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A Recent Systematic Review of Computational Thinking in Higher Education

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ABSTRACT

Computational thinking (CT) has emerged as a vital skill in the rapidly evolving landscape of higher education. As higher education institutions grapple with the imperative to prepare students for a digitally driven future, understanding the landscape of CT integration becomes essential. This review addresses the need to systematically synthesize the literature to foster a deeper recognition of CT role in higher education. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework leads the systematic review process, establishing rigor as well as transparency in selecting and analysing relevant studies. Advanced searching techniques are employed to enhance the precision and inclusiveness of the literature search. The review specifically leverages the Web of Science (WoS) as well as Scopus databases, tapping into their extensive repositories of scholarly work. The selected theme is derived from the assessment of experts, guiding the decision-making process with their valuable insights and expertise. The results are organized into two key themes: (1) Technology's Impact on CT and (2) Pedagogical approaches and educational strategies for CT. In conclusion, this systematic literature review adds to a contemporary understanding of the landscape of CT in higher education. By systematically reviewing recent research, the study provides valuable insights for educators, policymakers, and researchers alike. This review underscores the dynamic nature of CT implementation in higher education and emphasizes the importance of ongoing scholarship to inform effective educational practices.

Keywords:
Computational thinking; Computational thinking skills; Higher education; Problem-solving

1. Introduction

In the rapid higher education landscape, the integration of computational thinking (CT) has risen as a pivotal area of focus. CT refers to a cognitive process that transcends the boundaries of computer science. CT involves mastering basic computer science skills like reading, writing, and counting to solve problems and think critically in programming methods [1]. CT represents a fundamental skill set essential for problem-solving and decision-making in various disciplines [2-5]. At its core, CT

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comprises disintegrating complex problems into feasible components, recognizing patterns, and devising algorithmic solutions [6-8]. Figure 1 illustrates CT as a problem-solving process, emphasizing four skills: decomposition, abstraction, pattern recognition, and algorithms. Beyond its applications in computer science, CT serves as a universal language fostering analytical prowess and creativity amidst the rapid technological advancements characterizing our era.

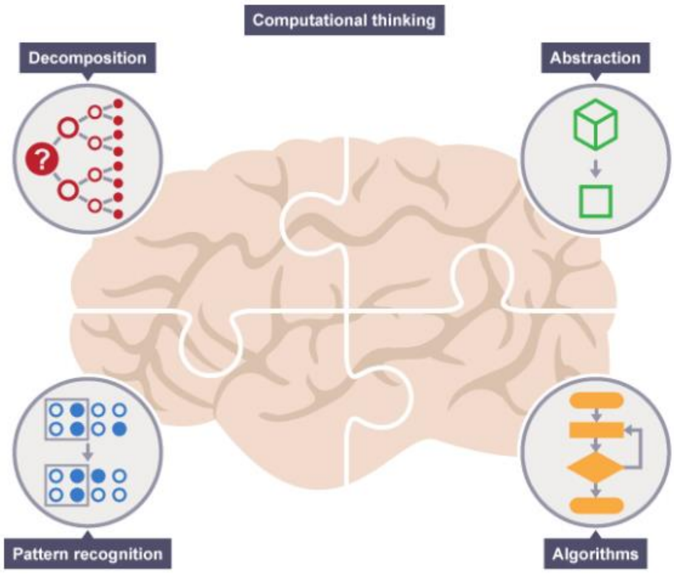

Fig. 1. CT skills [9]

Amidst the advent of Industry 4.0, there has been a notable surge in the significance of digital applications in education [10]. Digital applications offer engaging, interactive teaching methods, foster motivation, flexibility, self-directed learning, improved understanding, nurturing critical thinking skills, and enhanced student learning achievements and experiences [11-13]. As the world becomes increasingly digitized, the demand for individuals equipped with CT skills has surged, compelling higher education institutions to reassess and adapt their curricula. The imperative lies not only in producing graduates proficient in programming but in cultivating a broader mindset that integrates CT as a cornerstone for intellectual agility and innovative problem-solving. This paradigm shift in education reflects a response to the evolving needs of a global workforce, positioning CT as an essential conduit for preparing students to navigate the intricacies of the 21st century [14-16]. The challenge is not merely to impart technical skills but to instil a holistic understanding of CT as a cross-disciplinary and cross-functional tool, propelling graduates towards adept problem-solving, critical thinking, and adaptability in an increasingly complex and interconnected world [17].

