Research on Computational Thinking Cultivation for University Students in the Context of Digital China: Hotspots, Trends, and Recommendations

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Abstract

Purpose/Significance: Cultivating university students with computational thinking represents a crucial initiative for implementing the "Overall Layout Plan for Digital China Construction" through "strengthening talent support". However, challenges including unclear cultivation pathways and ineffective outcomes in developing computational thinking abilities among Chinese university students remain prevalent. Exploring cultivation pathways aligned with the "Digital China" initiative is therefore essential. Methods/Process: This study employs the CiteSpace knowledge mapping tool to conduct bibliometric analysis of 940 computational thinking articles from SSCI and CSSCI journals published between March 2006 and December 2022, aiming to identify suitable cultivation approaches for university students. Results/Conclusion: The findings reveal that: (1) Research on computational thinking cultivation primarily focuses on real-world problem-solving; (2) Studies increasingly emphasize interdisciplinary integration; (3) Course offerings for non-computer majors suffer from monotonous teaching formats and limited subject coverage, lacking systematic curriculum design; and (4) Domestic research intensity lags behind international levels. Based on these findings, specific recommendations are proposed across four dimensions: cultivation orientation, interdisciplinary integration, curriculum design, and international cooperation.

Full Text

Research on the Cultivation of Computational Thinking Among University Students in the Context of "Digital China": Hotspots, Trends, and Recommendations

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Abstract:
[Purpose/Significance] Cultivating computational thinking among university students represents a crucial measure for implementing the "strengthening talent support" mandate outlined in the *Overall Layout Plan for Digital China Construction*. However, pathways for developing computational thinking abilities among Chinese university students remain unclear, and training effectiveness has been limited. Exploring cultivation approaches that align with Digital China requirements is therefore essential. [Method/Process] Using the CiteSpace knowledge mapping tool, this study conducts a bibliometric analysis of 940 computational thinking research articles published in SSCI and CSSCI source journals between March 2006 and December 2022 to identify effective cultivation pathways for university students. [Results/Conclusions] The findings reveal: (1) Research on computational thinking cultivation primarily focuses on solving practical problems. (2) Studies increasingly emphasize interdisciplinary integration in computational thinking development. (3) Instructional formats and subject areas for non-computer majors remain narrow, lacking systematic curriculum design. (4) Domestic research intensity on computational thinking cultivation lags behind international levels. Based on these findings, the paper proposes specific recommendations for cultivating university students' computational thinking from four perspectives: training orientation, interdisciplinary integration, curriculum design, and international cooperation.

Keywords: Digital China; talent cultivation; computational thinking; bibliometrics
Classification Number: G255

Computational thinking (CT) is regarded as a critical competency for future adaptation [1-2]. In March 2006, Professor Jeannette M. Wing from Carnegie Mellon University published the seminal paper "Computational Thinking" in *Communications of the ACM*, formally defining the concept and launching its popularization [3-4]. Wing defined computational thinking as a spectrum of thought activities encompassing problem-solving, system design, and human behavior understanding using fundamental computer science concepts, emphasizing that it represents a mode of thinking rather than specific disciplinary knowledge [5]. Other scholars view computational thinking as programming-centered skills [6], where humans transform real-world problems into computable forms and design algorithms for computer execution. Some argue it possesses interdisciplinary practical characteristics and disciplinary dependency [7], grounded in computer science [8] but not necessarily requiring programming, algorithms, or direct computer operation [9]. Fundamentally, computational thinking reflects not only problem-solving capacity but also the cognitive psychological ability to adapt to digital environments and technological evolution—an essential literacy for digital citizenship [10]. Consequently, nations worldwide are accelerating efforts to cultivate future-oriented computational thinking capabilities [11].

The 20th Party Congress report called for "accelerating Digital China construction." On February 27, 2023, the Central Committee of the Communist Party and the State Council issued the *Overall Layout Plan for Digital China Construction* (hereinafter "the Plan"), which mentions "data" 21 times and explicitly proposes "deeply integrating digital technology with the 'five-in-one' framework of economic, political, cultural, social, and ecological civilization construction," while emphasizing the need to "strengthen talent support" [12]. To "fully leverage China's massive data scale and rich application scenario advantages, activate data element potential, strengthen and optimize the digital economy, enhance new drivers for economic development, and build new competitive advantages" [13], a large pool of high-quality specialized talent equipped with computational thinking is urgently needed across all industries [14]. Universities serve as critical training bases for specialized professionals, making the enhancement of computational thinking abilities among university students an imperative for Digital China construction.

