	8	474	39.50	59.25	4	12	0.333
2016	9	9	2	166	18.44	83.00	2	9	0.182
2017	15	15	9	155	10.33	17.22	5	12	0.500
2018	19	19	9	43	2.26	4.78	4	6	0.444
2019	16	16	10	287	17.94	28.70	5	16	0.625
2020	3	3	3	28	9.33	9.33	2	3	0.286
2021	19	19	17	423	22.26	24.88	9	19	1.500
2022	20	20	12	278	13.90	23.17	6	16	1.200
2023	23	23	18	305	13.26	16.94	7	17	1.750
2024	19	19	9	65	3.42	7.22	4	8	1.333
2025	25	25	11	40	1.60	3.64	3	5	1.500
2026	6	6	0	0	0.00	0.00	0	0	0.000
Total	616	616	239	2917	4.74	12.21	25	48	0.417

Abbreviations: g, g-index; h, h-index; m, m-index; NCA, number of contributing authors; NCP, number of cited publications; TC, total citations; TP, total number of publications.

International Journal of Modern Education
IJMOE
EISSN: 2637-0905
Volume: 8 Issue: 31 (September 2026) PP. 01-26

Publications by Source

The source analysis in Table 3 shows that Materials Evaluation and Insight: Non-Destructive Testing and Condition Monitoring were the most productive outlets, contributing 62 and 56 publications, respectively. However, the strongest citation impact was observed in Journal of Nondestructive Evaluation and NDT & E International, despite their smaller number of publications. Journal of Nondestructive Evaluation recorded 642 citations from only 6 documents, while NDT & E International accumulated 345 citations from 8 documents. This indicates that publication productivity and citation impact are not necessarily aligned. Professional NDT outlets such as Materials Evaluation and Insight appear to support wider dissemination of applied and practice-based NDT knowledge, whereas research-intensive journals such as Journal of Nondestructive Evaluation and NDT & E International contribute more strongly to scholarly impact. The presence of conference proceedings and technical sources further reflects the applied and multidisciplinary nature of NDT research, particularly in relation to personnel-related and performance-related keyword structures.

This distribution of sources suggests that the human dimension of NDT is not confined to education or certification literature alone, but is positioned across professional NDT practice, engineering standards, inspection science, and applied industrial research. This reinforces the need for a focused bibliometric mapping of competence development, formal recognition, and inspection outcomes within the broader NDT knowledge structure.

Table 3: Most Productive Source Title

Source Title	TP	NCA	NCP	TC	*h*	*g*	*m*
Materials Evaluation	62	62	2	107	5	10	0.094
Insight: Non-Destructive Testing and Condition Monitoring	56	56	16	76	5	8	0.152
Proceedings of SPIE - The International Society for Optical Engineering	20	20	17	27	3	4	0.083
American Society of Mechanical Engineers, Pressure Vessels and Piping Division (Publication) PVP	17	17	11	20	2	3	0.059
AIP Conference Proceedings	16	16	16	35	3	4	0.176
Rivista Italiana della Saldatura	15	15	0	1	1	1	0.024
ASTM Special Technical Publication	12	12	4	12	2	3	0.039
British Journal of Non-Destructive Testing	9	9	0	2	1	1	0.023
Materialpruefung/Materials Testing	9	9	4	15	2	3	0.039
NDT and E International	8	8	8	345	7	8	0.350
Defektoskopiya	7	7	0	1	1	1	0.029
NDT 2018 - 57th Annual Conference of the British Institute of Non-Destructive Testing	6	6	0	4	1	2	0.111
Proceedings of the Biennial International Pipeline Conference, IPC	6	6	6	10	2	3	0.118
Journal of Nondestructive Evaluation	6	6	6	642	5	6	0.313
Welding Journal (Miami, Fla)	5	5	0	3	1	1	0.022

IEEE Access	5	5	5	14	2	3	0.400
ASEE Annual Conference and Exposition, Conference Proceedings	5	5	0	17	3	4	0.150
American Society of Mechanical Engineers (Paper)	5	5	0	0	0	0	0.000
Key Engineering Materials	5	5	2	7	1	2	0.042
Non-Destructive Testing	4	4	4	3	1	1	0.017

Note: TP=total number of publications; NCA=number of contributing authors; NCP=number of cited publications; TC=total citations; h=h-index; g=g-index; m=m-index.

