





Mapping the Research Landscape of Computational Thinking Skills in Technical Education: A Bibliometric Analysis

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Abstract

Computational Thinking Skills (CTS) have become a key competency in technical and vocational education as digitalisation, automation, and Industry 4.0 continue to reshape workforce demands. Despite increasing scholarly attention, CTS research within technical education remains fragmented, with limited synthesis of publication trends, intellectual structures, and thematic focus. To address this gap, this study presents a bibliometric analysis of CTS research in technical education published between 2018 and 2025. Data were retrieved exclusively from the Scopus database, yielding 48 peer-reviewed articles after systematic screening. Data cleaning and harmonisation were conducted using OpenRefine and biblioMagika® to ensure consistency in bibliographic records. Bibliometric indicators and network analyses were then applied, with VOSviewer used to visualise co-authorship, citation, and keyword co-occurrence networks. The findings reveal a clear growth trend in CTS-related publications, particularly from 2023 onwards, indicating rising global interest in integrating computational thinking into technical and vocational learning. Thematic mapping highlights dominant research areas, including educational robotics, programming, STEM integration, and problem-solving pedagogies, reflecting the applied nature of CTS in technical education. However, the analysis also identifies key challenges, such as uneven regional research impact, limited standardisation of CTS assessment, and disparities in institutional readiness. Overall, this study provides a systematic overview of the CTS research landscape, offering insights to support curriculum development, professional training, and policy initiatives in technical education.

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Introduction

Computational Thinking (CT) is widely recognised as an essential 21st-century competence that extends beyond computer science into all areas of education (Li et al., 2020). As defined by (Wing, 2006), CT provides a foundational approach to problem-solving by employing systematic, algorithmic, and data-driven strategies. This enables learners to navigate complex challenges in both digital and physical contexts (Samodra et al., 2025). In technical education, as stated by Hermans et al. (2024), Computational Thinking Skills (CTS) complements hands-on technical training by fostering abstraction, logical reasoning, and innovative problem-solving. Such capabilities are crucial for addressing real-world technological problems and adapting to rapidly evolving tools and processes. In recent years, Technical and Vocational Education and Training (TVET) has increasingly emphasised the integration of CT skills to better align curricula with modern industry needs (Magagula & Awodiji, 2024). Magagula and Awodiji (2024) also stated that the onset of Industry 4.0 has amplified demand for cross-functional skills. Accordingly, graduates are now expected to possess trade-specific expertise, creativity, adaptability, and computational problem-solving abilities to thrive in technology-rich workplaces. In response, as Wang et al. (2021) and Akgunduz and Mesutoglu (2021) noted, educators are embedding CT into vocational programmes through Science, Technology, Engineering, and Mathematics (STEM) oriented projects, coding exercises, and other hands-on learning activities. This, in turn, reflects a natural synergy between computational problem-solving and technical skill development. Scholars further argue that CT should be a core component of digital literacy in vocational curricula. Nevertheless, current research on CT in TVET remains limited, indicating that this domain has yet to receive sufficient scholarly attention (Hermans et al., 2024).

Despite a global surge in CT education research over the past decade, the literature on CT in technical and vocational contexts remains fragmented and lacks a comprehensive overview. This gap underscores the need for a systematic mapping of the field. Accordingly, the present study undertakes a bibliometric analysis of research on CT skills in technical education between 2018 and 2025, drawing on Scopus and Web of Science records to chart publication trends, key contributors, and thematic developments. By illuminating how CT has been studied and applied in technical education, this analysis aims to identify dominant research themes, emerging trends, and persisting gaps (Samodra et al., 2025). Furthermore, the findings are expected to inform educational technology practice and workforce development strategies. This ensures that technical education keeps pace with the evolving demands of the digital economy and effectively prepares learners for the computational challenges of the contemporary workforce (Hermans et al., 2024; Kennedy & Odell, 2014).

Literature Review

CT has emerged as a critical competency across STEM and vocational disciplines. Initially coined by Wing (2006), CT involves problem-solving, system design, and understanding human-computer interaction, drawing on computer science concepts (Wing, 2006). As digitalisation reshapes industry, educators increasingly recognise CT as part of the advanced skill set needed in technical and vocational training (Hermans et al., 2024). For example, Hermans et al. (2024) asserted that CT should be “an inseparable part of digital literacy” and a core competence in vocational education, yet much research has overlooked vocational-specific challenges. In STEM

contexts, CT is regarded as a “fundamental skill” that empowers students to strengthen their systematic thinking and tackle complex problems (Tariq et al., 2024). Indeed, CT is frequently linked with STEM curriculum reform and workforce readiness: United Nations Educational, Scientific and Cultural Organization (UNESCO) and others promote STEM education partly because it cultivates the critical thinking and creativity that CT embodies (Hermans et al., 2024). In technical or engineering fields, CT underlies logical and design abilities; engineering education frameworks explicitly connect CT practices (such as abstraction and decomposition) with the analysis of scientific problems (Akgunduz & Mesutoglu, 2021; Osztian et al., 2022). In vocational training, CTS overlaps with Industry 4.0 skill demands. Correspondingly, workers must adapt to new technologies and solve problems in “technology-rich” environments, abilities that fall under CT (Yadav & Stephenson, 2017). Thus, the current literature positions CT as a bridge between traditional vocational competencies and the analytical, algorithmic mindset demanded by modern STEM and engineering roles (Li et al., 2020).

Empirical studies document clear benefits of CT instruction for problem-solving and logical reasoning. For instance, classroom interventions frequently report that engaging with CT exercises (e.g., programming, robotics) enhances students’ ability to decompose and solve problems. A Nigerian secondary programme discovered that students who learned CT through a Scratch coding project gained decomposition skills and a “wider imagination” for addressing problems (Sunday et al., 2025; Zaharin et al., 2018). The literature also emphasises that CT’s algorithmic focus directly boosts logical thinking: “step-by-step procedures promote students’ logical thinking” and creative organisation of ideas (Piedade & Dorotea, 2023). In practice, visual programming tools such as Scratch have proven effective. Multiple reviews also note that Scratch “promotes an easy understanding of CT concepts and skills” and stimulates interest in programming, with users generally outperforming peers who do not use it (Zaharin et al., 2018). In other words, CT tasks make abstract concepts tangible and motivate students by linking coding to problem-solving.

Several studies link CT to stronger programming outcomes. For example, Mohd Rosli and Mohd Matore (2023) highlighted that prior CT knowledge among vocational students helps them develop program code and solve coding problems (Tikva & Tambouris, 2021). Similarly, a European study mentioned that programming-rich courses significantly improve CT abilities and 21st-century skills in first-year engineering students (Gilanyi et al., 2022). It supports the view (Lye & Koh, 2014) that learning to code underpins CT development. A growing body of research confirms that a CTS-focused pedagogy, from block coding and robotics to engineering projects, enhances students’ analytical reasoning, problem-solving, and programming competencies (Osztian et al., 2022).

Several recent bibliometric studies have explored CT research trends in other fields of education using databases such as Scopus and tools such as VOSviewer and Bibliometrix, as summarised in Table 1. Langitasari et al. (2024) analysed 152 Scopus-indexed articles on CT in science education (2015-2024), reporting steady growth in publications, strong international collaboration, and active co-citation patterns. This is particularly evident with journals such as the *Journal of Science Education and Technology*, while recommending greater curricular integration of CTS in science. Similarly, Juliangkary et al. (2025) examined 165 Scopus articles on CT in mathematics education (2015-2025). They reported strong links among CT, STEM, project-based learning, and curriculum reform. Their findings also underscored challenges, including teacher readiness and disparities in

resource access (Juliangkary et al., 2025). Other bibliometric reviews adopt a broader lens on CT. In line with this, Sarji et al. (2025) combined citation, co-citation, and keyword analyses of CT publications (1993-2023) to identify core concepts and assessment practices. They emphasised the centrality of CT components such as abstraction, decomposition, and algorithms across disciplines. They also noted the integration of CT into robotics and STEM curricula. However, Sarji et al. (2025) highlighted that the field is fragmented, lacking a universal CT definition or standardised assessments.