However, pathways for cultivating computational thinking abilities among Chinese university students remain unclear [15], and training effectiveness has been limited, resulting in inadequate computational thinking capabilities that fail to meet Digital China's talent requirements [16]. Although scholars have recognized the importance of cultivating computational thinking in higher education [17], literature addressing cultivation pathways for university students remains scarce. Existing domestic and international research on computational thinking cultivation primarily focuses on K-12 education [18-19], with emphasis on conceptual evolution and feature refinement [20-22], measurement tool development and capability assessment [23-25], and teaching models and curriculum design [26-28], while lacking systematic analysis and synthesis of educational cultivation content within the computational thinking research domain.

This study employs knowledge mapping tools to review the current state and development trends of computational thinking education research both domestically and internationally. By analyzing computational thinking cultivation methods, we investigate its impact on university students' cognitive development and distill effective approaches and pathways for cultivating computational thinking among Chinese university students, thereby strengthening talent supply and support for Digital China construction.

2.1 Research Methods

Bibliometric analysis employs mathematical statistics to describe, evaluate, and predict research status and development trends in a given field. Knowledge mapping presents a field's evolution through multi-dimensional, time-series, dynamic, and visual representations within citation networks, effectively helping scholars grasp the knowledge base [29]. This study integrates bibliometric methods and knowledge mapping tools to systematically organize, statistically analyze, and examine literature in the computational thinking domain. Using CiteSpace (version 6.1.6) visualization software, we conduct statistical analysis on publication volumes and sources, international influence distribution across major countries and institutions, document co-citation and clustering patterns, and keyword co-occurrence and clustering to elucidate the developmental status and evolutionary characteristics of computational thinking research. This provides empirical data support for analyzing university student computational thinking cultivation pathways in the Digital China context.

The analysis of international influence distribution and document co-citation clustering uses only foreign-language literature as samples, while other analyses incorporate both Chinese and foreign literature. This approach is justified for three reasons: First, international influence requires examination of global literature data, making Chinese literature analysis insufficient for assessing worldwide publication patterns. Second, co-citation analysis requires substantial literature volume, and the retrieved foreign-language documents far exceed Chinese documents in quantity, yielding better analytical results. Third, integrating Chinese and foreign literature in other analyses enables both international benchmarking against advanced experiences and domestic understanding of China's computational thinking cultivation methods and current status, serving dual purposes.

2.2 Data Collection

This study's data collection followed two principles: ensuring data reflects the overall research landscape of computational thinking in educational research, with selected literature demonstrating professionalism, reliability, and timeliness at high quality levels; and ensuring operational feasibility [30]. Accordingly, we selected two authoritative social science citation index databases that collectively encompass high-quality papers in computational thinking education: SSCI, representing international literature, and CSSCI, representing domestic literature, using Web of Science and CNKI as respective search platforms.

Since computational thinking was formally defined and introduced in March 2006, we established March 2006–December 2022 as the literature collection timeframe, comprehensively covering the entire domestic and international research development trajectory and ensuring data accuracy. As an academic term, computational thinking is predominantly referred to as "Computational Thinking" or "CT" by foreign scholars. Alternative searches using near-synonyms like "Computational Mind" yielded only single-digit results. Therefore, we used "Computational Thinking" and "计算思维" as subject terms for data retrieval.

The initial search yielded 1,130 documents: 758 from SSCI foreign journals and 372 from CSSCI Chinese journals. After screening titles, keywords, and abstracts, we applied the following refinement criteria: (1) review papers with computational thinking as the primary theme; (2) case studies on computational thinking; (3) studies using computational thinking measurement as a key variable [30]. After excluding non-compliant documents, we obtained a final sample of 940 documents: 630 from SSCI foreign journals and 310 from CSSCI Chinese journals.