Publications by Authors

Table 4 presents the performance of leading authors in the selected NDT human-dimension data set. Lavender J. Stephen from the United Kingdom was the most productive author, with 13 publications, followed by Lavender J. Dave and Plumstead C. William with five publications each. Although the Lavender authors' citation impact was relatively low, their contribution is directly relevant to the human dimension of NDT. For example, Lavender & Lavender (1986) discussed the harmonization of SNT-TC-1A and BS 5750 to establish a quality system for the training, examination, and certification of NDT personnel. This article is important because it connects NDT personnel qualification with formal quality assurance and certification practice. In contrast, Zhang Xiaobing from China and Ramuhalli Pradeep from the United States published only 3 papers each but recorded substantially higher citation impact, with 59 and 43 total citations, respectively. Zhang Xiaobing achieved the highest citation per publication value of 19.67, while Ramuhalli Pradeep recorded 14.33 citations per publication. These findings indicate that author productivity and citation influence are not necessarily aligned. The results also suggest that research related to the human dimension of NDT is contributed by a relatively dispersed group of authors, with some contributing mainly to professional and applied NDT literature, while others have a stronger academic citation influence. The uneven relationship between author productivity and citation impact further supports the argument that the human dimension of NDT research is still emerging. While several authors contribute consistently to the literature, the most influential citations are found among authors with fewer but more highly cited publications, indicating that the field is shaped by both practice-based contributions and research-intensive technical studies.

Table 4: Most Productive Authors Who Published Three Or More Publications

Author's name	Country/Region	TP	NCP	TC	C/P	C/CP	h	g	m
Lavender J. Stephen	United Kingdom	13	2	2	0.15	1.0	1	1	0.023
Lavender J. Dave	United Kingdom	5	3	3	0.6	1.0	1	1	0.017
Plumstead C. William	United States	5	1	1	0.2	1.0	1	1	0.024
Vladimir Grenis	United States	4	3	10	2.5	3.33	2	3	0.1
Costa Girolamo.	Italy	4	1	1	0.25	1.0	1	1	0.024

Roe D. Strommen.	United Kingdom	4	1	1	0.25	1.0	1	1	0.042
Charles J. Hellier	United States	4	0	0	0.0	0	0	0	0.0
Michael L Turnbow	United States	4	0	0	0.0	0	0	0	0.0
Zhang Xiaobing	China	3	3	59	19.67	19.67	3	3	0.333
Ramuhalli Pradeep	United States	3	3	43	14.33	14.33	2	3	0.118

Publications by Countries

Table 5 presents the contribution of countries and regions to the selected NDT human-dimension dataset. The United States was the most productive country, with 179 publications and 619 citations, indicating its leading role in this research area. The United Kingdom ranked second in publication output with 76 publications, but recorded the highest citation count with 730 citations, suggesting strong academic influence. Germany and China contributed fewer publications, with 37 and 29 documents, respectively, but showed high citation impact, particularly in terms of citations per publication. Germany recorded 572 citations and a C/P value of 15.46, while China recorded 530 citations and the highest C/P value of 18.28 among the leading countries. These findings indicate that publication productivity and citation influence are not necessarily aligned. The results show that research on the human dimension of NDT is mainly concentrated in countries with strong engineering, industrial inspection, and safety-critical research ecosystems, particularly the United States, the United Kingdom, Germany, and China.

The dominance of the United States, United Kingdom, Germany, and China indicates that research on the human dimension of NDT is closely linked to advanced industrial, regulatory, and technological environments. This reinforces the need to understand the human dimension of NDT as an international competence and safety assurance issue, rather than a purely local training concern.

Table 5: Countries/Regions That Contributed Three Or More Publications

Country/Region	TP	NCP	TC	C/P	C/CP	h	g	m
United States	179	91	619	3.46	6.80	11	21	0.216
United Kingdom	76	38	730	9.61	19.21	10	26	0.172
Germany	37	14	572	15.46	40.86	6	23	0.133
China	29	22	530	18.28	24.09	9	23	0.429
Italy	24	8	33	1.38	4.12	3	5	0.081
Russian Federation	21	10	60	2.86	6.00	3	7	0.086

France	19	9	83	4.37	9.22	5	9	0.119
Canada	17	7	83	4.88	11.86	4	9	0.091
Japan	12	5	35	2.92	7.00	2	5	0.062
Sweden	9	2	23	2.56	11.50	2	4	0.057
Czech Republic	9	2	2	0.22	1.00	1	1	0.032
Netherlands	8	4	31	3.88	7.75	1	5	0.027
Brazil	7	5	19	2.71	3.80	3	4	0.107
South Korea	7	2	7	1.00	3.50	2	2	0.045
Turkey	7	2	5	0.71	2.50	1	2	0.034
India	6	4	35	5.83	8.75	3	5	0.075
Spain	5	3	46	9.20	15.33	1	5	0.071
Romania	4	3	23	5.75	7.67	2	4	0.077
Malaysia	4	2	7	1.75	3.50	2	2	0.125
Austria	4	1	1	0.25	1.00	1	1	0.024
Finland	3	3	145	48.33	48.33	2	3	0.333
Croatia	3	2	80	26.67	40.00	2	3	0.074
Norway	3	1	27	9.00	27.00	1	3	0.032
Slovenia	3	2	2	0.67	1.00	1	1	0.037
United Arab Emirates	3	0	0	0.00	0.00	0	0	0.000
Australia	3	0	0	0.00	0.00	0	0	0.000

Note: TP, total number of publications; NCP, number of cited publications; TC, total citations; C/P, average citations per publication; C/CP, average citations per cited publication; h, h-index; g, g-index; m, m-index.