Additionally, in vocational education, two recent bibliometric studies are noteworthy. Samual et al. (2025) analysed CT research in Indonesian vocational education using the Dimensions Artificial intelligence (AI) database (2014-2025), suggesting a rise in publications after 2019. Key themes included CT as a core skill, its integration into curricula, and its role in Industry 4.0 employability. Moreover, Handito et al. (2025) studied 1,695 Scopus documents (2015-2025) on CT and the "teaching factory" in Asian TVET. The study noted that while both topics were central (8.66% growth rate), there was limited integration between CT and the teaching factory model. Subsequently, they proposed a conceptual framework linking CT to vocational pedagogy through contextual, methodological, and technological dimensions.

Table 1. Previous Articles on CTS-related Studies and Bibliometric Analysis

Authors	Objective	Data Source & Year Covered	Total Document Entries (TDE)	Bibliometric Attributes Examined
Langitasari et al. (2024)	Map CT research trends in science education	Scopus (2015-2024)	152	Publication growth; author/institution productivity; co-citation networks; collaboration patterns
Juliangkary et al. (2025)	Map CT integration in mathematics education	Scopus (2015-2025)	165	Publication trends; author/journal productivity; co-word analysis; thematic evolution
Sarji et al. (2025)	Review CT definitions, components, and assessment tools	Various (1993-2023)	1000	Citation, co-citation, co-keyword analysis; CT components (abstraction, algorithmics) in curricula
Samual et al. (2025)	Map CT in Indonesian vocational education	Dimensions AI (2014-2025)	219	Publication growth; keyword co-occurrence; thematic clustering (CT foundations, curriculum, employability)
Handito et al. (2025)	Explore CT and Teaching Factory integration in TVET	Scopus (2015-2025)	1695	Publication growth; cluster centrality; bibliographic coupling; identified gaps in CT-teaching factory alignment

*TDE: Total Documents Examined

Despite growing interest in CT, existing research reveals notable gaps. Most bibliometric studies focus broadly on K-12 or STEM education, with limited attention to the TVET sector. As noted by Hermans et al. (2024), current research often overlooks the specific challenges of CT in vocational settings. Therefore, this study addresses that gap by focusing exclusively on vocational and technical programmes, highlighting sector-specific issues like hands-on curricula and alignment with industry needs.

Additionally, previous reviews vary in their data sources and time frames. Some use mixed databases or stop at early 2020s literature. In contrast, this study uses the Scopus database alone for consistency and broad coverage of CT-related education research, capturing publications through 2025 to reflect the most recent developments. Notably, by narrowing the scope to CT in TVET and integrating the latest data, this review offers a focused, timely analysis to inform teaching strategies and ensure that CT pedagogy evolves alongside industry demands.

Research Questions

This paper presents a bibliometric analysis of the metaverse in education by focusing on six main Research Questions (RQs):

RQ1: What is the current state of research on the CTS in technical education?

RQ2: What emerging trends are observable in scholarly publications on the CTS in technical education?

RQ3: Which journals and publication sources are central to the dissemination of CTS in technical education research?

RQ4: Who are the leading contributors — authors, institutions, and countries — in advancing CTS in technical educational research?

RQ5: What highly cited or landmark publications have significantly shaped the discourse on the CTS in technical education?

RQ6: What are the core research themes and conceptual clusters that define the evolution of CTS in technical education?

The comprehensive nature of this study offers an opportunity to fully understand the scope of research on CTS in technical education. Employing bibliometric and network analysis techniques provides a comprehensive understanding of the scholarly domain, core themes, and research clusters in this field. Its insights are crucial for guiding the evolution of more effective educational practices that leverage CTS and align with continuously evolving technological and educational standards. In essence, this study aims to delineate the complex realm of CTS in technical education. Through meticulous analysis, it aims to provide a clear overview of the field's historical and current conditions, laying the groundwork for future advancements. In particular, this endeavour aims to enhance the effectiveness and innovation of educational systems by integrating CTS.

Methods

This study drew on data retrieved from the Scopus database as of 18 December 2025. Scopus was selected deliberately, as it is widely recognised as one of the most comprehensive abstract and citation databases for peer-

reviewed literature. Its broad coverage across scientific, technical, medical, and social science domains is significant for examining research on the metaverse in education. The database also indexes work in social sciences and engineering, thereby providing a wide and reliable evidence base. Scopus is further distinguished by rigorous quality control procedures and extensive international coverage, making it highly suitable for conducting robust bibliometric analyses. In addition, it has rich metadata such as citation counts, authors' affiliations, and source information that supports detailed mapping of the research landscape (Aghaei Chadegani et al., 2013). For this study, the extracted data included document type, source type, language, subject area, publication trends over time, average number of authors per document, institutional contributions, country-level distribution of publications, and frequently occurring keywords.

Search Strategy

The review adopted the modified Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines for conducting systematic reviews (Page, McKenzie, et al., 2021). The search string *TITLE-ABS-KEY ("COMPUTATIONAL THINKING SKILL" , ("EDUCAT*" OR "LEARN*" OR "TEACH*" OR "PEDAGOG*") AND "ENGINEERING" OR "STEM" OR "TECHNICAL" OR "VOCATIONA") AND (LIMIT-TO (SUBJAREA , "SOCI") OR LIMIT-TO (SUBJAREA , "COMP") OR LIMIT-TO (SUBJAREA , "ENGI")) AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (LANGUAGE , "English")) AND (LIMIT-TO (OA , "all"))* was entered into the Scopus search engine. Subsequently, corresponding Scopus subject filters were applied based on the predefined scope of this review. Note that the search was restricted by source type, subject area, document type, and language to systematically eliminate irrelevant papers. Ultimately, this initial search yielded 284 documents (see Figure 2).

Prior to screening, Scopus automation tools removed 20 records that were marked as ineligible since they fell outside the selected subject areas (Social Sciences, Computer Sciences, and Engineering). Following this process, 264 documents were screened. During automated screening, 165 records were excluded for failing to meet the required document type (not an *article*). One additional record was manually excluded, as it was not written in English. This allowed 99 reports for retrieval.

Of these, 50 reports could not be retrieved since they were not available in Open Access. The remaining 49 reports were assessed for eligibility. After full-text screening, one report was excluded, as it was not written in English, resulting in a final dataset of 48 studies included in this review.

To maintain data quality and relevance, systematic inclusion and exclusion criteria were employed. The inclusion criteria required studies to focus explicitly on CTS within educational or vocational contexts, be indexed in Scopus, be available in English, and be classified as peer-reviewed journal articles or conference papers. Accordingly, exclusion criteria removed non-educational publications, non-English papers, editorials, book chapters, non-peer-reviewed documents, duplicates, and records with incomplete metadata. Essentially, this structured filtering process ensured a comprehensive, transparent, and methodologically rigorous bibliometric dataset for analysing CTS in education.

