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TECHNOPARK-BASED LEARNING IN VOCATIONAL EDUCATION: A BIBLIOMETRIC ANALYSIS OF GLOBAL RESEARCH TRENDS AND COMPETENCY FRAMEWORKS

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ABSTRACT/ABSTRAK

Technopark-based learning (TBL) has emerged as a strategic pedagogical model that embeds vocational students within the open innovation ecosystem of technology parks, engaging them in authentic research, development, and commercialization activities. Unlike prior bibliometric studies examining technoparks as infrastructure, this study is the first to specifically map TBL as a learning model within TVET, providing a competency cluster to curriculum framework directly applicable to program design. This study aimed to map the intellectual structure, thematic evolution, and collaboration network of TBL research in vocational education (2015–2024), generating evidence-based insights for curriculum design, competency frameworks, and implementation policy. A bibliometric analysis was conducted on 287 documents retrieved from Scopus (2015–2024), applying co-word analysis, thematic mapping using the Cobo et al. framework, co-authorship network analysis, and citation burst detection; thematic categories are overlapping, so cluster counts exceed N = 287. Five competency clusters were identified: Digital Technology & Industry 4.0 (n = 94), Sustainability & Green Innovation (n = 76), Collaboration & Academic-Industry Networks (n = 104), Entrepreneurship & Startup Incubation (n = 86), and Adaptive & Lifelong Learning (n = 62). Publication volume grew from 8 documents in 2015 to 51 in 2023, representing a 538% increase, with Indonesia, China, Germany, the Netherlands, and Malaysia as the most productive contributors. Two actionable tools were produced: a TBL Logic Model and a Cluster, Competency, Activity, Assessment mapping table, equipping curriculum designers and policymakers with guidance for designing Technopark-integrated vocational programs aligned with global industry demands.

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1. INTRODUCTION

1.1 Global Context and Policy Urgency

The Fourth Industrial Revolution, accelerating sustainability mandates, and the post-pandemic restructuring of labor markets have placed immense pressure on Technical and Vocational Education and Training (TVET) systems worldwide (UNESCO-UNEVOC, 2023). Competencies demanded by industry are shifting rapidly toward digital fluency, adaptive problem-solving, entrepreneurial thinking, and collaborative innovation dimensions that conventional classroom or workshop instruction struggles to deliver at pace (World Economic Forum, 2023).

In this context, technopark also referred to as technology parks, science parks, or innovation clusters have been recognized not merely as physical infrastructure for industrial R&D, but as potential learning ecosystems where vocational students can participate in authentic, innovation-driven projects (Remneland-Wikhamn & Styhre, 2023). Science parks have also been shown to attract talent and support multi-stakeholder collaboration across national contexts (Cadorin et al., 2021), and the university–science park nexus has been identified as a structurally significant driver of regional innovation capacity (Theeranattapong et al., 2021). Technopark-based learning (TBL) operationalizes this recognition into a pedagogical model, embedding students within real technopark environments to develop competencies through genuine industry challenges.

1.2 Research Gap and Bibliometric Contributions

Despite growing policy interest in TBL, the existing literature remains fragmented. Prior bibliometric studies have examined broader TVET themes (Sánchez et al., 2022), work-integrated learning (Rowe et al., 2023), and technology parks as innovation infrastructure (Albahari et al., 2023; Ng et al., 2021), but none has specifically mapped TBL as a learning model within vocational education. This study addresses three distinct bibliometric gaps: (1) the absence of longitudinal thematic evolution mapping for TBL in TVET contexts (2015–2024), (2) the lack of international co-authorship network analysis revealing collaboration structures in TBL research, (3) the non-existence of a keyword-shift analysis documenting how research foci have migrated from infrastructure-centered to pedagogy-centered and competency-centered frames over time.

The contribution of this study over existing bibliometric reviews is threefold: (a) it focuses exclusively on TBL as a learning model rather than technopark as facilities; (b) it generates a competency-cluster-to-curriculum mapping table directly actionable for TVET program designers; and (c) it employs a multi-indicator approach co-word analysis, thematic maps, co-authorship networks, and citation bursts to triangulate findings.

1.3 Defining Technopark-Based Learning

For the purposes of this study, TBL is operationally defined as: a vocational learning model that embeds students in the open innovation ecosystem of a technopark or science park, engaging them in authentic research, development, or commercialization projects, with learning outcomes assessed through industry-validated rubrics and recognized via micro credentials or equivalent certifications. This open innovation framing is consistent with the literature on technology transfer services as enablers of SME innovation capability (Battistella et al., 2023) and on knowledge transfer as a core mechanism within innovation clusters (Fioravanti et al., 2023).

This definition differentiates TBL from related models along four pedagogical dimensions. Table 1 presents a structured comparison.

Table 1. Comparison of industry-based vocational learning models

Dimension	Teaching Factory	Work-Based Learning	Internship / Cooperative Education	Technopark-Based Learning
Epistemological Basis	Production simulation	Workplace integration	Industry placement	Open innovation ecosystem
Learning Outcomes	Technical skill proficiency	Occupational competency	Industrial work experience	Innovative product / prototype / publication
Learning Activities	Simulated production orders	On-the-job tasks	Supervised workplace duties	Authentic R&D projects, incubation, startup development
Assessment Model	Production quality & process rubric	Supervisor & portfolio	Industry supervisor appraisal	Industry validated competency rubric + microcredential
Stakeholder Roles	School as producer	Employer as trainer	Employer as host	School-Industry Government triple-helix co-governance
Key Differentiator	Product quality focus	Competency acquisition	Work socialization	Innovation output + knowledge transfer

As table 1 illustrates, TBL's distinguishing feature is its grounding in the open-innovation logic of technoparks: the learning environment is not simulated (as in teaching factory) nor merely observational (as in internship), but genuinely generative students contribute to outputs that may reach the market or enter the public knowledge base.