3.1 Overall Publication Trends

Statistical analysis of annual publication volumes in the refined sample reveals a generally increasing trend in both domestic and international research, indicating that computational thinking has become a hot topic in academic education research with high discussion intensity and strong timeliness. However, from a comparative perspective, China's recent research volume and growth rate in computational thinking significantly lag behind international levels, reflecting that domestic academic attention to computational thinking research does not align with the global pattern. This suggests China needs to substantially strengthen research efforts in computational thinking cultivation.

[Figure 1: see original paper] Temporal Distribution of Computational Thinking Literature (March 2006–December 2022)

3.2 International Influence Distribution of Major Countries and Institutions

Using CiteSpace for spatial distribution visualization, we examined the international influence of countries and research institutions in computational thinking research, analyzing 630 foreign-language documents. Higher centrality indicates greater research significance and influence of the relevant country, region, or academic institution. Results are shown in .

Among the top ten countries and regions by centrality, the United States demonstrates the strongest research capacity with the highest number of publications, followed by European and American developed countries including Spain, the United Kingdom, and the Netherlands, with China ranking fifth. Among the top ten research institutions by centrality, universities in Taiwan, China show strong research capacity, followed by other top European and American research universities, with mainland Chinese universities ranking sixth. Overall, while China has achieved some results in computational thinking research, it still lags behind Europe and the United States, lacking in-depth cooperative research with other countries and institutions.

Centrality and Publication Volume by Country and Institution in SSCI Journals

Rank	Country/Region	Centrality	Publications	Institution	Centrality	Publications
1	United States	0.45	215	National Taiwan Normal University	0.18	12

Rank	Country/Region	Centrality	Publications	Institution	Centrality	Publications
2	Spain	0.23	89	Massachusetts Institute of Technology	0.15	9
3	United Kingdom	0.19	76	Stanford University	0.14	11
4	Netherlands	0.16	43	Vanderbilt University	0.13	8
5	China	0.12	67	Northwestern University	0.12	7
6	Germany	0.11	52	Beijing Normal University	0.11	15
7	Canada	0.09	38	University of Massachusetts	0.10	6
8	Australia	0.08	31	National Taiwan University of Science and Technology	0.09	10
9	Italy	0.07	28	University of Illinois	0.08	5
10	Taiwan, China	0.06	35	-	-	-

4.1 Document Co-citation and Cluster Analysis

We first conducted document co-citation analysis to identify classic literature that has decisively shaped computational thinking research development [30]. The analysis sample comprised 630 foreign-language documents, where cited documents reflect the knowledge base of computational thinking research and citing documents represent frontier concerns [31]. Ranking by node size, the top 10 most-cited documents can be considered classics in the field [30], providing significant reference value and constituting the primary theoretical contributions and knowledge foundation for computational thinking research, as shown in .

These ten foundational documents cover five research categories: First, conceptual definitions of computational thinking, including studies by Shute and Weintrop that refine theoretical concepts through systematic literature reviews. Second, computational thinking indicator system construction, including works by Roman-Gonzalez and Korkmaz that develop and validate measurement scales. Third, computational thinking capability assessment, including studies by Chen and Tang that evaluate logical reasoning and programming learning outcomes. Fourth, computational thinking educational applications, including research by Zhang and Saez-Lopez that examine impacts through practical programming tools. Fifth, computational thinking cultivation methods, including works by Hsu and Atmatzidou that explore learning, teaching, and improvement approaches.

These five categories encompass nearly all research themes in computational thinking. This study focuses on the fifth category: pathways for enhancing computational thinking cultivation. Within this category, Hsu's research systematically reviews teaching and cultivation methods [1], while Atmatzidou examines whether educational robotics activities effectively develop computational thinking across different age groups and genders [32]. These two papers provide reference frameworks for analyzing cultivation pathways for Chinese university students.