Thematic Map

Figure 2 shows the thematic map of harmonized authors' keywords related to the human dimension of NDT research. The map indicates that the main human-related themes are distributed across training and education, certification and standards, personnel competence, personnel qualification, workforce and professional practice, inspection performance, inspection reliability, probability of detection, and human factors. The central cluster, consisting of training and education, certification and standards, personnel competence, personnel qualification, and workforce and professional practice, is positioned close to the intersection of centrality and density. This indicates that these themes are relevant to the overall structure of NDT research but are still in a developing stage. The finding suggests that training, certification, and personnel competence are evident in the NDT literature but have not yet become a fully consolidated research stream.

International Journal of Modern Education
IJMOE
EISSN: 2637-0905
Volume: 8 Issue: 31 (September 2026) PP. 01-26
The theme inspection performance, together with safety-critical industries and technology-supported inspection, appears as a basic theme. This indicates that inspection performance is central to NDT research but remains insufficiently integrated with training, certification, and competence-related studies. This finding is important because inspection performance represents the practical outcome of competent NDT practice, particularly in industries where inspection errors may have serious safety consequences. Meanwhile, inspection reliability, probability of detection, and human factors appear as niche themes. These topics are internally developed but less connected to the broader structure of human-dimension NDT research. This suggests that reliability and human-factor studies exist as specialized areas, but they have not yet been fully integrated with training, certification, and personnel competence research.

The absence of a clear motor theme indicates that the human dimension of NDT research remains fragmented. The field has visible thematic components, but these components are not yet strongly integrated. This supports the need for future research that connects NDT training, certification, personnel competence, human factors, and inspection reliability within a more coherent competence assurance framework.

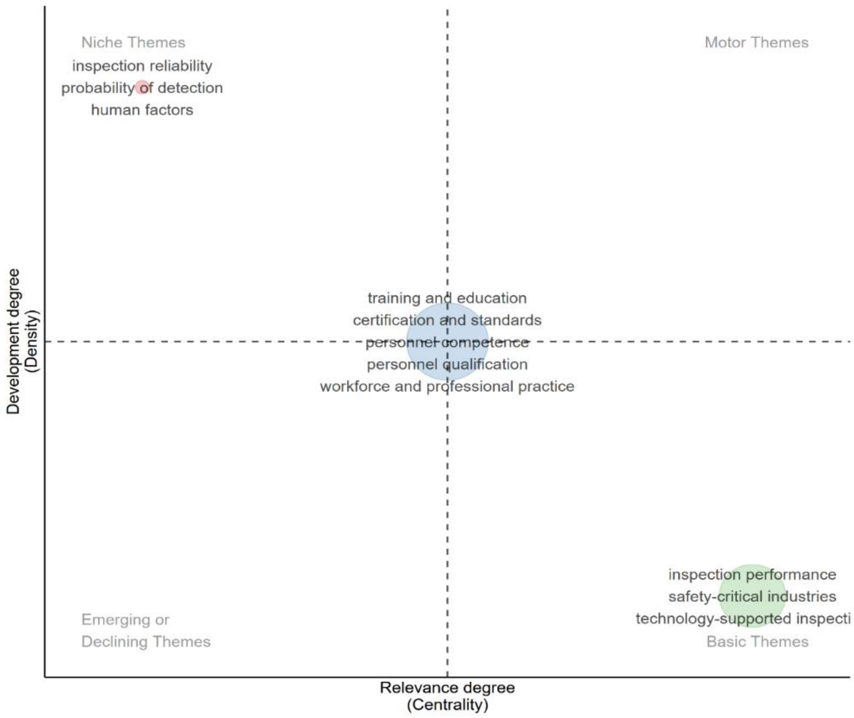

Figure 2: Thematic Map of The Author's Keywords in the Human Dimension of Non-Destructive Testing

Co-Occurrence Analysis of Author's Keywords

Keyword co-occurrence analysis was used to identify the conceptual relationships and latent thematic structures within the selected NDT literature. This technique is useful because keywords represent the core content and main viewpoints of publications, while their co-occurrence patterns reveal interrelationships, research hotspots, and possible future directions within a research domain (Zhou & Zhang, 2025). Figure 3 shows the keyword co-occurrence network of the human dimension in NDT research. Keywords indicate the primary research