In a comprehensive exploration of CT within diverse educational contexts, several studies offer insights into its development, application, and impact on students. In educational technology, research on immersive virtual reality (IVR) environments and educational games emphasizes the need to understand cognitive factors for effective CT development. An IVR study reveals that goal clarity refers to a principal predictor with respect to comprehension as well as reflective thinking, underlining the importance of designing clear objectives. The findings advocate for educators and developers to consider cognitive elements in IVR game-based interventions, fostering 21st-century problem-solving skills via critical thinking [18]. Studies exploring AI courses and thinking styles in CT development reveal the importance of visual programming languages in learning. Visual AI courses are seen as a gateway to lower the learning threshold, allowing students to delve into more challenging AI knowledge and cultivating talent in the field [19]. A study incorporating a flipped web programming course in Taiwan showcases significant improvements in both CT and learning achievement. The study underscores the framework's efficacy in fostering interdisciplinary learning, accentuating its role in attracting diverse talent [20]. A study conducted in Taiwan establishes a link between CT, enjoyment, and digital self-efficacy, highlighting their positive influence on self-exploration as well as learning satisfaction in an AppInventor-based liberal education course [21]. In contrast, another study scrutinizes text-based programming learning, identifying dominant skills in control and data but weak proficiency in algorithms. Notably, only a third of students witness continuous skill improvement, prompting proposed strategies to address gaps and enhance CT development in programming learning contexts [22].

Exploring the Fourth Industrial Revolution, with progress in augmented reality (AR), data science, and quantum computing changing society, CT skills are key to unlocking potential in various fields. Graduates in the 21st century are faced not only with the need for specialized knowledge in their respective domains but also with the demand for a broader set of skills that can traverse traditional disciplinary boundaries. The ability to think computationally becomes a unifying thread, enabling graduates to tackle complex challenges, leverage emerging technologies, and contribute meaningfully to the multifaceted landscape of our evolving global society [23]. This review explores the existing applications of CT in higher education across various academic disciplines. It highlights the potential of CT to enhance analytical abilities and inspire innovative solutions to challenges. The review also examines pedagogical strategies used in higher education to teach CT skills. The review emphasizes the employability of CT in the digital age and its integration into curricula to create a future-ready workforce. The review serves as a guide for educators and policymakers in the complex landscape of higher education, emphasizing the transformative power of CT.

2. Methodology

The analysis in this study employs the PRISMA methodology, a well-established standard for performing systematic literature reviews. Utilizing publication guidelines is commonly essential to assist authors in evaluating and ensuring the accuracy as well as rigor of a review, incorporating pertinent as well as crucial details. Furthermore, PRISMA underscores the importance of assessing randomized studies, a pivotal factor in systematic analysis reports for various study types [24] (Figure 2). In terms of methodology, two robust databases, WoS as well as Scopus, were employed to assess the research methodology. The resource offers various scholarly journal articles indexed by the ISI, facilitating access to a comprehensive collection of academic literature [25]. This section also presents a comprehensive overview of four key sub-sections: identification, screening, eligibility, including data abstraction and analysis.

2.1 Identification

Three main phases of the systematic review process are employed to choose relevant papers for this report. Here, the first stage is identifying keywords as well as searching for related phrases utilizing dictionaries, thesaurus, encyclopaedias, and prior scholarly investigations. Subsequently, when relevant keywords were identified, search strings were produced for the WoS as well as Scopus databases, as Table 1 illustrates. In the first stage of the systematic review process, 1512 publications were successfully retrieved from the databases that were used for this study.