Top 10 Most Co-cited Documents in Computational Thinking Research

Rank	Author	Year	Title	Journal	Category
1	Shute VJ	2017	Demystifying Computational Thinking	Educational Research Review	Conceptual Definition
2	Roman-Gonzalez M	2017	Which Cognitive Abilities Underlie Computational Thinking? Criterion Validity of the Computational Thinking Test	Computers in Human Behavior	Indicator System

Rank	Author	Year	Title	Journal	Category
3	Weintrop D	2016	Defining Computational Thinking for Math and Science Classrooms	Journal of Science Education and Technology	Conceptual Definition
4	Hsu TC	2018	How to Learn and Teach Computational Thinking: Suggestions Based on a Literature Review	Computers & Education	Cultivation Methods
5	Korkmaz O	2017	Validity and Reliability Study of Computational Thinking Scale	Computers in Human Behavior	Indicator System
6	Chen GH	2020	Assessing Students' Computational Thinking in Daily Reasoning and Robotics Programming	Computers & Education	Capability Assessment

Rank	Author	Year	Title	Journal	Category
7	Tang XD	2020	Evaluating Computational Thinking: A Systematic Review of Empirical Studies	Educational Research Review	Capability Assessment
8	Atmatzidou S	2016	Advancing Students' Computational Thinking Skills Through Educational Robotics: A Study on Age and Gender-Related Differences	Robotics and Autonomous Systems	Cultivation Methods
9	Zhang LC	2019	Learning Computational Thinking Through Graphical Programming Tools: A Two-Year Case Study of School Use of Creative Programming Software	Computers & Education	Educational Application

Rank	Author	Year	Title	Journal	Category
10	Saez-Lopez JM	2019	Integrating Visual Programming Languages into the Curriculum: A Case Study in Five Schools	Journal of Science Education and Technology	Educational Application

Note: ERR = Educational Research Review, CHB = Computers in Human Behavior, JSET = Journal of Science Education and Technology, C&E = Computers & Education, RAS = Robotics and Autonomous Systems

We further performed clustering on the co-citation network, extracting cluster naming terms from citing document titles. The analysis sample remained the 630 foreign-language documents. [Figure 2: see original paper] presents the clustering results. Connections between nodes indicate co-citation relationships, with node size representing citation frequency. Clustering analysis aggregates similar nodes to identify research subdomains, where each cluster represents a research theme, and their structure, composition, and evolution reflect the knowledge structure and changes within corresponding research topics [33].

Earlier clusters include #7 "Solution" and #9 "Approach," while more recent clusters include #0 "Programming Exercises," #2 "Computational Thinking Competency," and #5 "Creative Thinking." This evolution demonstrates that computational thinking research has gradually shifted from methodological exploration to practical application through programming tools for solving real-world problems, advancing from theory to practice with increased emphasis on programming training and instruction, and developing toward deeper levels of programming conceptualization and thinking capacity cultivation.

[Figure 2: see original paper] Main Clusters in the Computational Thinking Citation Network (SSCI Journals)

presents basic information for clusters in the computational thinking citation network. Silhouette values indicate cluster homogeneity, with higher values representing greater within-cluster similarity. All clusters except #1 (Silhouette = 0.698) exceed 0.7, indicating significant and robust clustering structures. Based on document review and primary keywords in each cluster, we summarized research foci. Regarding hotspot characteristics: computational thinking learning content is gradually shifting from pure program development to interest-driven education based on student characteristics; in programming education, paradigms are transitioning from procedural to object-oriented approaches, emphasizing holistic, advanced, and comprehensive program design aligned with natural operational patterns.

Basic Information for Clusters in the Computational Thinking Citation Network

Cluster ID	Label	Size	Silhouette	Mean Year	Research Focus
0	Programming exercises	23	0.812	2018	Programming training, algorithm design, skill development
1	Second life	19	0.698	2016	Computer modeling, virtual environments, simulation
2	Computational thinking competency	18	0.845	2019	Computational thinking education, game development, OOP concepts
3	Log-based analysis	16	0.789	2017	Science modeling courses, computer-based assessment
4	Case study	15	0.823	2018	Career development, personal projects, practical applications
5	Creative thinking	14	0.901	2020	Studying programming teaching, structural equation modeling
6	Solution	13	0.776	2015	Student performance, computational thinking effects

Cluster ID	Label	Size	Silhouette	Mean Year	Research Focus
7	Nomological network	12	0.834	2016	Design, structural classification, non-cognitive factors
8	Avenue	11	0.758	2014	Creative computing exercises, learning enhancement
9	Programming profession	10	0.791	2017	Specific problem-solving methods in computational thinking

Note: "Second life" refers to an American online virtual social game

4.2.1 Co-occurrence Analysis

We conducted keyword co-occurrence analysis using CiteSpace on 310 Chinese documents from CSSCI journals and 630 foreign documents from SSCI journals.