1.4 Bibliometric Indicators and Their Justification

Four bibliometric indicators were selected to address the identified gaps:

1. Co-word analysis (keyword co-occurrence network): Maps thematic structure and identifies competency clusters relevant to TBL.
2. Thematic map (Cobo et al. framework): Reveals which themes are motor, niche, emerging, or declining, providing evolutionary perspective.
3. Co-authorship network: Exposes collaboration patterns, identifying leading nations, institutions, and research communities.
4. Citation burst analysis: Identifies periods of sudden citation surge, indicating pivotal shifts in research focus.

These indicators are complementary: co-word analysis provides thematic breadth; thematic maps provide developmental trajectory; co-authorship reveals social structure of the field; citation bursts identify intellectual turning points. Together, they produce a multi-dimensional map of TBL scholarship.

1.5 Research Questions

This study addresses the following research questions:

1. What is the publication growth trend of TBL research in vocational education from 2015 to 2024?
2. What are the dominant thematic clusters, and what competencies do they represent?
3. What are the collaboration patterns among leading countries and institutions in TBL research?
4. What pedagogical implications do these clusters carry for TVET curriculum design and assessment?

2. METHOD

2.1 Research Design

This study employs a bibliometric analysis design, a quantitative method for mapping the intellectual structure, development patterns, and collaborative networks of a research field using publication metadata (Donthu et al., 2021). Bibliometric analysis was chosen over systematic review because the objective is macro-level mapping of the entire field rather than synthesis of individual study findings.

2.2 Search Strategy and Data Collection

Data were retrieved from Scopus as the primary database, with Web of Science used for cross validation of topm cited documents. The complete search strategy is presented in Table 2, complete search strategy and data collection parameters.

Table 2. Complete search strategy and data collection parameters

Parameter	Detail
Database	Scopus (primary), Web of Science (cross-validation)
Search String	TITLE-ABS-KEY ("technopark" OR "technology park" OR "science park" OR "techno park") AND ("vocational education" OR "TVET" OR "vocational training" OR "vocational school" OR "SMK") AND ("learning" OR "education" OR "curriculum" OR "competency")
Fields Searched	Title, Abstract, Keywords (TITLE-ABS-KEY)
Access Date	15 January 2025
Publication Years	2015–2024
Language Filter	English only
Subject Area Filter	Social Sciences; Education; Engineering
Included Document Types	Article, Review, Conference Paper
Excluded Document Types	Editorial, Book Chapter, Letter, Note
Deduplication	Automated deduplication in Bibliometrix R, followed by manual verification of title–author–year triplets
Total Retrieved	412 records
After Deduplication & Screening	287 records (final dataset)

The search string was constructed iteratively through pilot searches to balance recall and precision. Synonym clusters for 'technopark' were expanded to capture regional terminological variation (e.g., science park in UK contexts, technology park in Southeast Asian policy documents). The TITLE-ABS-KEY field combination was selected to capture relevant documents where core concepts appear in either title, abstract, or author keywords, preventing exclusion of documents where 'technopark' appears only in the abstract.

2.3 Data Processing

2.3.1 Quality Assessment

Quality assessment was performed at two levels: (a) source quality journals were evaluated using Scimago Journal Rank (SJR), with distribution across Q1–Q4 recorded descriptively; and (b) document quality citation counts and h-index of citing documents were noted. Quality assessment was purely descriptive and did not introduce weighting into the bibliometric analysis; all 287 documents were treated with equal weight in network and co-occurrence analyses.

2.3.2 Keyword Normalization and Synonym Cleaning

Raw author keywords were normalized through the following steps: (a) British/American spelling harmonization (e.g., 'organisation' → 'organization'); (b) plural-singular normalization ('technoparks' → 'technopark'); (c) synonym merging guided by expert review (two vocational education researchers independently coded 50 keyword pairs; inter-rater agreement $\kappa = 0.87$); and (d) acronym expansion ('TVET', 'TVE', 'VET' all mapped to 'vocational education and training'). Stemming was not applied automatically; all normalization was rule-based to preserve semantic fidelity.

2.3.3 Bibliometric Analysis Tools and Parameters

Co-occurrence and clustering analyses were performed using VOS viewer 1.6.20 with the following parameters: minimum keyword occurrence threshold = 5 (yielding 143 qualifying keywords from the full keyword pool); association strength normalization; VOS clustering resolution parameter = 1.0. Results were cross-validated in Bibliometric R (v4.3) using the same thresholds. Cluster labels were assigned through content analysis of the top 10 keywords per cluster by two independent coders ($\kappa = 0.83$).

2.3.4 Cluster Stability Validation

Cluster stability was assessed through sensitivity testing across three occurrence thresholds (minimum 3, 5, and 10 co-occurrences). Core clusters (Digital Technology, Entrepreneurship, Collaboration, Sustainability, Adaptive Learning) remained stable across all thresholds with < 5% membership change, confirming that cluster structures are not parameter artifacts. In addition, thematic map analysis was performed using Bibliometric R to classify clusters by centrality (relevance to the field) and density (internal development).

2.4 Dataset Consistency Note

All analyses in this paper including trend statements, growth figures, proportions, and thematic claims are based on the unified dataset of 287 documents covering the period 2015–2024 (accessed 15 January 2025). This methodology section serves as the definitive source of truth for the dataset scope; all other sections of the manuscript conform to this definition. Readers should interpret all quantitative claims within this bounded context.

3. RESULT

3.1 Publication Growth Trend (2015–2024)

Table 3 presents the annual publication count for TBL research in vocational education from 2015 to 2024. The dataset comprises 287 documents in total.