Table 1
The search strings

Scopus	WoS
TITLE-ABS-KEY ("computational thinking" AND ("higher education" OR university OR "graduate school" OR "higher learning" OR college OR polytechnic OR "tertiary school" OR "higher institution")) AND (LIMIT-TO (PUBYEAR , 2023)) AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (LANGUAGE , "English")) AND (LIMIT-TO (SRCTYPE , "j")) AND (LIMIT-TO (PUBSTAGE , "final"))	("computational thinking" AND ("higher education" OR university OR "graduate school" OR "higher learning" OR college OR polytechnic OR "tertiary school" OR "higher institution")) (Topic) and 2023 (Publication Years) and Article (Document Types) and English (Languages)

2.2 Screening

In this phase, any duplicate papers identified will be eliminated from the assembled list of papers that were studied. The initial screening phase excluded 1443 publications, while the subsequent phase involved the examination of 69 papers using distinct inclusion as well as exclusion criteria particularized in Table 2. The literature itself was the primary criterion used, with research articles serving as the main source of informative suggestions. This category also covered reviews, meta-analyses, book series, meta-synthesis, books, chapters, as well as conference proceedings not encompassed in the latest research. In addition, the review was limited to papers in the English language. Therefore, it is important to note that the strategy is exclusively centred on the year 2023. In conclusion, duplication criteria led to the exclusion of 24 articles.

2.3 Eligibility

A total of 45 articles have been produced for the eligibility phase, which is the third stage. At this point, the titles, as well as the key content of every article, were carefully examined to make sure that the inclusion criteria were met and that the papers fit within the current study and its goals. As a result, 13 reports were excluded since their abstracts had little to do with the study's purpose, their titles had no bearing on it, and their content was unrelated to the empirical data. Ultimately, 32 articles are available for review (see Table 2).

Table 2
The selection criterion is searching

Criterion	Inclusion	Exclusion
Language	English	Non-English
Timeline	2023	< 2023
Literature type	Journal (Article)	Conference, Review, Book,
Publication Stage	Final	In Press

2.4 Data Abstraction and Analysis

In this research, integrative analysis emerged as a key assessment strategy, encompassing diverse research designs such as qualitative, quantitative, as well as mixed methods. The primary objective of this comprehensive investigation was to pinpoint relevant topics as well as subtopics. In addition, the initial phase involved data collection, constituting the foundational step in theme development. Figure 2 illustrates the meticulous examination of 32 publications, wherein the authors systematically analysed assertions and content pertinent to the study's topics. Subsequently, a thorough assessment of significant studies related to CT ensued, encompassing methodologies and research findings. Collaborative efforts among authors facilitated the extraction of themes grounded in the context of the study, documented via a log that captured analyses, perspectives, queries, as well as other intuitions relevant to data interpretation. To ensure coherence, the authors conducted a comparative analysis of results, addressing any inconsistencies in theme design through internal discussions. In instances of conceptual disagreements, authors engaged in collaborative discussions. The produced themes underwent refinements for consistency. To bolster the findings' validity, assessments were independently conducted by two experts specializing in CT and instructional design and technology and ensuring domain validity. The iterative process involved adjustments based on the author's discretion, incorporating feedback as well as comments obtained from expert evaluations.

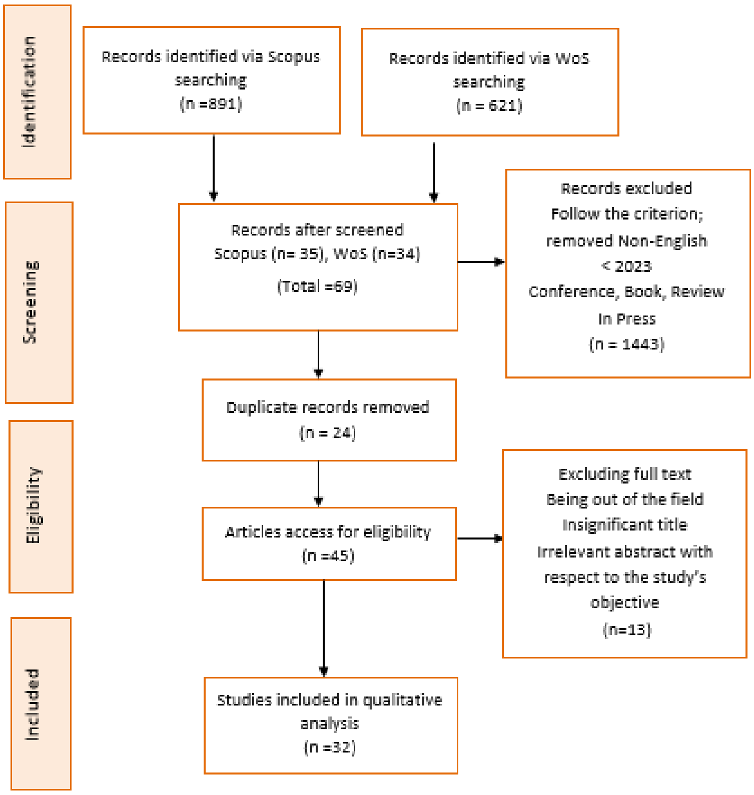

Fig. 2. Flow diagram of the suggested searching study [24]