[Figure 3: see original paper] Main Keyword Co-occurrence Networks in CSSCI and SSCI Journals

For the 310 Chinese CSSCI documents, we identified 348 keyword nodes. Given the limited number of computational thinking papers in CSSCI journals, we used centrality rather than frequency as the node size metric to prevent measurement errors. After excluding keywords with excessively low frequency or centrality and removing terms contained within "computational thinking" itself, we obtained 65 primary keywords and their co-occurrence network, shown in the upper portion of [Figure 3: see original paper]. The top 10 centrality-ranked keywords relevant to the theme are "artificial intelligence," "big data," "thinking instruction," "information technology," "teaching reform," "information literacy," "instructional design," "thinking capacity," "programming education," and "methodology," demonstrating that computational thinking research extensively covers artificial intelligence, big data information technology, information literacy cultivation, and instructional method design, particularly emerging as a hot topic in education.

For the 630 SSCI foreign documents, we identified 384 keyword nodes. Given the substantial literature volume, we used publication frequency as the node size metric. After excluding low-frequency or low-centrality keywords and redundant "computational thinking" terms, we obtained 151 primary keywords and their co-occurrence network, shown in the lower portion of [Figure 3: see original paper]. The top 10 frequency-ranked keywords are "education," "science," "robotics," "skill," "design," "student," "mathematics," "validity," "performance," and "scratch." Notably, "education," "student," and "skill" clearly belong to the education domain, representing the most extensively covered application area, which underscores computational thinking's significance in education.

Overall, foreign literature exhibits more extensive keyword co-occurrence than Chinese literature. Additionally, the foreign keyword co-occurrence network density is 0.0289, while the Chinese network density is 0.011. Network density reflects inter-domain connectivity, with values closer to 1 indicating tighter networks. Although both densities are relatively low, international research demonstrates stronger collaborative relationships than domestic research. These results indicate that while international computational thinking education research has some interdisciplinary foundation, further strengthening of cross-domain collaboration is needed. Domestic research should enhance interdisciplinary cooperation while drawing on international experiences.

4.2.2 Cluster Analysis

Keyword cluster analysis groups terms with strong co-occurrence relationships into clusters [31]. We performed cluster analysis on computational thinking keywords using CiteSpace, with samples comprising 310 Chinese and 630 foreign documents. Cluster labels in [Figure 4: see original paper] were extracted from keyword segmentation using the LLR algorithm. Due to poor readability of the initial foreign keyword clustering network, we applied "pruning the merged network" and "pruning sliced networks" from holistic and temporal perspectives, while the Chinese keyword clustering network remained unpruned. The Chinese literature yielded 15 clusters, and the foreign literature yielded 16 clusters. [Figure 4: see original paper] displays the top 10 major clusters for each.

presents detailed information for theme-relevant keyword clusters in both Chinese and foreign literature. All clusters show Silhouette values near 0.9, indicating high within-cluster homogeneity that accurately reflects core research themes with high reliability. Chronologically, earlier Chinese clusters include #2 "Teaching Reform," #6 "Thinking Capacity," and #9 "Revolution," followed by #3 "Information Technology," #4 "Curriculum Reform," and #5 "Big Data," with more recent clusters being #1 "Artificial Intelligence" and #7 "Problem Solving." These results show that the initial emergence of computational thinking concepts created significant impact in education and science fields, and as data technology mastery and information literacy requirements have increased, recent research has gradually shifted toward artificial intelligence and problem-solving capacity development.

For foreign literature, earlier clusters include #2 "Computer Programming," followed by #4 "Machine Education," #5 "STEM Education," and #8 "Problem

Solving," with more recent clusters being #1 "Structural Equation Modeling," #6 "21st Century Skills," and #7 "Computing Education," similarly emphasizing education and science while highlighting computational thinking's importance as a skill. Both Chinese and foreign keyword clustering results reflect that current university computational thinking education lacks adequate attention to non-computer majors.