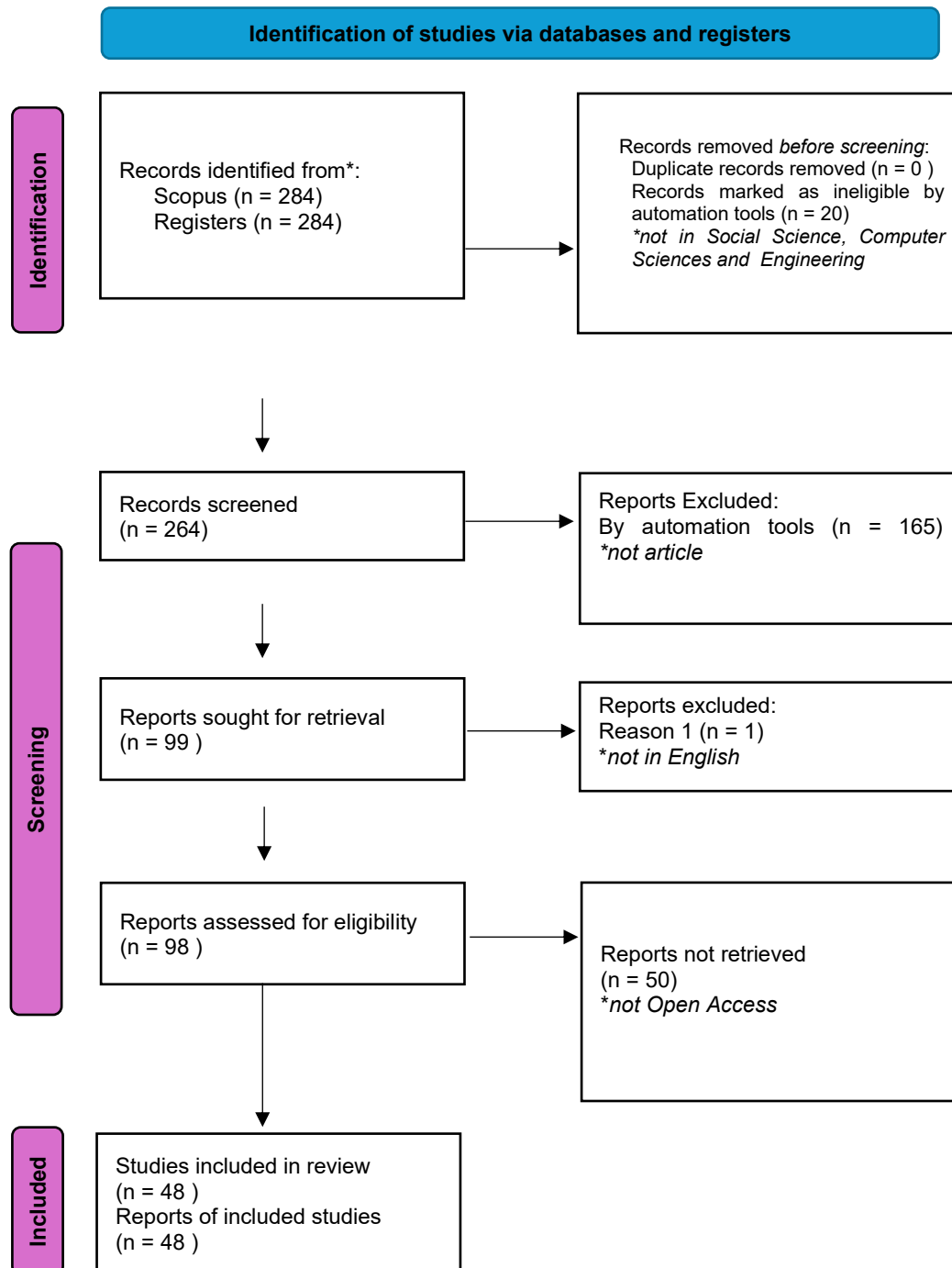


Figure 2. Flow Diagram of the Search Strategy (Page, Moher, et al., 2021).

Data Cleaning and Harmonisation

Data cleaning and harmonisation are pivotal to bibliometric analysis, which is critical to the accuracy and reliability of outcomes. In this study, this research utilised OpenRefine and biblioMagika® (Aidi Ahmi, 2024), two tools specifically designed to refine and align disorganised data. This includes author names, affiliations, keywords, and other key bibliographic details. These tools were instrumental in achieving data precision and consistency, especially considering the diversity of research outputs and the potential discrepancies in the dataset.

The cleaning procedure began with downloading Scopus data in CSV format. Subsequently, selected files were earmarked for purification, and specific columns, such as keywords, authors' names, and affiliations, were pinpointed for amendment using various methods and functions provided by the clustering tools. *biblioMagika*® was deployed for advanced bibliometric assessments, including Total Publications (TP), Number of Contributing Authors (NCA), Number of Cited Publications (NCP), Total Citations (TC), Citations per Publication (C/P), Citations per Cited Publication (C/CP), Citations per Author (C/A), Authors per Publication (A/P), Citations per Year (C/Y), citable year, h-index, g-index, m-index, and citation sum within the h-Core for various categories such as year, source titles, authors, institutions, and countries. Moreover, *biblioMagika*® helped pinpoint missing data, enabling manual completion of these gaps and facilitating data cleaning and harmonisation. By leveraging these advanced tools, the researchers ensured the integrity of their analyses and the soundness of their findings. In addition, the harmonisation and cleaning processes enhanced the detail and clarity of the research dataset. They also fortified it as a comprehensive foundation for delving into the intricate realm of CTS in technical education.

Data Analysis

The data analysis was designed to address the RQs. Specifically, the authors' strategy involved charting the current state of research on CTS in technical education, focusing on document type, source type, language, subject area, and citation metrics. The authors showcased the findings based on various criteria, including annual publication volume, contributions from top authors, leading institutions, prominent countries, and influential source titles. As a result, this approach helped spotlight the major contributors and prevailing trends within the discipline. To provide a detailed evaluation of the publications' impact and significance, the authors applied bibliometric indicators, including TP, NCP, TC, C/P, C/CP, h-index, g-index, and m-index within the h-core. Moreover, to elucidate the principal themes and concepts prevalent in this area, the authors employed techniques such as co-occurrence network analysis, thematic mapping, and factor analysis to visualise their keywords. Overall, these visualisations enabled us to discern clusters of related topics, reveal underlying patterns, and explore the links among various research subfields.

Tools

The study employed a range of specialised tools to ensure a rigorous bibliometric analysis, selecting each for its role in enhancing data accuracy and interpretability. In the initial stage, Microsoft Excel was used for initial data cleaning and organisation, allowing efficient sorting and structuring of Scopus data. Following this, *biblioMagika*® standardised metadata, resolving inconsistencies in author names, institutional affiliations, and country attributions. Meanwhile, OpenRefine was utilised to harmonise authors' keywords, ensuring uniformity in co-occurrence analysis. At the same time, VOSviewer facilitated the visualisation of bibliometric networks, mapping keyword trends, author collaborations, and citation relationships.

Results

In the upcoming results section, the authors will analyse the current state of research on CTS in education. This

detailed analysis will address the RQs, yielding a deep understanding of the field. Through this focused analysis, the authors are committed to delivering a detailed and insightful overview of CTS in the technical education domain, contributing valuable insights for scholars, practitioners, and decision-makers.

Current State of Research

To address RQ1, which aims to map the current state of research on CT skills in technical education, the bibliometric citation metrics generated using biblioMagika® were examined for the period 2018 to 2025 (see Table 2). These metrics collectively reflect the field's scholarly productivity, collaborative patterns, and overall impact, offering a comprehensive overview of the development and visibility of CT-related educational research. Across eight citable years, 48 publications were identified, demonstrating sustained and growing scholarly interest in CT within technical educational settings. These works were authored by 211 NCA, indicating a broad, interdisciplinary research community engaging in CT-related studies. Of the TP, 33 papers have been cited, signalling notable academic uptake and suggesting that a substantial proportion of CT research is influencing broader educational discourse.