International Journal of Modern Education
IJMOE
EISSN: 2637-0905
Volume: 8 Issue: 31 (September 2026) PP. 01-26

directions of publications, while their overall frequency in a dataset reflects the major research hotspots in a given field (Tang *et al.*, 2024). The map indicates that the field is organized around several interrelated themes, particularly training and education, certification and standards, personnel competence, personnel qualification, inspection performance, inspection reliability, and probability of detection. The central position of training and education suggests that personnel development acts as an important connecting theme within the selected literature. This theme is closely associated with certification, qualification, competence, and inspection performance, indicating that NDT training is part of a broader competence assurance process. The network also shows a strong relationship between certification and standards, personnel qualification, and personnel competence. This suggests that the literature frames NDT competence through formal standard-based mechanisms, including qualification, examination, certification, and compliance with technical requirements. The presence of inspection performance, inspection reliability, and probability of detection indicates that competence is not only defined by training completion or certification status, but also by reliable inspection outcomes.

The association between inspection performance, safety-critical industries, and technology-supported inspection further indicates that the human dimension of NDT is embedded in industrial environments where inspection decisions have direct safety implications. The presence of automation, neural networks, condition monitoring, and image analysis suggests that NDT personnel's competence is increasingly shaped by digital and automated inspection technologies. Therefore, the network supports the argument that future NDT competence development should integrate conventional training and certification with inspection reliability, human factors, and technology-supported inspection requirements.

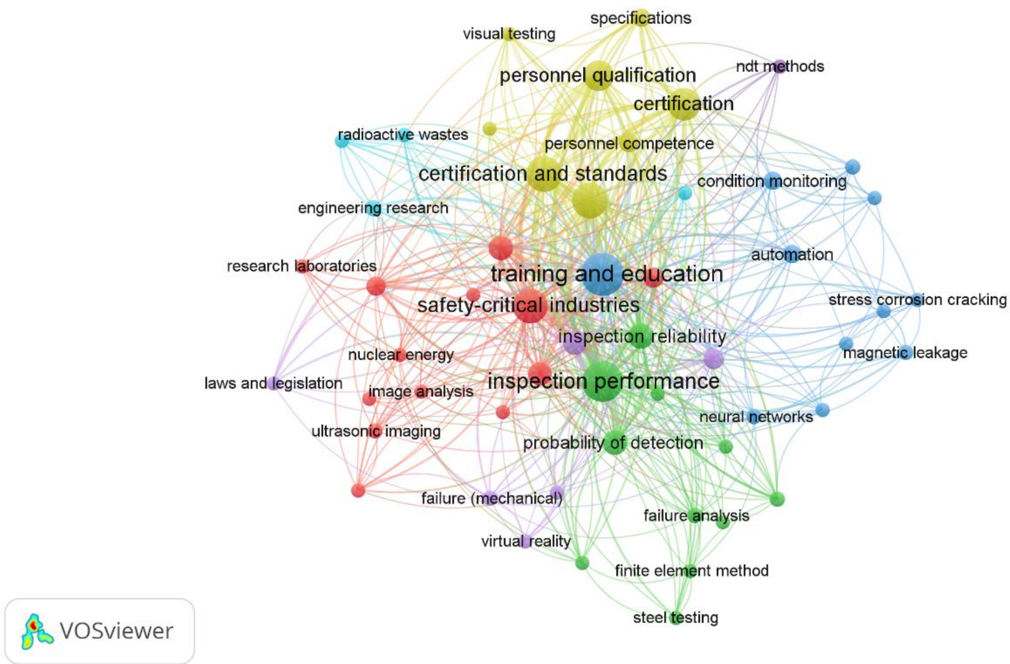

Figure 3: Network Visualization of a Term Co-Occurrence Network Based on The Author's Keywords.

International Journal of Modern Education
IJMOE
EISSN: 2637-0905
Volume: 8 Issue: 31 (September 2026) PP. 01-26

Discussion

This study mapped the human dimension of NDT research using bibliometric evidence on the competence assurance pathway linking personnel development and inspection reliability. The findings indicate that the human dimension of NDT is evident in the literature, but it remains less well consolidated than technology-oriented NDT research. This is shown by the publication trend, source distribution, author and country contribution, thematic map, and keyword co-occurrence network.

The publication trend shows that research on the human dimension of NDT has gradually developed from 1967 to 2026. The final dataset consisted of 616 Scopus-indexed documents, totalling 2,917 citations, with an average of 4.74 citations per publication and an overall h-index of 25. The strongest citation impact was observed after 2010, particularly between 2015 and 2023, suggesting that recent influential publications are increasingly connected with digital inspection, machine learning, automated defect detection, NDE 4.0, and inspection performance. However, the citation pattern also shows that the most influential literature remains largely technology oriented. This finding supports the central argument of this study: the human dimension of NDT has gained visibility but has not yet developed into a dominant research stream.