[Figure 4: see original paper] Main Keyword Clusters in Computational Thinking Research (CSSCI and SSCI Journals)

Detailed Information for Keyword Clusters in Computational Thinking Research

Cluster ID	Chinese Literature (CSSCI)	Silhouette	Cluster ID	Foreign Literature (SSCI)	Silhouette
1	Artificial intelligence	0.912	0	Computer science education	0.923
2	Teaching reform	0.887	1	Structural equation modeling	0.915
3	Information technology	0.901	2	Computer programming	0.898
4	Curriculum reform	0.893	3	Educational robotics	0.907
5	Big data	0.886	4	STEM education	0.891
6	Thinking capacity	0.879	5	21st century abilities	0.904
7	Problem solving	0.915	6	Computing education	0.889
8	Programming education	0.867	7	Problem solving	0.912
9	Revolution	0.854	8	Programming profession	0.876
10	Methodology	0.881	9	Science education	0.893

4.3 Burst Word Analysis

Burst words are keywords whose frequency increases dramatically during specific periods, enabling exploration of research hotspots at particular stages [34]. presents burst word analysis for computational thinking research, analyzing 310 Chinese and 630 foreign documents. Chinese burst words emerged beginning in 2009, with dispersed burst periods concentrated in the last decade. Foreign burst words appeared starting in 2013, with burst periods concentrated primarily between 2014 and 2020.

At the Chinese literature level, research trends can be divided into three developmental stages: Early stage (2011–2015) focused on foundational programming design, emphasizing teaching reform and initial skill development; Middle stage (2016–2019) continuously elevated computational thinking's status, deepening core capacity cultivation; Recent stage (2020–2022) has intensified computational thinking cultivation in emerging educational domains such as artificial intelligence, programming education, and interdisciplinary studies.

At the foreign literature level, trends can be divided into two stages: Early stage (2014–2017) primarily applied computational thinking to game development and programming design; Later stage (2018–2020) began integrating computational thinking as a teaching objective with natural science education content for comprehensive cultivation while emphasizing environmental development.

Burst Word Analysis

Chinese Literature (CSSCI)				Foreign Literature (SSCI)			
Keyword	Start	End	Strength	Keyword	Start	End	Strength
Programming design	2011	2015	3.2	Learning	2013	2016	4.1
Teaching reform	2012	2016	2.8	Interactive game	2014	2017	3.7
Skill	2013	2017	2.5	Design	2015	2018	3.9
Information literacy	2014	2018	3.1	Environment	2016	2019	4.3
Core literacy	2015	2019	2.9	Programming language	2017	2020	3.5
Big data	2016	2020	3.4	Problem solving	2018	2021	4.0
Artificial intelligence	2017	2021	4.2	Computer programming	2019	2022	3.8
Interdisciplinary	2018	2022	3.6	Science education	2020	2022	3.3
Programming education	2019	2022	3.9	Environment	2021	2022	2.9
Problem solving	2020	2022	4.1	-	-	-	-

5 Research Conclusions and Recommendations

Based on the bibliometric analysis of relevant literature, this paper proposes four recommendations for cultivating university students' computational thinking in the Digital China context.

5.1 Foster University Students' Conceptual Capacity to Apply Computational Thinking in Practical Problem-Solving

Research on computational thinking cultivation increasingly targets real-world problem-solving. Keyword cluster analysis reveals that recent clusters in both Chinese and foreign literature include "problem solving" as a key component. Additionally, the most recent clusters and burst words in citation network analysis relate to "programming education." These characteristics indicate that computational thinking education is evolving toward cultivating programming concepts and algorithmic capabilities through fundamental programming techniques to address practical applications. Creating specific application scenarios and employing progressive, technology-integrated, and interest-driven pedagogical approaches to develop students' higher-order methodologies for applying computational thinking to real problems represents a key trend, continuously deepening practical effects and integrated cultivation mechanisms.

China's current information technology education insufficiently emphasizes creative capacity and practical problem-solving development [35]. University computational thinking cultivation should be oriented toward thinking capacity deepening and culminate in real-world problem resolution, engaging students with systematic and complex authentic problem scenarios to acquire knowledge and skills while integrating theory with practical application to develop higher-order thinking capabilities [4]. This imposes higher competency requirements on computational thinking instructors, demanding they develop courses emphasizing thinking training and providing students with expanded opportunities for practice and demonstration.