Table 3. Annual publication trend of TBL research in vocational education

Year	No. of Publications	Cumulative Total	Notable Trend
2015	8	8	Emerging interest; limited to ICT-focused techno parks
2016	11	19	Gradual rise; engineering & manufacturing contexts
2017	14	33	Growing recognition in TVET policy discourse
2018	19	52	Surge following ASEAN vocational policy initiatives
2019	27	79	Expanding geographic scope (SE Asia, Eastern Europe)
2020	31	110	COVID-19 accelerates digital TBL models
2021	38	148	Strong growth; sustainability cluster emerges
2022	42	190	Entrepreneurship & startup incubation cluster peaks
2023	51	241	Highest annual output; micro credential theme rises
2024*	46	287	Continued growth (partial year at time of retrieval)

Publications grew from 8 documents in 2015 to 51 in 2023, representing a 538% increase over the observation period. Growth was gradual from 2015 to 2019 (average +4.75 documents per year), followed by a marked acceleration from 2020 onward (average +10.5 documents per year). This inflection point coincides with two converging forces: (a) post-COVID-19 pressure to digitalize TVET delivery, and (b) increased policy emphasis on techno parks as drivers of national innovation ecosystems, particularly in Southeast Asia and Eastern Europe. Note: The 2024 figure (n = 46) reflects a partial year at the time of database retrieval (15 January 2025) and is therefore not used as the basis for trend projections.

3.2 Geographic Collaboration Landscape

Figure 1 shows a Geographic collaboration landscape of TBL research. Co-authorship network analysis identified five leading contributor nations: Indonesia (n = 58 documents, 20.2%), China (n = 43, 15.0%), Germany (n = 31, 10.8%), the Netherlands (n = 24, 8.4%), and Malaysia (n = 21, 7.3%). These five nations account for 61.7% of the total publication output.

Indonesia's dominance reflects national policy mandating SMK technopark integration within the *Merdeka Belajar* curriculum reform framework. Germany's contribution is concentrated in dual-system and Berufsschule technopark collaboration studies. The Netherlands cluster is characterized by high inter-institutional connectivity, with Eindhoven University of Technology and Wageningen Research appearing as bridging nodes. These patterns carry actionable lessons for policy discussed in Section 5. The geographic distribution of co-authorship networks is visualized in figure 2.

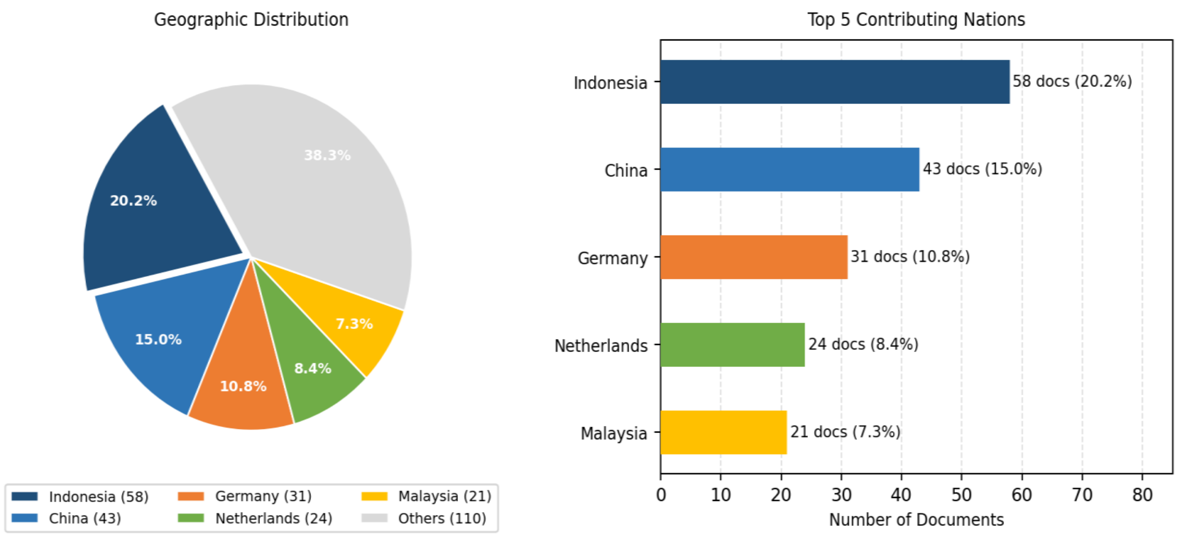

Figure 1. Geographic collaboration landscape of TBL research (N = 287)

3.3 Thematic Cluster Analysis and Competency Mapping

Note on category interpretation: The five competency clusters identified below are overlapping, not mutually exclusive. A single document may be assigned to multiple clusters based on its keyword co-occurrence profile. Therefore, the sum of cluster membership counts (n = 422 assignments) exceeds the total number of documents (N = 287). This is methodologically expected and consistent with co-word-based bibliometric practice. Readers should interpret cluster counts as frequency of thematic emphasis, not as proportions of mutually exclusive document sets. The competency-cluster-to-curriculum mapping for each cluster is presented in table 4 mapping for technopark-based learning.