3. Results and Findings

CT is crucial as it equips individuals with problem-solving skills as well as the ability to disintegrate complex problems into feasible steps, fostering logical reasoning essential for navigating a technology-driven world. A total of 32 articles were retrieved and examined pursuant to the search technique. Two primary topics were employed to classify all of the publications:

i. Technology's Impact on CT (16 articles)
ii. Pedagogical Approaches and Educational Strategies for CT (16 articles).

3.1 Technology's Impact on CT

Cutting-edge technological tools have emerged as transformative agents in shaping and elevating CT skills among learners, representing a diverse spectrum of advancements from artificial AI platforms such as ChatGPT to the immersive areas of AR and VR applications. These tools not only facilitate the acquisition of foundational computational skills but also revolutionize the learning experience by providing dynamic, interactive, and engaging environments. AI platforms contribute by offering personalized and adaptive learning experiences, tailoring content to individual student needs. AR and VR applications, on the other hand, provide visually immersive contexts that enhance conceptual understanding and problem-solving abilities. Table 3 shows a summary of Technology's Impact on CT.

Table 3
Summary of Technology's Impact on CT

Authors	Title	Journal	Methodology	Advantages and finding
Yilmaz *et al.,* [26]	The effect of generative artificial intelligence (AI)-based tool use on students' computational thinking skills, programming self-efficacy and motivation	Computers and Education: Artificial Intelligence (2023)	The research investigated the ChatGPT impact on 45 undergraduate students' CT skills, self-efficacy, as well as motivation in a university-level programming course. During weekly practices, ChatGPT was beneficial to the experimental group but not to the control group.	The study found that experimental group students demonstrated significantly higher CT skills, programming self-efficacy, as well as motivation in computer programming courses compared to control group students, suggesting the potential of AI technologies such as ChatGPT in programming training.
Ou Yang *et al.,* [27]	Effect of augmented reality-based virtual educational robotics on programming students' enjoyment of learning, computational thinking skills, and academic achievement	Computers and Education (2023)	The study developed an AR Bot, a virtual educational robotic system, to enhance spatial ability and promote deeper CT processes. It compared AR Bot with Scratch, assessing their impact on the internal learning processes of the students, CT skills, as well as academic achievement.	According to the study, when compared to Scratch students, AR Bot students showed greater academic achievement and enjoyment of learning, algorithm design, and efficiency skills yet lacked issue decomposition skills. The tool's theoretical and practical implications are discussed.

Agbo *et al.,* [28]	Design, development, and evaluation of a virtual reality game-based application to support computational thinking	Educational Technology Research and Development (2023)	The study explores the establishment as well as assessment of a virtual reality game-based application, iThinkSmart, to enhance computer science knowledge. The prototype was tested with 47 Nigerian university computer science students, comparing its effectiveness and areas for improvement.	The study reveals that VR enhances students' CT skills and programming education by using visualization of CT concepts, leading to increased cognitive benefits and interest in learning.
Lampropoulos *et al.,* [29]	Integrating augmented reality, gamification, and serious games in computer science education	Education Sciences (2023)	The study evaluates the utilization of gamification, AR, as well as serious games in computer science education, involving 117 higher education students and analysing a 49-item questionnaire.	The study reveals that incorporating gamification, AR, as well as serious games in teaching may improve students' social-emotional, cognitive, knowledge, critical thinking, CT skills and foster positive emotions.
Agbo *et al.,* [18]	Examining the relationships between students' perceptions of technology, pedagogy, and cognition: the case of immersive virtual reality mini-games to foster computational thinking in higher education	Smart Learning Environments (2023)	The study investigated the impact of game elements, IVR technology features, and learners' cognitive abilities on cognitive development using an experiment with 49 undergraduate students using iThinkSmart mini-games.	The study reveals that goal clarity, immersion, and adequate learning content significantly influence reflective thinking as well as comprehension in an educational game-based IVR application, enhancing 21st-century problem-solving skills.
Lubis *et al.,* [30]	The effectiveness of Scratch coding activities in English language learning	World Journal of English Language (2023)	The study explores the use of Scratch Coding Activities (SCA) in English Language Learning to improve CT skills, particularly reading comprehension. It explores Pre-Service Teachers' motivation and interest in learning English via these activities using a quantitative approach.	According to the study, incorporating SCAs into EYL classrooms improved ELL students' language mastery, CT skills, motivation, as well as interests.
Martín-Núñez *et al.,* [31]	Does intrinsic motivation mediate perceived artificial intelligence (AI) learning and computational thinking of students during the COVID-19 pandemic?	Computers and Education: Artificial Intelligence (2023)	The study explores the correlation between students' motivation to learn AI throughout the COVID-19 pandemic, their understanding of AI concepts, as well as the dynamic relationship between AI and CT.	The study reveals that innate motivation significantly influences the correlation between perceived AI learning as well as CT.