Table 2. Citation Metric

Main Information	Data
Publication Years	2018 - 2025
Total Publications	48
Citable Year	8
Number of Contributing Authors	211
Number of Cited Papers	33
Total Citations	590
Citation per Paper	12.29
Citation per Cited Paper	17.88
Citation per Year	84.29
Citation per Author	2.80
Author per Paper	4.40
Citation sum within h-Core	571
h-index	14
g-index	24
m-index	1.750

Source: Generated by the author(s) using biblioMagika® (Ahmi, 2024)

The literature accumulated 590 TC, yielding an average of 12.29 C/P. The C/CP ratio is notably higher at 17.88, indicating that the core set of referenced publications carries significant scholarly weight. An annual citation rate of 84.29 C/Y further suggests that interest in CT is rising and that the field is becoming increasingly prominent within the broader educational research landscape. From an authorship perspective, the field recorded 2.80 C/A. At the same time, each publication involved an average of 4.40 NCA, reflecting a moderate-to-high degree of

collaboration across disciplines. Such collaborative patterns are characteristic of CT research, which often intersects with computer science, STEM education, cognitive science, and digital pedagogy. In addition, the citation sum within the h-core, recorded at 571, highlights the strong influence of the most impactful contributions in the dataset.

In terms of impact indices, the dataset demonstrates an h-index of 14, indicating that 14 publications have received at least 14 citations each, which suggests a significant marker of maturity and sustained relevance in CT research. By contrast, the g-index of 24 suggests that the top-cited publications continue to accumulate citations significantly beyond the h-index threshold, highlighting a small group of highly influential works that anchor the field. Additionally, the m-index of 1.750, which normalises the h-index over the number of active years, indicates consistent annual scholarly influence and a positive growth trajectory across the covered period. Taken together, these metrics portray CT research in technical education as an emerging yet increasingly established domain. The steady rise in publications, combined with growing citation impact and distributed author participation, signals that CT has become an essential component of contemporary educational innovation. In essence, this trend underscores its growing importance in preparing learners for digitally driven, problem-solving-oriented learning environments. It also affirms its position as a critical area for ongoing research and pedagogical development.

Publication Trends

To address RQ2, which aims to identify emerging trends in scholarly publications on CT skills in technical education, the yearly distribution of publications and citations from 2018 to 2025 was analysed, as illustrated in Figure 3 and detailed in Table 3. Concurrently, the findings reveal a dynamic and evolving research landscape, characterised by fluctuating publication activity, shifting citation patterns, and growing scholarly engagement with CT over time. The earliest appearance of CT-related educational research within the dataset was recorded in 2018, with a single publication that received three TC, marking the beginning of scholarly attention in this area. A substantial increase followed in 2019, where publication numbers rose to three, accompanied by an exceptional spike of 198 TC. This resulted in the highest average C/P of 66.00 and C/CP of 66.00 across all years, suggesting that early CT studies were highly influential and laid important foundations for subsequent research. The years 2020 to 2022 demonstrate moderate, yet steady, publication activity, averaging two to four TP per year. These outputs continued to attract considerable scholarly attention, with 2020 and 2021 recording 104 and 70 TC, respectively. The high citation averages in these years ($C/P = 34.67$ in 2020; 35.00 in 2021) indicate that, despite relatively low publication numbers, the works produced were impactful and central to shaping the academic discourse on CT in educational contexts.

A notable expansion occurred in 2023, which saw *eight TP* and *42 NCA*, reflecting a broader, more collaborative research community. Although the year's TC (91) was lower than earlier peaks, the increasing h-index (6) and g-index (8) indicate that research on CTS was gaining wider recognition and diversifying in scope. This year also marks the beginning of more sustained research activity, as publication numbers remained elevated compared to earlier years.

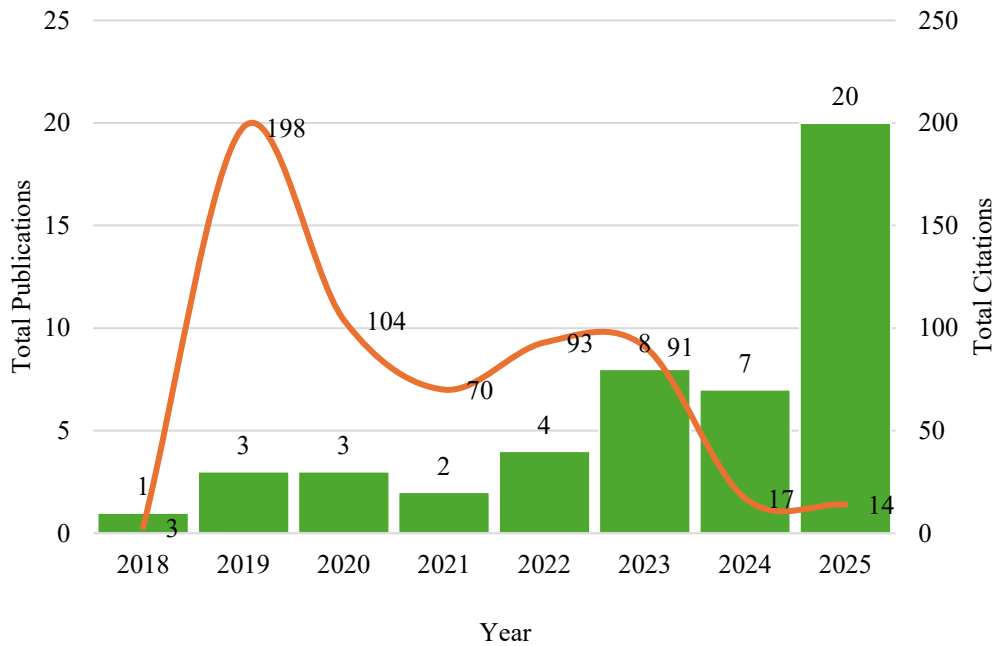


Figure 3. Total Publications and Citations by Year (as data is only available up to 18 December 2025)

Table 3. Publication by Year

Year	TP	NCA	NCP	TC	C/P	C/CP	h-index	g-index	m-index
2018	1	5	1	3	3.00	3.00	1	1	0.125
2019	3	15	3	198	66.00	66.00	3	3	0.429
2020	3	10	3	104	34.67	34.67	3	3	0.500
2021	2	7	2	70	35.00	35.00	2	2	0.400
2022	4	11	4	93	23.25	23.25	3	4	0.750
2023	8	42	8	91	11.38	11.38	6	8	2.000
2024	7	34	5	17	2.43	3.40	3	4	1.500
2025	20	87	7	14	0.70	2.00	2	3	2.000
Grand Total	48	211	33	590	12.29	17.88	23	28	7.704

Notes: TP = Total number of Publications; NCA = Number of Contributing Authors; 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.

* Publication data for 2025 is only up to 18 December 2025.

In 2024, publication output remained strong with seven publications; however, citation numbers dropped significantly to 17. The decline in citation averages ($C/P = 2.43$) is likely due to the recency of these publications, which have had limited time to accumulate citations. Nevertheless, the contribution of 34 authors and a consistent m-index value (1.500) indicate continued engagement and the emergence of more collaborative research structures. The most striking development occurs in 2025, with a sharp rise to 20 publications, the highest in the dataset. Although citation numbers remain low (14 citations), this is expected given that data for 2025 extends only until 18 December and newly published works require time to be indexed and cited. The vigorous publication activity reflects a growing momentum and increased visibility of CT as a key component in educational research,

particularly as global interest in digital skills, problem-solving competencies, and computational pedagogies intensifies.

Overall, the 2018 to 2025 period produced 48 TP, 211 NCA, and 590 TC, demonstrating both the growth and maturation of research on CTS in technical education. The cumulative indices (h-index = 23, g-index = 28, m-index = 7.704) further underline the sustained scholarly impact of key contributions within the field. In summary, the emerging trends highlight a field that has evolved from sporadic early contributions to a more active, collaborative, and diverse research domain. While citation patterns fluctuate with publication timing, the apparent rise in research productivity was evident in 2023 and 2025. This, in turn, signals increased global interest in CT as an essential educational competency. The data collectively highlight a steadily expanding and influential area of educational research.