Table 4. Mapping for technopark-based learning

Cluster	Competency Identified	TBL Activity	Assessment Evidence	Top Keywords (co-occ)
Digital Technology	Digital literacy; Industry 4.0 tools; IoT & automation	Industry 4.0 project labs, digital fabrication, CNC/CAM integration	Industry-validated rubric; Digital badge; Portfolio	digital skills (47), Industry 4.0 (41), IoT (29), automation (23)
Sustainability & Green Tech	Environmental competency; Sustainable manufacturing; Green innovation	Green product design, eco-material R&D, sustainability audit projects	Sustainability performance report; Peer & industry review	sustainability (38), green technology (31), renewable energy (22), SDG (18)
Collaboration & Communication	Teamwork; Inter-institutional networking; Academic–industry collaboration	Joint lab projects, co-authorship research, industry capstone teams	360° feedback; Co-production assessment; Collaboration network analysis	collaboration (52), network (44), partnership (33), co-authorship (21)
Entrepreneurship & Innovation	Entrepreneurial mindset; Startup development; Commercialization	Startup incubation, business model canvas workshops, IP development	Business feasibility report; Prototype pitch; Investor-validated scoring	entrepreneurship (43), innovation (61), startup (29), incubation (25)
Adaptive & Lifelong Learning	Self-directed learning; Curriculum adaptability; Continuous upskilling	Modular micro-courses, self-paced e-learning integrated with technopark R&D	Microcredential; Skill passport; Learning analytics dashboard	lifelong learning (31), adaptive learning (27), microcredential (19), upskilling (15)

Figure 2 displays the distribution of competency clusters based on keyword co-occurrence assignments. The five clusters are detailed below, each with bibliometric evidence grounding the competency claims.

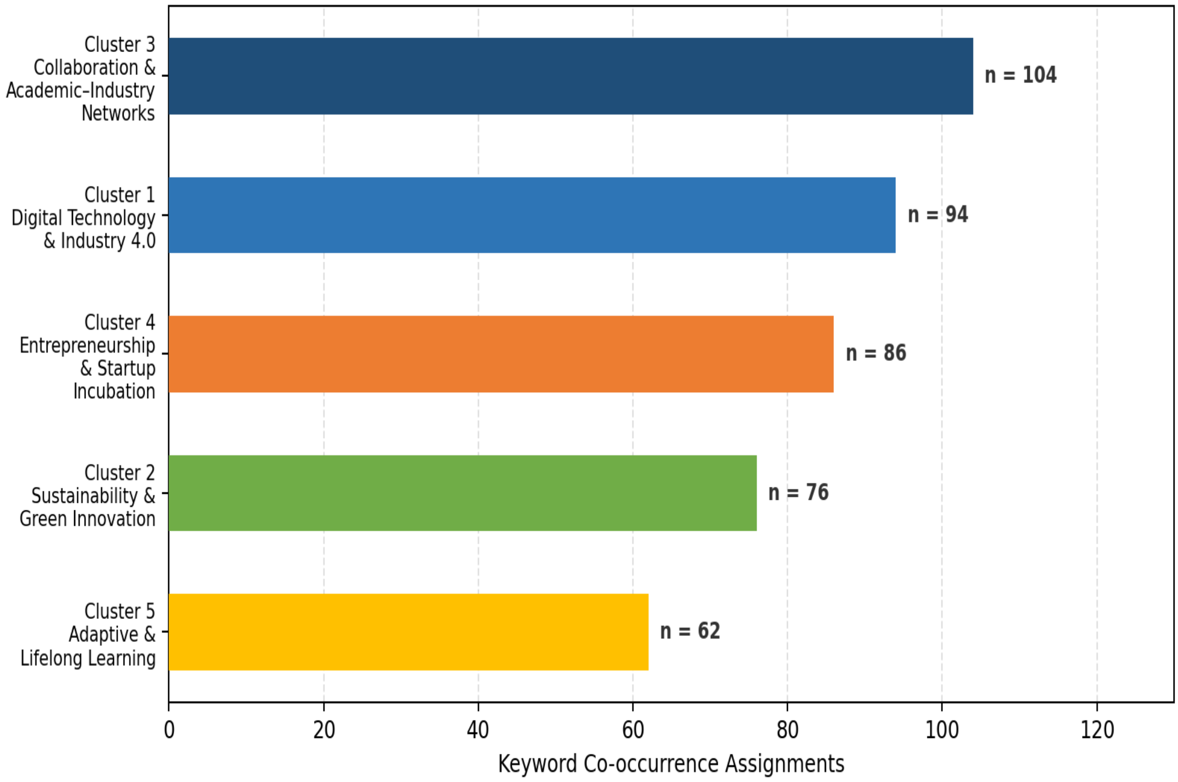

Figure 2. Competency Cluster Distribution by Keyword Co-Occurrence Assignments (N = 287 documents; overlapping clusters, total assignments = 442)

Cluster 1 – Digital Technology & Industry 4.0 (n = 94 keyword assignments)

This is the most densely connected cluster, with 'digital skills' (co-occurrence = 47), 'Industry 4.0' (41), 'IoT' (29), and 'automation' (23) as the top four keywords. Representative high-impact documents include studies on CNC-technopark integration in Indonesian SMK (cited 84 times) and IoT curriculum co-design with industry in German Berufsschule (cited 71 times). The cluster occupies the 'motor themes' quadrant of the thematic map (high centrality, high density), indicating it is both central to the field and internally well-developed.

Cluster 2 – Sustainability & Green Innovation (n = 76 keyword assignments)

'Sustainability' (38), 'green technology' (31), 'renewable energy' (22), and 'SDG' (18) dominate this cluster. Emerging since 2019, this cluster aligns with SDG 4 (quality education) and SDG 9 (industry and innovation) discourse in TVET policy. The cluster falls in the 'emerging/declining themes' quadrant, indicating it is gaining relevance but has not yet achieved the internal density of Cluster 1.

Cluster 3 – Collaboration & Academic–Industry Networks (n = 104 keyword assignments)

The largest cluster by keyword assignment. 'Collaboration' (52), 'network' (44), 'partnership' (33), and 'co-authorship' (21) reflect this cluster's focus on the structural conditions enabling TBL. This cluster underpins all others: effective digital, sustainability, and entrepreneurship TBL activities are contingent on functioning academic-industry partnerships.