The source analysis further confirms the applied and multidisciplinary nature of NDT research. Professional and practice-oriented outlets such as *Materials Evaluation* and *Insight: Non-Destructive Testing and Condition Monitoring* were the most productive sources. However, the strongest citation impact came from research-intensive journals such as *Journal of Nondestructive Evaluation* and *NDT & E International*. This indicates that publication productivity and citation influence are not necessarily aligned. It also suggests that human-dimension NDT research is positioned between professional practice, engineering standards, inspection science, and applied industrial research. This pattern is important because the competence assurance pathway linking personnel development and inspection reliability is not confined to education literature alone but is embedded within the wider NDT knowledge ecosystem.

The author-level findings also show that the human dimension of NDT research remains dispersed. The most productive authors, such as Lavender J. Stephen and Lavender J. Dave, contributed to practice-based discussions on training, examination, certification, and quality systems for NDT personnel. However, authors with fewer publications, such as Zhang Xiaobing and Ramuhalli Pradeep, recorded stronger citation impact. This indicates that the field is shaped by two types of contribution: professional-practice contributions and research-intensive technical contributions. The uneven relationship between productivity and citation impact suggests that the human dimension of NDT has not yet been consolidated around a stable group of highly influential scholars.

The country-level analysis shows that the United States, United Kingdom, Germany, and China are the leading contributors to this research area. The United States recorded the highest publication output, while the United Kingdom recorded the highest total citations. Germany and China produced fewer publications but showed strong citation impact per publication. This distribution suggests that research on the human dimension of NDT is closely linked to countries with strong engineering, industrial inspection, regulatory, and safety-critical research

International Journal of Modern Education
EISSN: 2637-0905
IJMOE
Volume: 8 Issue: 31 (September 2026) PP. 01-26
ecosystems. It also shows that NDT personnel competence is an international issue rather than a purely local training concern.

The thematic map provides the most important conceptual finding of this study. The central cluster, consisting of training and education, certification and standards, personnel competence, personnel qualification, and workforce and professional practice, was positioned close to the intersection of centrality and density. This indicates that these themes are relevant to the overall structure of NDT research but remain in a developing stage. In other words, training, certification, and personnel competence are present in the literature, but they have not yet become a fully mature and integrated research stream.

The thematic map also shows that inspection performance, safety-critical industries, and technology-supported inspection are among the basic themes. This means that inspection performance is central to the field, but still requires stronger integration with training, certification, and competence-related research. This finding is important because inspection performance represents the practical outcome of competent NDT practice. In safety-critical industries, inspection errors may have serious consequences for safety, the economy, the environment, and operations. Therefore, NDT training and certification should not be evaluated solely on formal compliance, but also on their contribution to reliable inspection outcomes.

The position of inspection reliability, probability of detection, and human factors as niche themes is also significant. These themes are internally developed but less connected to the broader structure of human-dimension NDT research. This indicates that reliability and human-factor studies exist as specialised research areas, but they have not yet been fully integrated with training, certification, and personnel competence. This fragmentation is important because NDT reliability depends not only on equipment and methods, but also on human judgement, procedure compliance, interpretation skill, environmental conditions, and decision-making.

The keyword co-occurrence network strengthens this interpretation. The network shows that training and education is centrally connected with certification, personnel qualification, competence, and inspection performance. It also shows that certification and standards are closely associated with personnel competence and personnel qualification. This suggests that the literature frames NDT competence through formal, standard-based mechanisms such as qualification, examination, certification, and compliance with technical requirements. At the same time, the presence of inspection performance, inspection reliability, and probability of detection indicates that competence is not only defined by training completion or certification status, but also by reliable inspection outcomes.

The findings suggest that the human dimension of NDT research should be understood as a competence assurance pathway. Training and education provide the foundation for personnel development. Certification and standards provide formal recognition and control of competence. Personnel competence represents the professional capability to perform inspection tasks. Inspection performance and reliability represent the practical outcomes of competent NDT practice.