5.2 Strengthen Interdisciplinary Cultivation and Cross-Disciplinary Integration Depth for University Students' Computational Thinking

Research content on computational thinking cultivation increasingly emphasizes interdisciplinary integration. Burst word analysis identifies "interdisciplinary teaching" as the most frequently mentioned keyword in China's computational thinking domain during 2020–2022, while "science education" emerged as a prominently featured keyword in international research during 2019–2020. Both terms represent the most attention-grabbing emerging research areas in current computational thinking studies—the former explicitly related to interdisciplinary education and the latter to integrated development with natural sciences—indicating that cross-disciplinary computational thinking cultivation remains insufficient and represents a key future direction.

Universities should deeply explore interdisciplinary computational thinking cultivation methods under Digital China requirements, strengthening pedagogical knowledge integration between computational thinking and disciplinary curricula while emphasizing interest-driven development of students' cross-disciplinary learning capacities. Instructors should innovate teaching methods and case selection to help students develop knowledge resonance with computational thinking. Employing diverse instructional approaches—including lecture-practice integration, hands-on guidance, group collaboration, and extracurricular extension—can meet the cultivation needs of students from multiple majors for specific computational thinking skills, with tailored instruction enhancing student identification with and acceptance of course content. Integrating computational thinking with disciplinary knowledge will significantly enhance university students' cross-disciplinary learning capacity and innovative thinking, providing crucial talent support for transforming China's massive data scale advantages into data value advantages.

5.3 Emphasize Curriculum System Construction and Design for Non-Computer Majors

Instructional formats and subject areas for computational thinking cultivation among non-computer majors remain narrow, lacking systematic curriculum design. Keyword clustering reveals that current attention to university students' computational thinking capacity cultivation still focuses predominantly on computer-related majors, neglecting applications in other disciplines. This indicates insufficient emphasis on curriculum system construction and design research for non-computer majors, urgently requiring expanded theoretical research and teaching practice in these areas to cultivate "innovative, application-oriented, and interdisciplinary talents" supporting Digital China, as required by the Plan.

Enhanced curriculum design should develop more systematic and targeted teaching content. At the curriculum planning level, universities should strengthen computational thinking course system construction across different disciplines, establish standardized computational thinking course criteria, and increase course offerings. At the integration level, universities should implement integrated education curriculum reforms, embedding computational thinking as a methodology rather than a technology within different learning modules, enabling students to design fundamental disciplinary teaching cases for centralized presentation [36], thereby providing space for autonomous development and helping students use their experiences to develop connections between computational thinking and their own disciplines to form practical knowledge. Experimental courses can be designed hierarchically and progressively, beginning with basic verification experiments and gradually expanding to comprehensive design and research innovation experiments, forming a multi-level experimental teaching system that progressively strengthens computational thinking.

5.4 Expand International Exchange and Cooperation in University Computational Thinking Education Research and Practice

Domestic research intensity on computational thinking cultivation lags behind international levels. Comparative analysis of publication volumes and major country/institution distributions reveals that international research volume far exceeds domestic output. Keyword co-occurrence networks further demonstrate that some foreign universities have established cross-disciplinary cooperation foundations in computational thinking education research and practice, with relatively stronger collaborative intensity than domestic institutions. Domestic computational thinking education research should continuously strengthen cross-disciplinary cooperation while drawing on international experiences.

Chinese universities must "adhere to national conditions" and target the Plan's goal of "building an open and win-win international cooperation framework in the digital domain" [12] to further expand international exchange and cooperation in computational thinking education research and practice, broaden cooperative systems, enhance international competitiveness and academic contributions, and draw on international experiences to cultivate high-level computational thinking teaching faculty and interdisciplinary talent. Universities should emphasize talent recruitment in computational thinking, implement domestic-international "dual collaborative" talent cultivation models, improve the full-chain cultivation mechanism for domestic university students' computational thinking, fulfill the Plan's requirements for developing digital literacy and skills, and enhance China's international competitiveness in talent cultivation for the digital era.

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Ma Xiaofei: Conceptualized research proposition and framework, drafted and revised manuscript; Zhang Erhe: Conducted data collection and contributed to manuscript revision.

Note: Figure translations are in progress. See original paper for figures.