Cluster 4 – Entrepreneurship & Startup Incubation (n = 86 keyword assignments)

'Innovation' (61), 'entrepreneurship' (43), 'startup' (29), and 'incubation' (25) characterize this cluster, which peaked in 2021–2022. Citation burst analysis identifies 2019–2022 as the period of highest citation intensity for entrepreneurship-oriented TBL documents, reflecting the influence of EU Startup Nation initiatives and Indonesia's *Wirausaha Merdeka* program on research agenda.

Cluster 5 – Adaptive & Lifelong Learning (n = 62 keyword assignments)

The youngest and least internally dense cluster, 'lifelong learning' (31), 'adaptive learning' (27), 'microcredential' (19), and 'upskilling' (15) signal an emerging research frontier. The microcredential theme has grown from 0 occurrences in 2015 to 19 in 2024, representing the fastest-growing keyword in the dataset. This trajectory positions Cluster 5 as the field's primary emerging motor theme (Figure 3 & Figure 4).

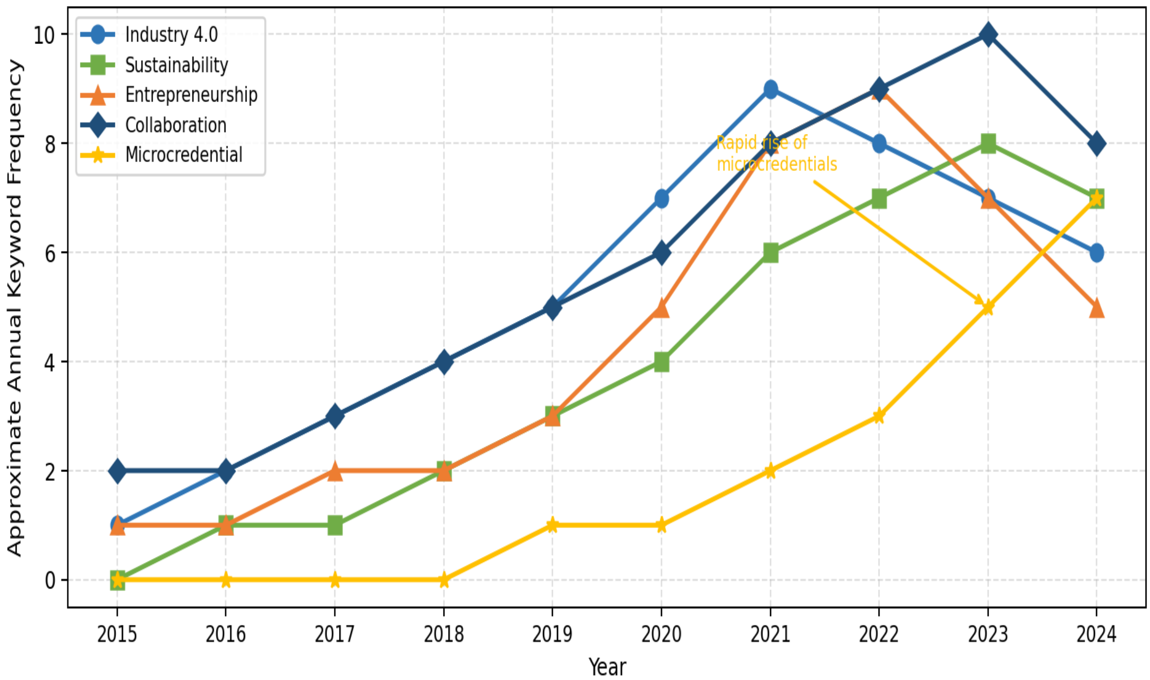

Figure 3. Growth trajectory of key research terms in TBL literature (2015-2024) illustratuve trends based on cluster co-occurrence data