Paucar-Curasma *et al.,* [32]	Use of technological resources for the development of computational thinking following the steps of solving problems in engineering students recently entering college	Education Sciences (2023)	The authors suggest utilizing Arduino boards, sensors, and mBlock to enhance CT in first-year students through algorithm development, programming, and debugging using a playful interface.	Activities influence students' practices, cognitive processes, as well as technological perspectives. A causal relationship exists between CT skills as well as problem-solving phases in college engineering students, requiring further analysis.
Liu *et al.,* [33]	What influences computational thinking? A theoretical and empirical study based on the influence of learning engagement on computational thinking in higher education	Computer Applications in Engineering Education (2023)	The research investigates the correlation between learning engagement as well as CT, involving 341 freshmen from central China, focusing on three dimensions of engagement.	The study reveals that emotional and cognitive engagement significantly predict CT, with the learning environment playing a crucial role. Smart classrooms show a closer relationship with learning engagement, offering potential methods for improving students' CT.
Sala-Sebastià *et al.,* [34]	Didactic–Mathematical–computational knowledge of future teachers when solving and designing robotics problems	Axioms (2023)	The study examines the didactic-mathematical as well as computational knowledge of aspiring kindergarten teachers in resolving robotics challenges. It identifies aspects of this knowledge from 97 Spanish university students and analyses their justifications for designing robotics problems.	Future teachers demonstrate didactic-mathematical knowledge in resolving robotics challenges, but ambiguities, as well as errors in procedures and programming representations, affect their didactic suitability. Training should incorporate didactic-mathematical as well as computational knowledge for logical, spatial, and CT.
Mehrvarz *et al.,* [35]	Improving computational thinking: the role of students' networking skills and digital informal learning	Interactive Learning Environments (2023)	The study investigates the correlation between computer-based networking skills and CT among 351 Shiraz University students through digital informal learning.	Networking skills significantly enhance students' CT, having digital informal learning acting as a mediator, highlighting the importance of integrating these skills in education.

Alfaro-Ponce *et al.,* [36]	Components of computational thinking in citizen science games and its contribution to reasoning for complexity through digital game-based learning: A framework proposal	Cogent Education (2023)	The study proposes a multifaceted approach that integrates citizen science as well as digital game-based learning (GBL) in improving university students' CT abilities.	The study suggests that designing a digital citizen-science game can enhance CT and improve students' teamwork as well as engagement in data collection and analysis while also elevating their CT skills, knowledge, including complex thinking competency.
Hijón-Neira *et al.,* [37]	Prototype of a recommendation model with artificial intelligence for computational thinking improvement of secondary education students	Computers (2023)	The study enhances CT in secondary education using visual and text programming, integrating AI recommendation models and personalized modules, with an experiment conducted among 23 pre-service teachers in Madrid and Galway.	The Scratch group showed significant improvement in overall results, with the Loop concept being the most significant in specific programming concepts analysis.
Li *et al.,* [38]	The influence of art programming courses on design thinking and computational thinking in college art and design students	Education and Information Technologies (2023)	The study examines the influence of art programming education on 27 junior digital media students, examining the relationship between CT and design thinking (DT).	The study reveals that art programming courses enhance students' programming attitudes in both DT and CT, with no significant difference in DT and CT. It confirms the importance of these two thinking types in problem-solving and creative design.
Paucar-Curasma *et al.,* [39]	Development of Computational Thinking through STEM Activities for the Promotion of Gender Equality	Sustainability (Switzerland) (2023)	The study assesses CT skills among industrial engineering and systems engineering students in Peru, focusing on abstraction, decomposition, generalization, algorithmic design, and evaluation. Utilizing microcontrollers, sensors, and actuators, it is suggested that CT be strengthened in the areas of agriculture, the environment, livestock, safety, as well as education.	The inferential analysis reveals no significant differences in CT skills between male and female students, possibly due to the educational strategy focusing on real-world problem-solving, generating equal enthusiasm.