Publications by Source Titles

To address RQ3, *which journals and publication sources are central to the dissemination of CTS in technical education research?* The analysis examined the top source titles appearing in the dataset, as presented in Figure 4 and Table 4. These journals represent the most active publication outlets, with at least two documents on CT in technical and vocational contexts, indicating their growing relevance and recognition in this research domain.

The results reveal that Education Sciences is the leading and most productive source title, contributing five publications, making it the primary hub for disseminating CT-related educational research. With 105 TC and a citation average of 21.00 C/P, Education Sciences demonstrates strong visibility and sustained scholarly influence. Moreover, its h-index (3) and g-index (5) further signal that the journal hosts multiple well-cited, impactful works in the area of CT and technical education. Several other journals also make meaningful contributions to the field, publishing two papers each. These include Sustainability (Switzerland), Participatory Educational Research, Computers and Education, and the International Journal of Interactive Mobile Technologies. Among them, *Computers and Education* stands out with 80 TC and a notably high citation average of 40.00 C/P, indicating the journal's established reputation and readership's intense engagement with CT-related topics. Similarly, *Sustainability (Switzerland)* records 52 citations with a C/P of 26.00, highlighting diverse interdisciplinary interest linking CT, technology, and sustainable educational systems.

Journals such as Journal of Intelligence, TEM Journal, and the Eurasia Journal of Mathematics, Science and Technology Education also feature prominently, each contributing two publications with citation averages ranging from 3.50 to 11.50. Their consistent h-index and g-index scores (mostly 1 or 2) reflect emerging yet growing academic impact within the CT research sphere. This is especially evident for studies linking CT with cognitive skills, STEM learning, and the development of problem-solving skills in technical education. The International Journal of Information and Education Technology, while contributing two publications, has recorded zero citations, suggesting that these articles are recent entries and may require more time to attract scholarly attention. Overall, the bibliometric evidence reveals a wide range of publication sources contributing to CT scholarship within technical and vocational education. High-productivity journals such as Education Sciences and high-impact

outlets such as Computers and Education serve as primary dissemination channels. Meanwhile, the presence of multidisciplinary journals, spanning sustainability, intelligence research, interactive mobile technologies, and engineering education, demonstrates increasing cross-disciplinary interest in integrating CT into technical and engineering education contexts. Collectively, these journals form the core publication ecosystem for CT skills research, providing key platforms for scholars to disseminate empirical, theoretical, and pedagogical advancements in CT within technical education.

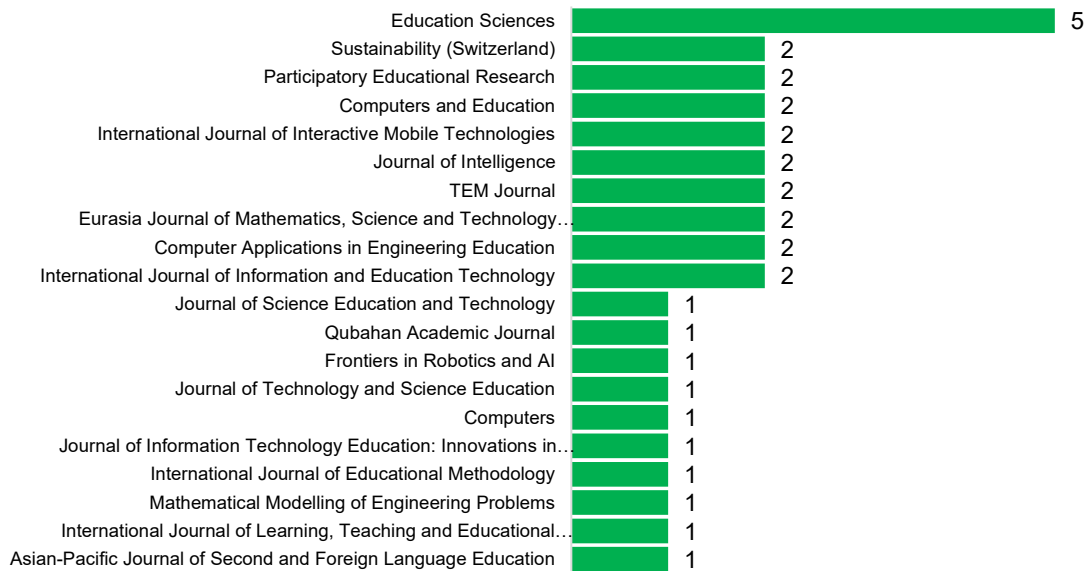


Figure 4. Top 20 Most Productive Source Titles

Table 4. Top 10 Most Active Source Titles

Source Title	TP	NCA	NCP	TC	C/P	C/CP	h	g	m
Education Sciences	5	22	5	105	21.00	21.00	3	5	0.500
Sustainability (Switzerland)	2	8	2	52	26.00	26.00	2	2	0.500
Participatory Educational Research	2	4	1	48	24.00	48.00	1	2	0.143
Computers and Education	2	11	2	80	40.00	40.00	1	2	0.143
International Journal of Interactive Mobile Technologies	2	5	2	52	26.00	26.00	2	2	0.333
Journal of Intelligence	2	10	1	11	5.50	11.00	1	2	0.333
TEM Journal	2	16	2	7	3.50	3.50	1	2	0.500
Eurasia Journal of Mathematics, Science and Technology Education	2	6	1	8	4.00	8.00	1	2	0.333
Computer Applications in Engineering Education	2	7	2	6	3.00	3.00	1	2	0.500
International Journal of Information and Education Technology	2	9	0	0	0.00	0.00	0	0	0.000

Note: TP=Total number of Publications; NCA=Number of Contributing Authors; 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.

Highly Cited Documents

To address RQ5, which aims to identify landmark publications that have shaped scholarly discourse on CT skills in technical and vocational education, Table 5 presents the 10 most highly cited articles in the dataset. These works collectively represent the intellectual foundations of CT-related research and illustrate the conceptual, pedagogical, and empirical developments that have influenced the field. The most cited article is *Città et al. (2019)*, titled “The effects of mental rotation on computational thinking,” published in *Computers and Education*, which has accumulated 79 TC. This study is influential due to its early demonstration of how cognitive abilities, specifically mental rotation, relate to students’ CT performance. Its strong citation performance indicates that it remains a reference point for researchers examining cognitive factors linked to CT development, especially in STEM and technical learning contexts.

Following closely is the work by *Chiazzese et al. (2019)*, “Educational robotics in primary school: Measuring the development of CTSs with the Bebras tasks,” published in *Informatics*, with 71 TC. This publication is widely recognised for introducing rigorous CT assessment instruments (Bebras tasks) and demonstrating how robotics-based learning environments support CT acquisition. Its methodological contributions have made it a commonly cited reference in both engineering and vocational education studies. The third highly cited article is *Nunes Piedade et al. (2020)*, “On teaching programming fundamentals and CT with educational robotics,” published in *Education Sciences* (62 TC). This study is notable for its practical instructional design insights, particularly for teacher education and pre-service training, positioning it as an essential reference for curriculum developers in technical education settings.

Other notable contributions include *Korkmaz and Sahin (2019)* in *Participatory Educational Research* (48 TC), which examines project-based applications and CT skill development, and *Sun et al. (2021)* in the *International Journal of STEM Education* (47 TC), which analyses learners’ knowledge and attitudes across different instructional modes of computing education. These articles have advanced understanding of pedagogical strategies that strengthen CT skills in secondary and technical education.

More recent, though still influential, works include *Tripon (2022)* in *Sustainability (Switzerland)* (37 TC), which explores CT skill promotion among future teachers, and *Mogalli et al. (2022)* and *Beycioglu et al. (2022)*, both published in the *International Journal of Interactive Mobile Technologies* (28 and 25 TC, respectively). These studies examine mobile learning, robotics integration, and project-based CT enhancement, advancing contemporary approaches to technology-enhanced CT instruction. Closing the list are *Bedar and Al-Shboul (2020)* (24 TC) with empirical findings from Jordanian secondary education contexts, and *Dorotea et al. (2021)* in *Education Sciences* (23 TC), which investigates student interest and self-confidence in relation to programming and robotics education.