International Journal of Modern Education
IJMOE
EISSN: 2637-0905
Volume: 8 Issue: 31 (September 2026) PP. 01-26

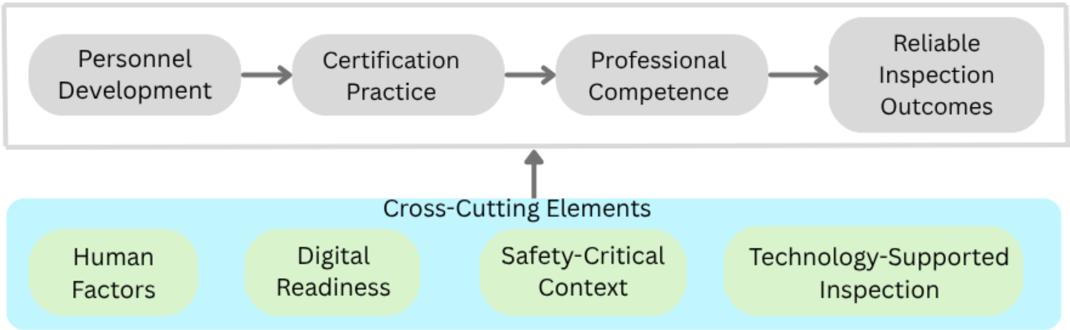

Figure 4: Integrated Competence Assurance Framework for The Human Dimension Of NDT, Synthesised from The Bibliometric Findings.

As shown in Figure 4, the bibliometric findings can be synthesized into an integrated NDT competence assurance framework. The framework positions personnel development as the foundation for certification practice, which, in turn, supports professional competence and contributes to reliable inspection outcomes. This pathway is influenced by cross-cutting elements, including human factors, digital readiness, safety-critical context, and technology-supported inspection. The framework reinforces the argument that NDT reliability should not be understood solely as a technical issue, but also as a human performance and competence assurance issue. This framework also reflects a socio-technical view of NDT, suggesting that inspection reliability is shaped by the interaction between personnel capability, certification systems, inspection technologies, working conditions, and safety-critical decision contexts.

Conclusion

This study mapped the human dimension of NDT research through bibliometric analysis, with specific focus on NDT personnel competence and performance assurance. Based on 616 Scopus-indexed documents from 1967 to 2026, the study examined publication trends, source productivity, author contribution, country contribution, thematic structure, and keyword co-occurrence patterns.

The results show that the human dimension of NDT research has developed gradually over time, with stronger visibility in recent years. However, the most influential publications remain largely connected to technology-oriented NDT research, including digital inspection, automated defect detection, machine learning, NDE 4.0, and inspection performance. This indicates that human-related themes are present but remain less dominant compared with technical and technology-driven themes.

The thematic map and co-occurrence analysis show that the human dimension of NDT is organised around training and education, certification and standards, personnel competence, personnel qualification, workforce and professional practice, inspection performance, inspection reliability, probability of detection, and human factors. However, these themes are not yet fully consolidated. Training, certification, and personnel competence occupy a central but developing position. Inspection performance is a basic theme, while inspection reliability, probability of detection, and human factors are niche themes.

The main conclusion of this study is that the human dimension of NDT research is visible but fragmented. It spans several related themes, but these themes have not yet formed a mature, integrated research stream. This finding supports the need for a more systematic research

International Journal of Modern Education
EISSN: 2637-0905
IJMOE
Volume: 8 Issue: 31 (September 2026) PP. 01-26
agenda that connects NDT training, certification, personnel competence, human factors, digital readiness, and inspection reliability. Such integration is necessary to ensure that NDT personnel development contributes not only to certification achievement but also to reliable inspection performance in safety-critical and technology-supported environments.

Limitations and Future Research Directions

This study has several limitations. First, it maps the bibliometric visibility and conceptual positioning of human-dimension themes in NDT, but it does not measure the actual competence or inspection performance of certified NDT personnel. Because the dataset was purposively constructed using human-dimension search terms, the study does not estimate the absolute proportion of human-related studies within the entire NDT literature. Instead, it examines the internal structure and conceptual position of human-dimension themes within the selected dataset.

Second, the analysis was limited to the Scopus database and relied mainly on bibliometric metadata, including titles, abstracts, author keywords, index keywords, citations, sources, authors, and countries. Although Scopus provides broad coverage and standardised metadata, it may not capture all relevant materials, especially industry reports, technical standards, training manuals, certification scheme documents, and some professional conference outputs. Future studies may extend the dataset by including Web of Science, IEEE Xplore, ASNT publications, BINDT sources, ISO-related documents, ICNDT documents, and regional databases.

Third, the keyword harmonisation process involved interpretive judgement. Although the thesaurus and cleaning procedures improved the clarity of the thematic map, decisions to merge, standardise, or suppress keywords may influence the structure of the visualisation. Future studies should report keyword harmonisation procedures transparently, provide thesaurus files as supplementary materials, and involve multiple reviewers or expert validation to improve reliability.

Fourth, the citation indicators used in this study may favour older publications because they have had more time to accumulate citations. Recent publications from 2024 to 2026 may show lower citation impact due to citation time lag. Future research should complement total citations with normalised citation indicators, citations per year, field-weighted citation impact, or altmetric indicators where available.