Authors	Title	Journal	Methodology	Advantages and finding
Zhang *et al.,* [22]	Exploring the differences and evolution of college students' computational thinking in programming learning through data analysis	Computer Applications in Engineering Education (2023)	The paper investigates college students' CT skills through text-based programming and data analysis, revealing five categories of CT difference and nine subcategories of CT evolution among students.	The study found that Control as well as Data skills were the dominant skills among students, while Algorithm skills were weak. Only 1/3 of students experienced continuous skill improvement, and programming learning did not significantly impact CT skills. The study suggests strategies for CT skill development.

3.2 Pedagogical Approaches and Educational Strategies for CT

Pedagogical approaches and educational strategies for CT encapsulate a rich spectrum of methodological innovations strategically designed to cultivate and enhance critical cognitive skills among learners. This multifaceted landscape encompasses a comprehensive array of teaching methodologies, instructional designs, and learning interventions meticulously crafted to instil proficiency in CT—an essential cognitive skill set vital for navigating the complexities of the modern technological era. These pedagogical approaches not only prioritize the development of problem-solving abilities but also emphasize the cultivation of analytical thinking, algorithmic reasoning, and creative problem-solving capacities. Table 4 shows a summary of Pedagogical Approaches and Educational Strategies for CT.

Table 4
Summary of Pedagogical Approaches and Educational Strategies for CT

Authors	Title	Journal	Methodology	Advantages and finding
Zhou and Tsai [40]	The effects of socially shared regulation of learning on the computational thinking, motivation, and engagement in collaborative learning by teaching	Education and Information Technologies (2023)	The study analysed the effect of SSRL on the academic performance of 72 third-year undergraduates in a data mining course at a Chinese public university.	The experimental class significantly improved students' motivation, engagement, and CT, leading to higher academic achievements, indicating the need for future research on project-based learning and psychological variables.
Jou *et al.,* [41]	The developmental characteristics of computational thinking and its relationship with technical skills: taking the Department of Engineering as an example	Interactive Learning Environments (2023)	The study explores the influence of creative problem-solving (CPS) education on CT and its correlation with technical skills.	The study reveals that CPS can enhance CT and motor skills in engineering students, with technology-based students showing greater improvement.

Wang Y. [42]	The role of computer-supported project-based learning in students' computational thinking and engagement in robotics courses	Thinking Skills and Creativity (2023)	The study examined the influence of computer-supported project-based learning (CSPBL) on the cognitive and learning engagement of 79 Chinese students in two courses taught by the same instructor.	The CSPBL enhanced students' CT, cooperation, as well as problem-solving skills in robotics learning through simulation project training on the SenseStudy platform, proving effective for programming experience students.
Kang *et al.,* [43]	Developing college students' computational thinking multidimensional test based on life story situations	Education and Information Technologies (2023)	The study investigates CT, identifying five dimensions and developing a life-based assessment tool for college students relevant to Google CT education.	The study's CT test was deemed effective due to its strong internal validity and ability to discriminate across various college disciplines.
Helsa and Juandi [44]	TPACK-based hybrid learning model design for computational thinking skills achievement in mathematics	Journal on Mathematics Education (2023)	The study examines the effect of a hybrid learning model incorporating Technology Pedagogy and Content Knowledge on CT skills achievement among lecturers and 38 first-year students at Padang State University.	The study found that language, content, as well as e-learning practices fulfilled valid criteria, having practicality scores of 77.5% and student assessment scores of 82.9%, suggesting a hybrid learning model for 21st-century abilities.
Zhang *et al.,* [45]	Progressive flowchart development scaffolding to improve university students' computational thinking and programming self-efficacy	Interactive Learning Environments (2023)	A quasi-experiment involving 49 Chinese tertiary students was conducted to assess the effectiveness of progressive and non-progressive training during a programming course.	The study revealed that a progressive thinking training approach with flowcharts significantly improved academic outcomes involving critical thinking, cooperative learning, as well as problem-solving compared to the control group.
Zhong *et al.,* [46]	Developing creative material in STEM courses using integrated engineering design based on APOS theory	International Journal of Technology and Design Education (2023)	The study analysed the STEM course influence on students' creativity, incorporating STEM, CT, as well as CDIO engineering design, utilizing a pre-test-post-test non-equivalent-groups design.	The study analysed the STEM course influence on students' creativity, incorporating STEM, CT, as well as CDIO engineering design, utilizing a pre-test-post-test non-equivalent-groups design.