Collectively, these 10 highly cited publications represent the core scholarly works that have shaped CT research in technical and vocational education. Their substantial citation impact indicates their continued relevance in informing instructional design, robotics-based learning, CT assessment, and teacher preparation practices. As

such, these works serve as foundational anchors for emerging studies and continue to influence ongoing discussions on how CT skills can be effectively developed in technical education systems.

Table 5. Top 10 Highly Cited Articles

No.	Author(s)	Title	Source Title	TC
1	Città, G.; Gentile, M.; Allegra, M.; Arrigo, M.; Conti, D.; Ottaviano, S.; Reale, F.; Sciortino, M. (2019)	The effects of mental rotation on computational thinking	Computers and Education	79
2	Chiazzese, G.; Arrigo, M.; Chifari, A.; Lonati, V.; Tosto, C. (2019)	Educational robotics in primary school: Measuring the development of computational thinking skills with the bebras tasks	Informatics	71
3	Nunes Piedade, J.; Dorotea, N.; Pedro, A.; Matos, J.F. (2020)	On teaching programming fundamentals and computational thinking with educational robotics: A didactic experience with pre-service teachers	Education Sciences	62
4	Karaahmetoğlu, K.; Korkmaz, Ö. (2019)	The effect of project-based arduino educational robot applications on students' computational thinking skills and their perception of basic STEM skill levels	Participatory Educational Research	48
5	Sun, D.; Gutiérrez-Castillo, F.; Li, Y.; Zhu, C. (2021)	Comparing learners' knowledge, behaviors, and attitudes between two instructional modes of computer programming in secondary education	International Journal of STEM Education	47
6	Tripon, C. (2022)	Supporting Future Teachers to Promote Computational Thinking Skills in Teaching STEM—A Case Study	Sustainability (Switzerland)	37
7	Moraiti, I.; Fotoglou, A.; Drigas, A. (2022)	Coding with Block Programming Languages in Educational Robotics and Mobiles, Improve Problem Solving, Creativity & Critical Thinking Skills	International Journal of Interactive Mobile Technologies	28
8	Bertacchini, F.; Scuro, C.; Pantano, P.; Bilotta, E. (2022)	A Project-Based Learning Approach for Improving Students' Computational Thinking Skills	Frontiers in Robotics and AI	25
9	Bedar, R.A.-H.; Al-Shboul, M. (2020)	The effect of using STEAM approach on developing computational thinking skills among high school students in Jordan	International Journal of Interactive Mobile Technologies	24
10	Dorotea, N.; Nunes Piedade, J.; Pedro, A. (2021)	Mapping k-12 computer science teacher's interest, self-confidence, and knowledge about the use of educational robotics to teach	Education Sciences	23

Notes: TC = Total Citations; C/Y = average Citations by Year

Publications by Authors

Table 6 identifies the most productive authors who have published more than two documents in the field of CTS within technical education. These authors are evaluated using several key bibliometric indicators, including TC, citation averages (C/P and C/CP), and author-level metrics such as the h-index, g-index, and m-index. Collectively, these indicators help determine both productivity and scholarly influence.

Table 6. Most Productive Authors who have Published More than Two (2) Documents

Full Name	Current Affiliation	Country	TP	NCP	TC	C/P	C/CP	h	g	m
Miranda, Gara	Universidad de la Laguna	Spain	3	2	16	5.33	8.00	2	3	0.667
Segredo, Eduardo	Universidad de la Laguna	Spain	3	2	16	5.33	8.00	2	3	0.667
Hidayat, Hendra	Universitas Negeri Padang	Indonesia	3	2	7	2.33	3.50	1	2	0.500
León, Coromoto	Universidad de la Laguna	Spain	3	2	16	5.33	8.00	2	3	0.667
Herrero-Alvarez, Rafael	Universidad de la Laguna	Spain	3	2	16	5.33	8.00	2	3	0.667

Notes: 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 = index.

The analysis indicates that the leading contributors are predominantly from the Universidad de la Laguna in Spain and Universitas Negeri Padang in Indonesia. Among them, Miranda Gara, Segredo Eduardo, Herrero Alvarez Rafael, and Leon Coromoto, of the Universidad de la Laguna, each contributed three publications, positioning the institution as a central hub for CT research within the technical and engineering education domain. Each of these authors recorded 16 TC, yielding identical citation averages ($C/P = 5.33$ and $C/CP = 8.00$). Meanwhile, their h-index values (2) and g-index values (3) indicate consistent scholarly engagement and influence. In contrast, the m-index of 0.667 suggests steady citation growth across their publication years.

Furthermore, from Indonesia, Hendrayadi Hidayat of Universitas Negeri Padang is another notable contributor, also with three TP. Although his TC (7) is comparatively lower, his scholarly footprint remains meaningful, with averages of 2.33 C/P and 3.50 C/CP. His h index (1), g index (2), and m index (0.500) demonstrate an emerging yet growing contribution to CT research within vocational and technical education.

Overall, the bibliometric metrics in Table 6 highlight the prominence of Spanish authors from Universidad de la Laguna, whose consistent output and citation performance indicate their central role in shaping current research on CTS. Meanwhile, contributions from Indonesia reflect expanding regional interest and growing engagement in this field of education. Together, these key authors form the intellectual backbone of the research area, influencing methodological approaches, empirical directions, and emerging themes within CT in technical

education.

Publications by Institutions

Table 7 presents the most productive institutions contributing to research on CTSs within the context of technical education. The table highlights institutions with at least five publications, providing insight into institutional productivity, citation impact, and patterns of scholarly engagement. The Universidad de La Laguna (Spain) emerges as the most productive institution, with 13 TP and 13 NCA. With 64 TC, the institution records a C/P value of 4.92 and a C/CP of 8.00. Its h-index of 5, g-index of 8, and m-index of 1.667 collectively indicate sustained influence and a well-established research presence in CT within technical and engineering education.

Following closely, Universitas Negeri Padang (Indonesia) has produced 12 TP, with 10 NCA and 35 TC. Although the C/P value (2.92) is comparatively modest, its h-index of 3, g-index of 5, and m-index of 2.500 suggest a rapidly developing institutional footprint, demonstrating strong year-on-year growth in scholarly impact. In Malaysia, Universiti Kebangsaan Malaysia contributes 10 publications, receiving 11 TC. Although its citation metrics (C/P = 1.10) indicate emerging influence, the institution maintains an h-index of 2 and an m-index of 0.500, demonstrating steady contributions to CT research within Southeast Asia's technical education landscape.

A notable high-impact institution is The University of British Columbia (Canada), which, despite contributing nine TP, has accumulated an outstanding 153 TC. This results in a high C/P value of 17.00 and a C/CP value of 17.00, with an h-index of 9, g-index of 9, and an exceptional m-index of 3.000, positioning it as one of the most influential global leaders in CT and engineering education research.

Similarly, the National Autonomous University of Peru has contributed eight TP, receiving 24 TC, with consistent citation metrics (C/P = 3.00). Its h-index of 3 and m-index of 3.000 reflect strong research performance, particularly within Latin America's technical education sector. Another institution demonstrating strong academic engagement is Universitas Negeri Yogyakarta (Indonesia), which contributed eight TP and accumulated 78 TC. With a high C/P value of 9.75 and a C/CP of 11.14, along with an h-index of 3 and an m-index of 1.000, the institution demonstrates notable impact in engineering education and in the integration of CT. Within Europe, the Universidade de Lisboa (Portugal) stands out with seven TP and a remarkable 317 TC, resulting in an exceptionally high C/P value of 45.29. With an h-index of 7 and an m-index of 1.167, this institution demonstrates significant global influence, indicating the presence of landmark work in CT and STEM education.