Finally, this study focused on the broad human dimension of NDT and did not provide method-specific comparison across ultrasonic testing, radiographic testing, penetrant testing, magnetic testing, eddy current testing, or visual testing. Future studies should examine how competence requirements, certification expectations, inspection reliability, and digital readiness differ across NDT methods. More empirical research is also needed to investigate the relationship between NDT certification and actual inspection performance, particularly in safety-critical and technology-supported inspection environments. Such studies could support the development of an integrated competence assurance framework linking training design, certification requirements, industrial experience, human factors, digital literacy, inspection reliability, and performance-based assessment.

Acknowledgements:	The authors would like to acknowledge Universiti Tun Hussein Onn Malaysia for academic support during the preparation of this manuscript.
Funding Statement:	No specific funding was received for this research from any public, commercial, or not-for-profit funding agency.
Conflict of Interest Statement:	The author(s) certify that this manuscript is an original work and has not been previously published, submitted, or considered for publication elsewhere, either in whole or in part. The author(s) further declare that there is no conflict of interest concerning the subject matter, materials, or findings discussed in this manuscript.
Ethics Statement:	This study did not involve any human participants, animals, or sensitive data requiring ethical approval. The authors confirm that the research was conducted in accordance with accepted academic integrity and ethical publishing standards.
Author Contribution Statement:	All authors contributed substantially to the development of the study, analysis of the data, and preparation of the manuscript.

References

Abdelkader, E. M., Zayed, T., & Faris, N. (2023). Synthesized Evaluation of Reinforced Concrete Bridge Defects, Their Non-Destructive Inspection and Analysis Methods: A Systematic Review and Bibliometric Analysis of the Past Three Decades. *Buildings*, *13*(3). https://doi.org/10.3390/buildings13030800

Abdulwahd, A. K., Mugisha, S., Chavula, P., & Kayusi, F. (2025). Bibliometric Insights into Advances in Nondestructive Testing Techniques for Delamination Detection. *Mesopotamian Journal of Civil Engineering*, *2025*, 49–67. https://doi.org/10.58496/MJCE/2025/004

Ahmi, A. (2024). *biblioMagika, available from*. https://bibliomagika.com

Aria, M., & Cuccurullo, C. (2017). bibliometrix: An R-tool for comprehensive science mapping analysis. *Journal of Informetrics*, *11*(4), 959–975. https://doi.org/https://doi.org/10.1016/j.joi.2017.08.007

Bato, M. R., Hor, A., Rautureau, A., & Bes, C. (2019). Impact of human and environmental factors on the probability of detection during NDT control by eddy currents. *Measurement: Journal of the International Measurement Confederation*, *133*, 222–232. https://doi.org/10.1016/j.measurement.2018.10.008

Bertovic, M. (2015). *Human Factors in Non-Destructive Testing (NDT): Risks and Challenges of Mechanised NDT*. *September*. https://doi.org/https://doi.org/10.14279/depositonce-4685

Brougui, M., Andor, K., & Szabó, P. (2025). Evaluation of Timber Mechanical Properties Through Non-Destructive Testing: A Bibliometric Analysis. *Buildings*, *15*(13). https://doi.org/10.3390/buildings15132192

Chen, W., Hou, J., Hao, S., Zhu, Y., & Yu, M. (2025). Mapping knowledge structure and themes trends of corrosion detection of steel: A bibliometric analysis. *Computational Materials Science*, *253*. https://doi.org/10.1016/j.commatsci.2025.113889

Donthu, N., Kumar, S., Mukherjee, D., Pandey, N., & Lim, W. M. (2021). How to conduct a bibliometric analysis: An overview and guidelines. *Journal of Business Research*, *133*(March), 285–296. https://doi.org/10.1016/j.jbusres.2021.04.070

Gupta, M., & Khan, M. (2021). Advances in applications of Non-Destructive Testing (NDT): A review. *Advances in Materials and Processing Technologies*, *8*, 2286–2307. https://doi.org/10.1080/2374068x.2021.1909332

Ibrahim, A., Faris, N., Zayed, T., Qureshi, A. H., Abdelkhalek, S., & Abdelkader, E. M. (2026). Application of infrared thermography in concrete bridge deck inspection: current practices, challenges and future needs. *Nondestructive Testing and Evaluation*, *41*(1), 1–44. https://doi.org/10.1080/10589759.2024.2443810

ICNDT. (2024). *ICNDT Guide and Recommendations for Qualification and Certification of NDT Personnel*. *July*. http://www.icndt.org/Documents/ICNDT-Guide

ISO. (2021). *ISO 9712 : Non-destructive testing - Qualification and certification of NDT personnel*.

ISO. (2026). *ISO/IEC 17024:2026: Conformity assessment-General requirements for bodies operating certification of persons*.