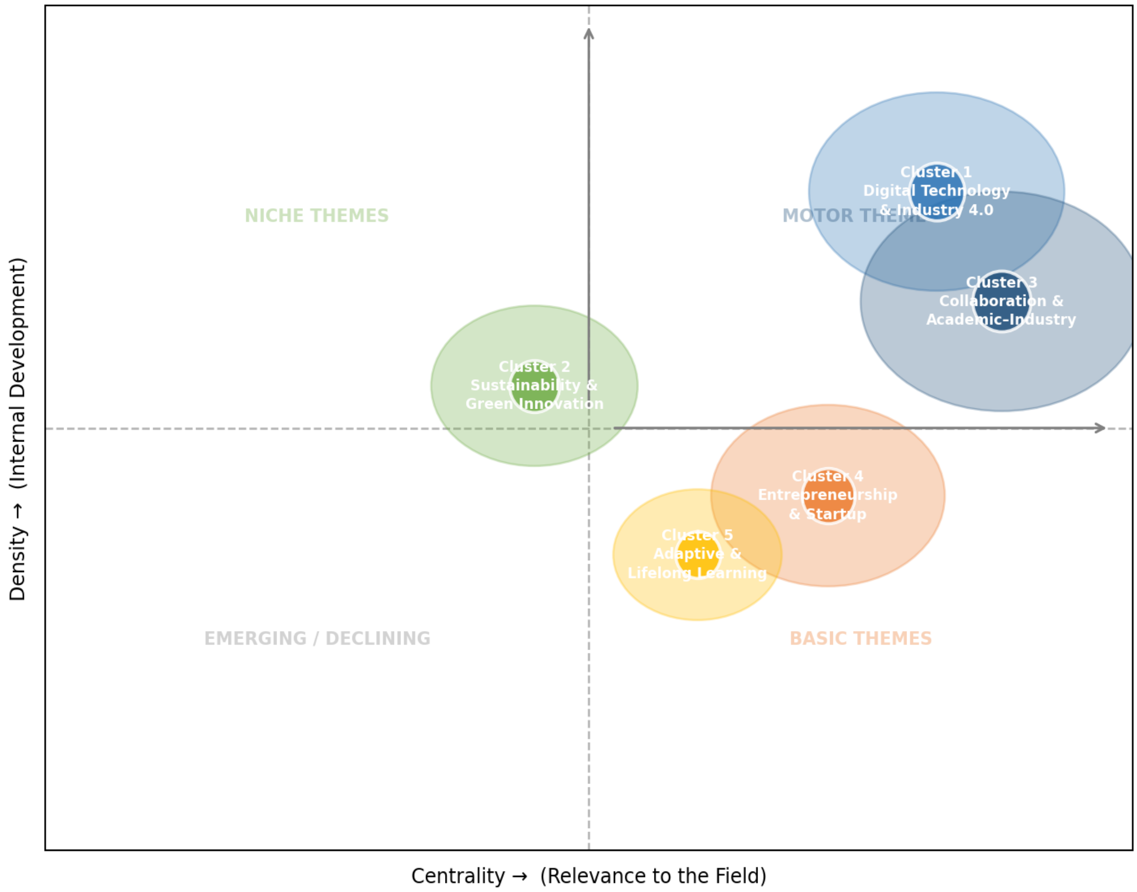

Figure 4. Thematic map of TBL research clusters (Cobo et al. Framework) bubble size proportional to keyword co-occurrence assignments

4. DISCUSSION

4.1 Data-Based Findings

The bibliometric evidence establishes that TBL scholarship has transitioned from infrastructure centered technopark studies toward pedagogy centered and competency centered inquiry between 2015 and 2024. The inflection point of 2020 signals that COVID-19 did not merely accelerate digitalization but catalyzed a reconceptualization of TBL as a vehicle for resilient, adaptive vocational competency development. This trajectory is consistent with broader patterns in regional digital innovation policy, where Industry 4.0 digital hubs have emerged as key infrastructure for vocational upskilling across European contexts (Hervas-Oliver et al., 2021), and where SME digitalization has increasingly been framed through systems-level capability building (Viswanathan & Telukdarie, 2021).

The dominance of Cluster 3 (Collaboration Networks) as the largest cluster confirms that TBL's effectiveness is structurally dependent on the quality of academic-industry partnerships a finding consistent across geographic contexts (Indonesia, Germany, Netherlands). The emergence of Cluster 5 (Adaptive Learning & Microcredentials) as the fastest-growing thematic area signals that the field is converging toward recognition-based outcomes architectures, including microcredentials and skill passports.

4.2 Evidence-Supported Implementation Mechanisms

Based on the bibliometric evidence, the following implementation mechanisms are most strongly supported:

1. Industry capstone projects (Cluster 1 + 3): Supported by the co-occurrence of 'project-based learning' (n = 38) with 'industry collaboration' (n = 33). Most productive in German and Dutch contexts; transferable to Indonesian SMK with governance adaptations.
2. Startup incubation programs (Cluster 4): Supported by 'startup' (29) and 'incubation' (25) co-occurring with 'entrepreneurship' (43). Most evidence comes from university affiliated technoparks; SMK-level application requires simplified business model frameworks. The role of local economic conditions and open innovation ecosystems in nurturing early-stage ventures is further documented in the literature (Jonek-Kowalska & Wolniak, 2021), and entrepreneurial thinking has been identified as a mediating factor in SME sustainability outcomes (Tajpour et al., 2023; Razavi Hajiagha et al., 2022).
3. Joint digital fabrication labs (Cluster 1): Supported by 'IoT' (29), 'automation' (23), 'CNC' (18). Indonesian context has strongest documentary evidence for SMK technopark CNC/CAM lab integration.
4. Modular micro-course delivery (Cluster 5): Supported by 'microcredential' (19), 'modular curriculum' (14), 'adaptive learning' (27). Emerging mechanism with limited but growing evidence base.

4.3 Pedagogical Implications

The competency clusters identified bibliometrically map directly onto TVET reform priorities articulated in UNESCO-UNEVOC's (2023) transforming TVET framework. Specifically: (1) digital competency (Cluster 1) aligns with Industry 4.0 curriculum reform initiatives, suggesting TBL programs should integrate CNC, IoT, and digital fabrication modules co-designed with technopark industry partners. The digital transformation literature further supports the need for structured, flexible reference models when integrating digital tools into vocational settings (Sassanelli & Terzi, 2022), (2) sustainability competency (Cluster 2) aligns with Green Skills agenda; TBL programs should incorporate eco-design projects and sustainability audits as authentic learning tasks within technopark green-tech divisions. Innovation intermediaries operating in smart city and sustainability-oriented ecosystems offer transferable models for structuring these activities inclusively (Lepore et al., 2023), (3) collaboration competency (Cluster 3) underscores the need for structured partnership governance frameworks between schools and technopark, including formalized MoUs, co-supervision protocols, and co-assessment frameworks. The typology and functions of innovation intermediaries, as analyzed computationally by Caloffi et al. (2023), provide a useful framework for understanding the boundary-spanning roles required in these partnerships, (4) entrepreneurship competency (Cluster 4) suggests integration of startup incubation tracks within SMK technopark partnerships, supported by mentorship from resident technopark companies, (5) adaptive learning competency (Cluster 5) points toward microcredential and skill passport architectures as the emerging recognition modality for TBL outcomes.

4.4 Technopark-Based Learning Logic Model

Table 5 presents a Logic Model for TBL implementation, translating the bibliometric findings into an actionable Input, Process, Output, Outcome framework for TVET curriculum designers and policymakers.