The Vanderbilt University School of Engineering (United States) also demonstrates considerable impact with seven TP and 22 TC. Its h-index of 3 and C/P of 3.14 highlight its role as an active contributor to CT research in engineering disciplines. Collectively, the institutions contributing to CT research span Asia, Europe, and North America, reflecting the global relevance and interdisciplinary nature of CT in technical education.

The data demonstrates varying levels of research maturity, with some institutions producing high volumes of publications. In contrast, others exhibit exceptional citation performance indicative of influential, high-quality scholarly contributions. Together, these institutions form the backbone of global research efforts advancing CT

within technical and vocational education.

Table 7. Most Productive Institutions with a Minimum of Five (5) Publications

Institution Name	Country	TP	NCA	NCP	TC	C/P	C/CP	<i>h</i>	<i>g</i>	<i>M</i>
Universidad de la Laguna	Spain	13	13	8	64	4.92	8.00	5	8	1.667
Universitas Negeri Padang	Indonesia	12	12	10	35	2.92	3.50	5	5	2.500
Universiti Kebangsaan Malaysia	Malaysia	10	10	6	11	1.10	1.83	2	3	0.500
The University of British Columbia	Canada	9	9	9	153	17.00	17.00	9	9	3.000
National Autonomous University of Tayacaja	Peru	8	8	8	24	3.00	3.00	3	4	3.000
Universitas Negeri Yogyakarta	Indonesia	8	8	7	78	9.75	11.14	3	8	1.000
Universidade de Lisboa	Portugal	7	7	7	317	45.29	45.29	7	7	1.167
Vanderbilt University School of Engineering	United States	7	7	7	22	3.14	3.14	3	4	1.000
University of California	United States	6	6	6	6	1.00	1.00	1	2	1.000
Universitat de València	Spain	6	6	5	64	10.67	12.80	5	6	0.833
Institute for Educational Technology	Italy	6	6	6	474	79.00	79.00	6	6	0.857
Universitas Jambi	Indonesia	5	5	0	0	0.00	0.00	0	0	0.000
Universitas Lampung	Indonesia	5	5	0	0	0.00	0.00	0	0	0.000

Notes: 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* = index.

Publications by Countries

Table 8 provides an overview of the countries that have contributed two or more publications to the field of CTS in technical education. The global distribution presented in Figure 5 indicates that research activity is geographically widespread. However, the intensity of contributions varies significantly across regions. Indonesia emerges as the most productive country, recording eight publications supported by a substantial NCA. Although its TC is 32 and citation averages ($C/P = 4.00$; $C/CP = 5.33$) are moderate, the country achieves a strong *h*-index of 5 and a *g*-index of 8. This indicates that Indonesia is active in producing research while also generating studies that are beginning to gain recognition within the scholarly community. Its *m*-index of 1.000 further suggests steady growth in citation impact over time.

Malaysia follows closely with seven publications. Nonetheless, its TC count is relatively low ($TC = 13$), resulting in a lower citation impact ($C/P = 1.86$; $C/CP = 2.60$). Despite this, the country records an *h*-index of 3 and a *g*-index of 5. These metrics suggest that while publication productivity is firm, the visibility and scholarly influence of Malaysian research are still developing. Spain also contributes six publications with a comparatively higher

citation impact ($TC = 39$), producing notable citation averages ($C/P = 6.50$; $C/CP = 9.75$). With an h-index of 4 and a g-index of 6, Spain demonstrates a balanced profile of productivity and scholarly influence. The m-index of 0.667 indicates consistent citation growth over time.

The United States and China each contribute three publications, though their scholarly impact differs. China accumulates 58 TC, resulting in high citation averages ($C/P = 19.33$; $C/CP = 29.00$), and achieves an h-index of 3 and a g-index of 3. As a result, this reflects substantial impact per study and positions China as an influential contributor despite producing fewer publications. By comparison, the United States, while matching China in publication count, records 19 TC with C/P and C/CP both at 6.33. While its h-index (3) and g-index (3) suggest a consistent influence, it has a more moderate influence.

Italy demonstrates remarkable citation performance with only three TP generating 175 TC, resulting in exceptionally high citation averages ($C/P = 58.33$; $C/CP = 58.33$). Its h-index of 3 and g-index of 4, together with an m-index of 0.429, highlight Italy as the home of seminal works that have significantly shaped the discourse on CT in technical education. Countries such as Greece, Turkey, Peru, Portugal, Viet Nam, and the Philippines each contribute two publications, with varying citation impact. Notably, Peru records a high C/P of 42.50. At the same time, Greece and Turkey demonstrate strong citation averages (28.00 and 16.00, respectively), despite lower overall publication counts. These metrics suggest that although these countries contribute fewer studies, their outputs tend to be influential and well-cited.

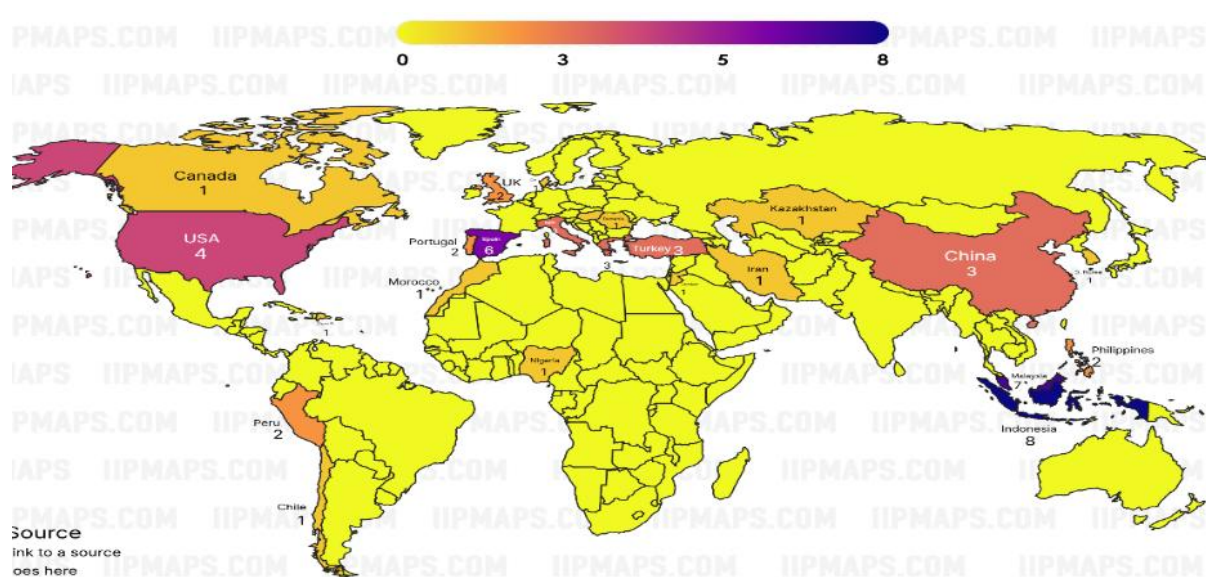


Figure 5. Visualisation of Global Distribution of Metaverse in Education Publications

Overall, the findings indicate that CT research within technical education is driven primarily by contributions across Asia and Europe, with notable influence from selected countries in the Americas. Differences in citation metrics, h-index values, and m-index scores reflect variations in research maturity, international visibility, and collaboration patterns. Collectively, these countries form an emerging global network of scholars advancing CT in technical and vocational education.

and developed over time. At the centre of the network, “*computational thinking*” emerges as the most dominant and highly connected node. Its prominence and proximity to multiple concepts indicate that CT is the primary focus across studies, often associated with STEM pedagogy, programming, problem-solving, and technical learning environments. In particular, the size and centrality of this node highlight the strong foundational role of CT within technical and vocational education research.