Kanzler, D., & Rentala, V. (2023). Reliability evaluation of testing systems and their connection to NDE 4.0. *Proc.SPIE*, *12491*, 1249109. https://doi.org/10.1117/12.2658857

Lavender, S. J., & Lavender, J. D. (1986). Harmonization of SNT-TC-1A and BS 5750 to create a quality system for the qualification of NDT personnel. *NDT International*, *19*(6), 407–409. https://doi.org/https://doi.org/10.1016/0308-9126(86)90033-7

Li, X., Liu, R., & Chen, S. (2025). Application and development of non-destructive testing techniques for storage tanks and pressure vessels in the last two decades: A bibliometric-based visualization analysis. In C. L. & Z. A.B.M. (Eds.), *Proceedings of SPIE - The International Society for Optical Engineering* (Vol. 13574). SPIE. https://doi.org/10.1117/12.3067443

Meyendorf, N., Ida, N., Singh, R., & Vrana, J. (2023). NDE 4.0: Progress, promise, and its role to industry 4.0. *NDT and E International*, *140*(September), 102957. https://doi.org/10.1016/j.ndteint.2023.102957

Mohamad, Z., Ismail, A., Md Hani, M. H., & Aris, N. (2026). A Conceptual CIPP-Based Model for Professional NDT Certification in Malaysian TVET Institutions. *International Journal of Research and Innovation in Social Science*, *X*(IV), 6415–6427. https://doi.org/10.47772/IJRISS.2026.100400459

Moher, D., Liberati, A., Tetzlaff, J., & Altman, D. G. (2009). Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *Bmj*, *339*.

Nguyen, T., Kamma, S., Adari, V. C., Lesthaeghe, T., Boehnlein, T., & Kramb, V. (2021). Mixed reality system for nondestructive evaluation training. *Virtual Reality*, *25*, 1–10. https://doi.org/10.1007/s10055-020-00483-1

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., … Moher, D. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *Bmj*, *372*. https://doi.org/10.1136/bmj.n71

Punj, N., Ahmi, A., Tanwar, A., & Abdul Rahim, S. (2023). Mapping the field of green manufacturing: A bibliometric review of the literature and research frontiers. *Journal of Cleaner Production*, *423*(September), 138729. https://doi.org/10.1016/j.jclepro.2023.138729

Rayendra, Aulia, F., Mulyadi, D., Ismail, A., & Hardika, J. (2026). Deep Learning and Digital Literacy: A Systematic Literature Network and Bibliometric Review. *International Journal of Modern Education and Computer Science*, *18*(3), 74. https://doi.org/10.5815/ijmecs.2026.03.05

Škrinjarić, B. (2022). Competence-based approaches in organizational and individual context. *Humanities and Social Sciences Communications*, *9*(1), 1–12. https://doi.org/10.1057/s41599-022-01047-1

Tang, Y., Liu, L., Pan, T., & Wu, Z. (2024). A bibliometric analysis of cultural heritage visualisation based on Web of Science from 1998 to 2023: a literature overview. *Humanities and Social Sciences Communications*, *11*(1), 1–12. https://doi.org/10.1057/s41599-024-03567-4

Tsougkranis, A. (2018). In-service inspection; training and certification aspects. *NDT 2018 - 57th Annual Conference of the British Institute of Non-Destructive Testing*, 225–237. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85060786313&partnerID=40&md5=36660c9e7cfdfd51c779965b8acb42c9

van Eck, N. J., & Waltman, L. (2010). VOSviewer : A Computer Program for Bibliometric Mapping. *Scientometrics*, *84*, 523–538.

Vardari, L., Qabrati, I., & Kâhiloğullari, A. (2025). A Bibliometric Review of Sustainable Finance and Investment. *Pakistan Journal of Life and Social Sciences (PJLSS)*, *23*(1), 694–709. https://doi.org/10.57239/pjlss-2025-23.1.0055

Vasconcelos, V., Soares, W. A., Marques, R. O., Silva Jr, S. F., & Raso, A. L. (2019). Human reliability in non-destructive inspections of nuclear power plant components: modeling and analysis. *Brazilian Journal of Radiation Sciences*, *7*(2B), 1–12. https://doi.org/10.15392/bjrs.v7i2b.368

Wall, M., Burch, S., & Lilley, J. (2009). Human factors in POD modelling and use of trial data. *Insight-Non-Destructive Testing and Condition Monitoring*, *51*(10), 553–561.

Zhou, Y., & Zhang, B. (2025). Progress and Trends in Museum Interactive Experience Research: A Bibliometric Visualization Analysis. *Pakistan Journal of Life and Social Sciences (PJLSS)*, *23*(1), 996–1013. https://doi.org/10.57239/pjlss-2025-23.1.0078