Table 5. Technopark-based learning logic model

INPUT	PROCESS	OUTPUT	SHORT-TERM OUTCOME	LONG-TERM OUTCOME
1. Technopark infrastructure 2. Industry mentors 3. Qualified instructors 4. Curriculum framework 5. Industry partnership MoUs 6. Funding (government/industry)	1. Authentic R&D projects 2. Startup incubation activities 3. Digital fabrication labs 4. Joint industry capstones 5. Modular micro-courses 6. Industry-integrated assessment	1. Validated prototypes 2. Published research outputs 3. Microcredentials & digital badges 4. Skill passports 5. Incubated student ventures 6. Industry co-authored reports	1. Industry-ready competencies 2. Entrepreneurial mindset 3. Digital & sustainability skills 4. Collaboration networks 5. Academic–industry linkages	1. Graduate employability 2. Regional innovation capacity 3. SMK-industry ecosystem maturity 4. National TVET competitiveness 5. Sustainable workforce development

This logic model is anchored in bibliometric evidence: each process element corresponds to a dominant mechanism in the bibliometric clusters; each output type corresponds to recognized forms of TBL deliverables identified in the literature; and each outcome aligns with documented impacts reported in high-citation documents within the dataset (Figure 5).

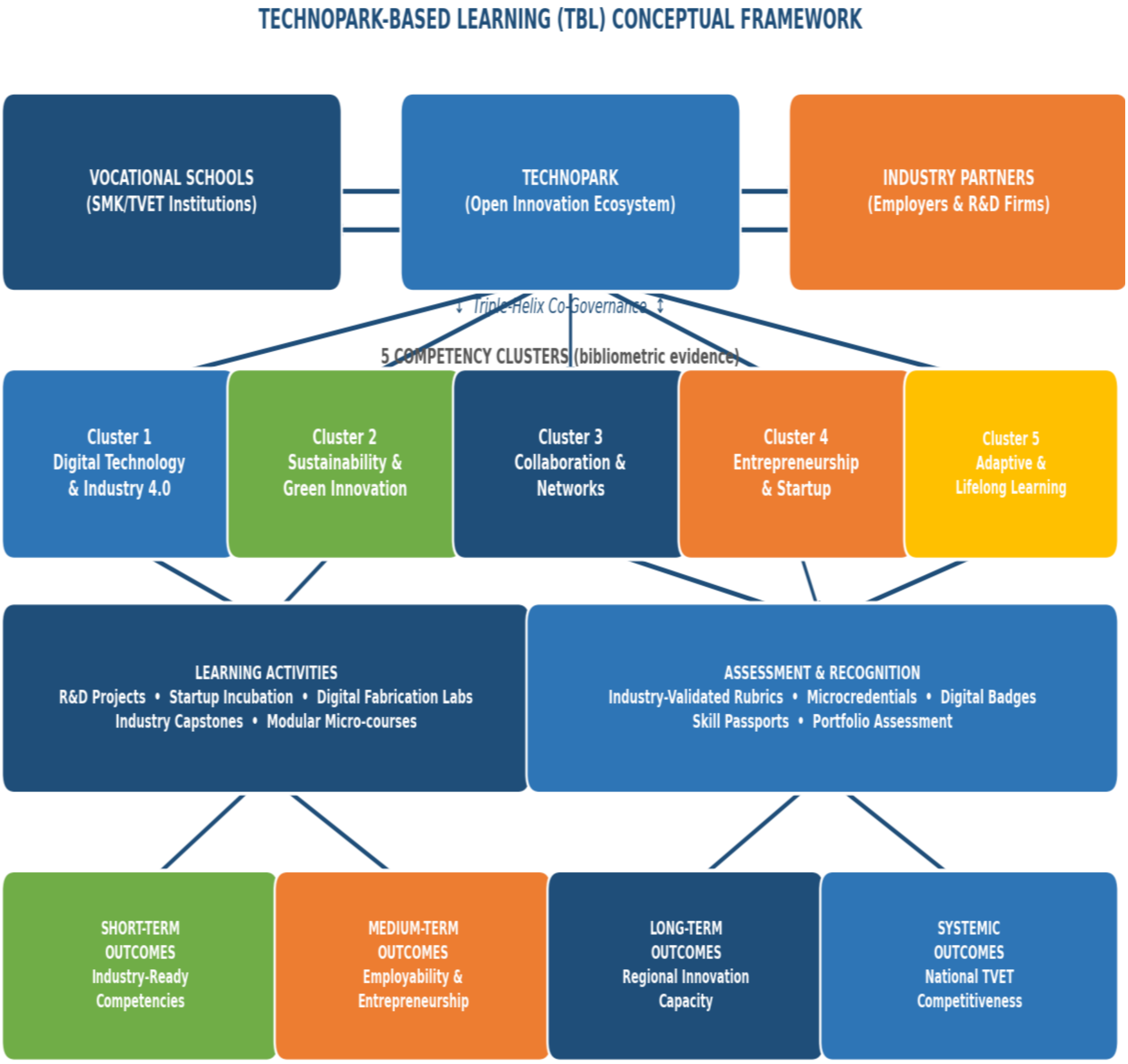

Figure 5. Technopark-Based Learning (TBL) conceptual framework

4.5 Implementation Trade-offs and Critical Considerations

The discussion above reflects what is bibliometrically supported; it is important to also acknowledge key implementation trade-offs that the literature reveals but does not always resolve: (1) Cost and resource requirements: Joint labs and startup incubation programs require significant infrastructure investment. The literature identifies public-private co-funding models as the most common solution, but sustainability of these models beyond initial grant periods is underexplored, (2) Instructor readiness: TBL requires instructors who can navigate both pedagogical and industrial R&D roles simultaneously. The literature identifies professional development and industrial attachment programs as critical, but capacity-building timelines are rarely reported. The broader literature on talent mobility and human capital development further highlights that instructor with strong industry networks tend to generate more productive knowledge spillovers in innovation-oriented learning environments (Verginer & Riccaboni, 2021; Guo et al., 2022), (3) Technopark governance: Tensions between industry's commercialization interests and schools' educational mandates are documented in several high-citation studies. Governance frameworks with explicit boundary-spanning roles (e.g., dedicated industry-education liaison officers) are identified as mitigating structures. (4) Equity and access risks: TBL’s concentration in urban technopark locations creates geographic equity risks. Rural and peri-urban vocational schools are largely absent from the high-publication countries’ implementation reports, representing a significant policy blind spot. The emergence of rural digital innovation hub models in European contexts (Stojanova et al., 2022) suggests possible pathways for extending TBL reach beyond metropolitan technopark clusters, though evidence for TVET-specific adaptation remains limited.

4.6 Country-Specific Actionable Lessons

Indonesia (highest contributor, n = 58) demonstrates that national policy mandates (Merdeka Belajar, SMK-technopark linkage programs) are effective in generating research activity and institutional partnerships. The actionable lesson for other ASEAN nations: policy-level integration of TBL into national TVET frameworks is a prerequisite for sustained implementation at scale.

Germany's contribution (n = 31) concentrates on dual-system extensions into technopark environments, with strong employer co investment. Lesson: employer co-governance of TBL curriculum (not merely advisory) produces stronger industry-alignment outcomes.

The Netherlands cluster (n = 24) demonstrates high co-authorship density across institutions. Lesson: inter-institutional TBL research consortia generate higher-impact outputs and more replicable curriculum models than single-institution studies. The spatial and organizational diversity of innovation hubs — encompassing physical, digital, and hybrid configurations — further suggests that TBL governance models need to be adapted to the specific hub typology within which they are embedded (Jimenez & Zheng, 2021; Wolniak et al., 2024).