The blue cluster represents a concentration of themes related to STEM education and educational robotics, underscoring the integration of robotics, programming, and simulation-based environments as key strategies for strengthening CT among learners. Keywords such as *robotics simulation*, *programming*, and *project-based learning* in this cluster indicate ongoing interest in hands-on, immersive, and technology-enhanced approaches to support CT development. This is particularly evident in engineering and technical training settings.

The green cluster, anchored by engineering education, computer science, and thinking skills, points to a significant research emphasis on instructional models and cognitive processes underlying CT. Furthermore, the co-occurrence of terms such as *problem-solving*, *learning models*, *collaborative learning*, and *teaching* suggests a robust focus on how CT is taught, structured, and assessed within technical curricula. This cluster highlights a pedagogical shift toward active, inquiry-based, and cognitively demanding tasks central to technical education. In contrast, the red cluster, comprising terms such as secondary education, *students*, *computer programming*, and *professional aspects*, reflects a learner-oriented research theme. Studies within this cluster examine the development of CT competencies in school-based and vocational learning environments, the role of programming activities in fostering CT, and the relevance of CT for future professional and workforce demands. This cluster indicates the importance of CT as a foundational skill for both academic progression and technical career preparation.

A smaller yellow cluster connects STEM, academic achievement, and *education*, highlighting research that explores the broader educational outcomes of CT integration. This includes evaluating how CT skills influence performance in STEM subjects and contribute to cognitive and academic development. The presence of these terms suggests growing interest in linking CT with measurable student outcomes and educational policy priorities. Overall, the co-occurrence network reveals a well-defined thematic structure characterised by four major clusters: (1) robotics-based and STEM-integrated pedagogies, (2) cognitive and instructional approaches to CT, (3) learner competencies within vocational and technical contexts, and (4) broader STEM and academic outcome research. In essence, these clusters collectively illustrate the evolving priorities of CT research in technical education, highlighting its interdisciplinary nature and its increasing relevance in preparing learners for technologically driven industries.

Discussion

Through a bibliometric analysis of research on CT skills in technical and vocational education, this study reveals an expanding global interest in developing CT as a core competency for learners in engineering, STEM, and vocational training settings. In addition, the analysis demonstrates that CT is increasingly recognised as a foundational skill for navigating digital, automated, and Industry 4.0 work environments. This is particularly true

in fields such as robotics, programming, and engineering education (Bocconi et al., 2022; Hsu et al., 2021). In addition, publications consistently emphasise integrating CT into practical, hands-on learning activities, primarily through educational robotics, problem-solving tasks, and programming-based interventions. This provides learners with opportunities to apply CT principles in authentic technical contexts (Kazimoglu et al., 2022; Durak & Saritepeci, 2023).

Despite growing attention, several challenges persist in implementing CT in technical education. One primary concern relates to curriculum alignment and instructional readiness. Research indicates that many educators lack sufficient training in CT pedagogies, which limits their ability to create effective CT-rich learning environments (Lockwood & Mooney, 2018). Furthermore, disparities in infrastructure across vocational institutions, particularly in lower-resource settings, restrict access to technologies such as robotics kits, programming tools, and engineering software essential for CT skill development (Sentance & Waite, 2020). These barriers echo broader concerns in STEM education, where resource gaps can impede the adoption of innovative teaching technologies and exacerbate digital inequalities among learners (Yu & Roque, 2022; Repenning et al., 2021).

Another prominent trend is the use of educational robotics and project-based learning as central strategies for developing CT skills in technical fields. Highly cited works in this domain show that robotics-based interventions significantly enhance students' problem-solving abilities, algorithmic reasoning, and engagement, particularly in engineering and vocational training programmes (Chalmers et al., 2021; Susanti et al., 2022). However, concerns surrounding the cost, scalability, and sustainability of robotics-based CT curricula remain pressing. Several studies warn that high implementation costs, frequent hardware updates, and limited teacher expertise may hinder long-term adoption in underfunded educational settings (García-Peñalvo & Mendes, 2018; Benitti, 2012).

Emerging research in the field highlights the integration of CT with STEM education, computing education, and educational robotics, forming strong thematic clusters in the co-occurrence analysis. These clusters demonstrate an increasing convergence between computational competencies, engineering practice, and digital problem-solving models. Studies emphasise CT as a key enabler of higher-order thinking, self-directed inquiry, and creative engineering design attributes highly valued in technical and vocational contexts (Sáez-López et al., 2022; Lye & Koh, 2014). Additionally, the high relevance of CT in technical education suggests a shift towards equipping students with adaptable cognitive tools for emerging technological landscapes.

Moreover, CT research is increasingly linked to student outcomes, including academic performance, motivation, and mastery of skills. The bibliometric network reflects growing interest in understanding how CT supports learners' engineering identity, STEM readiness, and workforce preparation (Scherer et al., 2019; Kong & Wang, 2023). Nevertheless, several scholars caution that while CT improves cognitive and problem-solving abilities, its assessment remains inconsistent across institutions, creating challenges in establishing standardised benchmarks for CT competency (Atmatzidou & Demetriadis, 2016).

The findings of this study underscore the transformative potential of CT in advancing technical education, particularly in robotics, engineering, and vocational training. Nonetheless, they also highlight the need for clear curricular frameworks, sustained professional development for instructors, and improved institutional infrastructure to ensure that CT can be integrated effectively. In response, policymakers play an essential role in

supporting CT adoption by promoting equitable access to digital resources, investing in teacher training, and establishing national CT competency standards aligned with industry needs (Voogt et al., 2015). As the field continues to evolve, future research should prioritise scalable, cost-effective CT models tailored to diverse technical education environments. Thus, developing robust assessment frameworks, exploring XR-enhanced CT learning experiences, and addressing the digital divide are critical to advancing equitable, high-quality CT education globally.

Conclusion

This study provides a comprehensive bibliometric overview of research on Computational Thinking Skills within technical and vocational education between 2018 and 2025, revealing a field that is rapidly expanding yet still evolving in conceptual coherence and pedagogical maturity. The findings demonstrate a clear upward trajectory in publication volume and scholarly engagement, particularly from 2023 onwards, signalling growing recognition of computational thinking as a core competency for technical, engineering, and vocational learning environments. The analysis highlights the central role of themes such as educational robotics, programming, STEM integration, and problem-solving, which collectively reflect a strong emphasis on hands-on, technology-enhanced pedagogies aligned with Industry 4.0 demands. At the same time, the distribution of publications across countries and institutions illustrates an increasingly global research landscape, with notable contributions from Asia and Europe alongside high-impact outputs from selected institutions in North America. Despite this growth, the findings also reveal persistent gaps, including uneven citation impact across regions, limited standardisation in computational thinking assessment, and challenges related to curriculum alignment and instructional readiness in technical education contexts. The dominance of robotics- and programming-based interventions suggests effective pedagogical pathways, yet it also raises concerns regarding scalability, sustainability, and equitable access to resources, particularly in under-resourced vocational settings. Overall, this bibliometric mapping underscores the transformative potential of computational thinking in advancing technical education while emphasising the need for coherent curricular frameworks, targeted professional development, and inclusive policy support. By clarifying research trends, influential contributors, and thematic structures, this study offers a valuable evidence base for educators, researchers, and policymakers seeking to strengthen computational thinking integration and better prepare learners for complex, technology-driven workplaces.

Statements and Declarations

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During the preparation of this study, we employed AI tools, including ChatGPT 5.2, to improve the article's readability, and to ensure grammatical accuracy. Additionally, we utilized AI tools to ensure the integrity and proofreading of the data. Following the use of these tools, we carefully reviewed and validated the final version of the manuscript. As the authors, we assume full responsibility for the content of the published work.

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