Muchsini *et al.,* [47]	Promoting college students' computational thinking: the use of constructionism-based accounting spreadsheets designing activities	Cogent Education (2023)	The research utilized a participatory qualitative approach to explore the relationship between students and lecturers in creating accounting spreadsheets involving 38 Accounting education majors, utilizing data from work artifacts, classroom observations, and discussion notes.	The study suggests that constructionism-based accounting spreadsheet designing activities can improve CT in college students by addressing errors and deficiencies in spreadsheet design.
Bacelo *et al.,* [48]	Characterizing algorithmic thinking: A university study of unplugged activities	Thinking Skills and Creativity (2023)	This research examines algorithmic thinking in a university Mathematics Bachelor's Degree context, focusing on unplugged tasks and establishing connections between mathematical as well as algorithmic working spaces in 3D.	The study confirms the interaction between dimensions and predicts better programming performance, adding new insights into the role and interaction of mathematical as well as CT categories in algorithmic thinking.
Remshagen and Huett [49]	Youth hackathons in computing for the community: A design case	TechTrends (2023)	The article details a hackathon for teenagers at a US university, where they collaborated to create software-based solutions to a community problem, using naturalistic inquiry, peer debriefing, data sources, as well as member checks.	This design case provides extensive descriptions as well as rationales for youth hackathons, offering logistical and pedagogical resources for designers to support their implementation in novel settings.
Şen Ş. [50]	Relations between pre-service teachers' self-efficacy, computational thinking skills and metacognitive self-regulation	European Journal of Psychology of Education (2023)	The study examined the correlation between CT skills, pre-service teachers' self-efficacy, as well as metacognitive self-regulation utilizing the Motivated Strategies for Learning Questionnaire and the CT Scale.	The study revealed a strong positive correlation between self-efficacy for learning and performance, pre-service teachers' CT skills, as well as metacognitive self-regulation.
Chen P.P. [51]	Interactions between self-regulated learning and assessment for learning in an undergraduate introductory computer science course	New Directions for Teaching and Learning (2023)	This paper explores self-regulated learning (SRL), assessments to facilitate learning (AfL), as well as CT practices in CS, illustrating how these practices are structured in undergraduate introductory courses using online and offline support.	The finding evaluates the CS course and offers practical suggestions to aid student SRL in their learning of CS programming.

Lai Y.-H. [52]	Multi-ethnic computational thinking and cultural respect in unmanned aerial vehicle-assisted culturally responsive teaching	Frontiers in Psychology (2023)	The study utilized unmanned aerial vehicle (UAV) technology to establish culturally responsive teaching for multi-ethnic students, utilizing CT to solve problems. This approach helped students and teachers understand diverse cultures and collaborate effectively.	The study explores the impact of UAV-assisted culturally responsive teaching on CT abilities, revealing that it enhances learning effectiveness and cultural respect for indigenous and Han Chinese students, improving their programming abilities and multicultural education.
Yuen *et al.,* [53]	Competitive programming in computational thinking and problem-solving education	Computer Applications in Engineering Education (2023)	This article presents a case study with regard to a Python programming contest with an automatic judgment system for Competitive Programming training, adopting a hybrid model due to COVID-19. The DOM judge platform was deployed for online contest management, reducing human effort.	The study suggests that contests can enhance students' innovative thinking, independent learning, as well as problem-solving skills, resulting in enhanced employability. It suggests that students should participate in open competitions to improve their skills and prepare them for graduate school. Employers place high importance on student experiences in programming events such as the Microsoft Imagine Cup as well as Google Code Jam.
Lee *et al.,* [54]	Peer assessment for engineering design education: An exploratory study	International Journal of Engineering Education (2023)	The study examined the impact of peer assessment in engineering design classes on learning outcomes as well as the perceptions of both students and instructors.	Peer assessment in engineering design classes enhances CT, creative problem-solving, and collective efficacy. However, students face challenges like insufficient time for assessment activities and doubts about their abilities. This study contributes to understanding peer assessment's role in engineering design education.