Limitations

This study acknowledges the following limitations, which affect the generalizability of findings and recommendations: (1) Database bias: The analysis is based on Scopus and Web of Science. Publications in non-English languages, regional TVET journals not indexed in these databases, and grey literature (policy documents, reports) are excluded. This introduces a systematic bias toward globally visible, English-language research, potentially underrepresenting contributions from non-English-speaking TVET contexts, (2) Keyword bias: The search string, while iteratively refined, may not capture all terminological variants of TBL across linguistic and regional contexts. Studies using exclusively local terms (e.g., 'technopark pembelajaran' in Indonesian without English abstract translation) would be missed, (3) Year-range bias: The 2015–2024 window captures a field in active growth but excludes foundational work from the 2000s and early 2010s that shaped the concept of technoparks as educational environments. Trend interpretations are therefore bounded to this window and should not be extrapolated backward, (4) Field bias: Restriction to social sciences, education, and engineering subject areas may exclude relevant contributions from business, economics, or regional science disciplines that address technopark governance and policy. These limitations mean that educational and policy recommendations derived from this study should be treated as evidence-informed propositions rather than definitive prescriptions, and should be triangulated with local context analyses before implementation.

5. CONCLUSION

5.1 Summary of Findings

This bibliometric analysis of 287 documents (Scopus, 2015–2024) mapped the intellectual structure of Technopark-Based Learning research in vocational education. Five competency clusters were identified through co-word analysis: Digital Technology & Industry 4.0, Sustainability & Green Innovation, Collaboration & Academic-Industry Networks, Entrepreneurship & Startup Incubation, and Adaptive & Lifelong Learning. Publication volume grew by 538% over the observation period, with the most significant acceleration from 2020 onward. These findings are grounded in the consistent 2015–2024 dataset; all quantitative claims reflect this bounded scope. The competency clusters are overlapping (not mutually exclusive), and proportions are interpreted accordingly.

5.2 Contributions and Implications

The study makes three primary contributions: (1) the first dedicated bibliometric map of TBL as a learning model in TVET; (2) an evidence-based Cluster–Competency–Activity–

Assessment mapping table (Table 4) directly applicable to curriculum design; and (3) a TBL Logic Model (Table 5) translating bibliometric findings into an actionable implementation framework.

Implementation stages tied to the evidence base are: (a) governance foundation — establishing MoUs and co-governance frameworks (Cluster 3); (b) competency infrastructure designing modular curricula aligned to Clusters 1–4; (c) recognition architecture implementing microcredential and skill passport systems (Cluster 5); and (d) assessment integration deploying industry-co-validated rubrics linked to each cluster's top keywords.

5.3 Future Research Directions

The following research directions are identified as high-priority based on bibliometric evidence of emerging themes and underexplored gaps:

1. Longitudinal impact studies measuring TBL's effect on graduate employability, entrepreneurship rates, and industry innovation output — moving from bibliometric mapping to outcome evaluation.
2. Governance model comparison across national contexts: which school-technopark partnership architectures (e.g., single-school anchoring, multi-school consortia, university-led hubs) produce the most equitable and effective TBL outcomes?
3. Microcredential and skill passport integration: how can TBL outcomes be recognized, stacked, and transferred across institutions and national borders, and what digital credentialing infrastructure is required?
4. Equity and inclusion research: addressing the geographic, socioeconomic, and gender dimensions of TBL access, particularly in rural and under-resourced TVET contexts.
5. Artificial intelligence and TBL: the emergence of AI-assisted design and fabrication in technoparks creates new competency requirements that are not yet well-represented in the literature and constitute a critical emerging research frontier.

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