Chang and Wongwatkit [55]	Effects of a peer assessment-based scrum project learning system on computer programming's learning motivation, collaboration, communication, critical thinking, and cognitive load	Education and Information Technologies (2023)	The study examines how 98 third-year college students' programming projects, collaboration, learning motivation, critical thinking, communication, as well as cognitive load are affected by the peer assessment-based Scrum project (PA-SP) method.	The PA-SP approach substantially enhances learning achievement, collaboration, motivation, communication, as well as critical thinking, offering practical insights to promote students' CT for enhancing programming education in universities.

4. Discussion

The comprehensive examination of the impact of technology on CT presented in the various studies demonstrates the varied and nuanced influence of technological tools on learning outcomes. The integration of AI technologies, for instance, ChatGPT in programming training, is shown to significantly enhance programming self-efficacy, CT skills, as well as motivation, indicating the potential of such tools in shaping educational experiences. AR and VR technologies contribute to improved algorithm design, enjoyment of learning, as well as efficiency skills, as well as enhanced visualization of CT concepts. The incorporation of AR, gamification, and serious games emerges as a multifaceted strategy that positively affects cognitive, social-emotional, and critical thinking skills, fostering positive emotions. The role of goal clarity, immersion, and learning content in educational game-based VR applications highlights the importance of these factors in promoting reflective thinking and 21st-century problem-solving skills. Furthermore, the studies emphasize the interconnectedness of intrinsic motivation, AI learning, and CT. Networking skills, digital informal learning, as well as the design of digital citizen-science games are identified as influential factors in enhancing CT. The significance of art programming courses in shaping programming attitudes and the equal enthusiasm of male and female students in a real-world problem-solving-focused educational strategy underscores the inclusivity of technology-driven learning. However, challenges, such as weak algorithm skills and the need for continuous skill improvement, are recognized, prompting the development of targeted strategies for CT skill enhancement.

The comprehensive review of pedagogical approaches, as well as educational strategies for CT presented in various studies, underscores the multifaceted nature of effective teaching in this domain. The findings consistently highlight the positive impact of diverse methods such as project-based learning, computer-preferred study, simulation project training, progressive thinking training, constructionism-based activities, and culturally responsive teaching on students' motivation, engagement, and CT skills. The emphasis on practicality, hybrid learning models, and the integration of 21st-century abilities reflects a nuanced understanding of the educational landscape. Notably, the positive outcomes extend beyond technical proficiency to encompass collaborative and creative aspects of learning, contributing to critical thinking, problem-solving, and cultural respect. The studies also acknowledge the importance of gender-specific considerations and advocate for participation in competitive events to enhance employability. However, challenges such as time constraints and doubts about abilities in peer assessment are recognized.

5. Conclusion

Based on the systematic review, it is recommended to further enhance CT skills and bridge the gap between academic learning as well as real-world industry implementation. The implementation of CT through Pair Programming (PP) in higher education is strongly recommended as a strategic pedagogical approach to preparing students for the demands of the contemporary workforce. Integrating CT and PP methodologies not only enhances students' problem-solving skills and algorithmic reasoning but also fosters collaborative abilities crucial for professional success. Moreover, the emphasis on collaborative projects facilitated by PP ensures that students develop a practical understanding of applying CT principles in multifaceted real-world contexts. This approach not only aligns with the academic objectives of higher education but also mirrors the collaborative nature of industry practices, where teams routinely engage in paired programming to address complex challenges efficiently. By integrating PP into the educational framework, students are not only equipped with essential computational skills but also gain practical experience that directly translates to the collaborative demands of the industry, enhancing their readiness for seamless integration into the workforce.

Overall, these findings collectively highlight the transformative potential of technology and pedagogical framework in shaping the landscape of CT. It offers valuable insights for educators, curriculum designers, and policymakers seeking to harness the benefits of technology and programming education for effective and inclusive learning experiences.

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