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Computational Thinking (CT) integrated entrepreneurship education (EE): a synthesis of current research and initiatives

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Abstract

Purpose – Emerging research has shown a significant integration between Computational Thinking (CT) and Entrepreneurship Education (EE), suggesting that CT skills can positively influence business sustainability and catalyze innovation. In this context, this study aims to identify the core themes of CT and EE and their integration with ethical considerations and to determine the diverse perspectives and definitions presented for CT and EE to analyze the range of educational contexts using various research methodologies and approaches employed.

Design/methodology/approach – This study adopted an exploratory research method with thematic, discourse, and comparative analyses to encompass the systematic approaches and techniques employed to investigate and further address the research gaps.

Findings – This study synthesizes the potential interconnections and overlaps between CT and EE, with key findings to underscore the growing importance of CT as a fundamental skill and its impact on learning outcomes, such as problem-solving and critical thinking, required for sustainable business through EE through ethical aspects with the mediating role of CT between EE and digital literacy in business sustainability.

Research limitations/implications – A meta-synthesis of research on coding and CT across the EE curriculum identifies key features of learning environments, their impact on learning outcomes, pedagogical constraints and underlying learning approaches for sustainable businesses.

Social implications – This study provides new, dimensional social aspects for better sustainable livelihoods through CT-integrated EE.

Originality/value – To the best of the authors' knowledge, no prior research has attempted to synthesize the few current research and initiatives in integrated CT and EE.

Keywords Computational Thinking (CT), Entrepreneurship education (EE), Integrated CT and EE, Digitalization of EE, CT integrated curriculum of EE

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Introduction

The twenty-first century presents a complex landscape shaped by rapid digitization, production innovations and the pressing challenges of climate change. These challenges demand the reevaluation of the skills prioritized by education systems and the labor market (Burgsteiner *et al.*, 2024). In this evolving context, Computational Thinking (CT) and Entrepreneurship Education (EE) have been identified as critical competencies for individuals to navigate and thrive in this dynamic environment (Bentz, 2024; Burgsteiner *et al.*, 2024; Digital Promise, 2017). The study of integrating CT and EE was explored, and the identified aspects were discussed. According to J. Bae *et al.* (2022), "CT aims to perform effective and efficient problem-solving to address real-life problems using computing technology such as AI. Therefore, ethical considerations in AI education can be regarded as an important element of CT." According to Wing (2006), "CT builds on the power and limits of computing processes, whether they are executed by a human or by a machine. Computational methods and models give us the courage to solve problems and design systems that no one of us would be capable of tackling alone." Recent progress and success in artificial intelligence (AI), especially machine learning applications, and the ethics of AI have become popular topics in academic and public discussions about the future of technology, as they fundamentally relate to CT (Mark Coeckelbergh, 2020).

According to D. Rae (2009), "the experience of creating and running the student Placements for Entrepreneurs in Education (SPEED) programme as an innovative multi-higher education institute project that explores the processes of action learning for educators and student entrepreneurs. It develops a conceptual model of entrepreneurial action learning as a transferable approach in relation to new venture creation."

CT extends beyond the technical realm of computer science, serving as a fundamental analytical skill applicable across diverse disciplines (Digital Promise 2017). A work group report (2017) at MIT underscored this, stating that "CT is as essential a tool for every student as is scientific thinking." This involves understanding human behavior through problem-solving and system design from the perspective of computer science (Digital Promise, 2017). Furthermore, countries such as the UK, Finland, South Korea and Australia are actively encouraging the development of CT as a vital twenty-first-century skill (Wardana *et al.*, 2024).

Conversely, EE broadens its scope beyond mere business creation and cultivates skills and attitudes that foster personal and professional growth (Sarri *et al.*, 2020). EE offers "a solid grounding in multidisciplinary skills and especially those relating to technology entrepreneurship" (Philbin, 2021a). In sustainable entrepreneurship, "observation with 'open eyes and ears and direct contact with those affected is essential for the innovation process, especially in the first phase of problem identification" (Bentz, 2024).

Emerging research highlights the significant synergy between CT and EE. Studies indicate a "robust link between CT and business sustainability" (Wardana *et al.*, 2024), suggesting that CT skills can positively influence the longevity and success of entrepreneurial endeavors. This paper positions "entrepreneurship as a new frontier for research on computational creativity" (Goel *et al.*, 2021). Moreover, "Innovating Education and Entrepreneurship Through CT" posits that CT can be a catalyst for innovation in both education and entrepreneurship, leading to "New Pathways for Economic Development."

Several initiatives actively promote the integration of these skills. The Erasmus+ project "Come-Think-Again" (CTA) directly addresses the challenges of digitization and climate change by fostering "CT Skills," "EE and Innovation Skills" and "Social Responsibility, Sustainability and Green Skills" (Burgsteiner *et al.*, 2024). A key outcome is the development of a "cross-sectoral, standardized training and Certification System called CTA-CETS" for these three pillars, employing a "train-the-trainer approach" and utilizing "blended-learning, e-learning, Massive Open Online Courses (MOOCs), nano-degrees and micro-certifications embedded into a state-of-the-art learning management system (LMS)" (Burgsteiner *et al.*, 2024). The curricula align with major European frameworks, such as DigComp, EntreComp and the European Sustainability Competence Framework (Burgsteiner *et al.*, 2024).

Pedagogical approaches to teaching these skills are diverse. A meta-synthesis on "coding and CT across the curriculum" seeks "to systematize the features of learning environments to develop coding expertise and other learning outcomes when integrated strategically across curriculum areas" (Mills *et al.*, 2024). This review identified pedagogical constraints such as a "lack of teacher and student skills, knowledge, experience, and creativity" (Mills *et al.*, 2024). Conversely, "project-based learning" is utilized in "EE for Engineers" (Philbin, 2021b). Notably, a study on "The impact of a short-term training on student and teacher self-efficacy in CT, programming and entrepreneurship" found that even brief interventions can lead to a "significantly increased student and teacher self-efficacy in aforementioned domains" (Huruzoğlu, 2019). This underscores the potential of targeted educational interventions.

The synergistic relationship between CT and EE is vital for preparing individuals for the complexities of the 21st century (Bentz, 2024; Burgsteiner *et al.*, 2024; Digital Promise, 2017; Goel *et al.*, 2021; IGI Global, n.d.; Wardana *et al.*, 2024). Initiatives like the CTA and research into effective pedagogical methods, while acknowledging existing constraints (Burgsteiner *et al.*, 2024; Mills *et al.*, 2024; Philbin, 2021a; Sarri *et al.*, 2020), are crucial for fostering these essential competencies across educational landscapes (Burgsteiner *et al.*, 2024; Huruzoğlu, 2019; Mills *et al.*, 2024; Philbin, 2021b). This study contributes to a deeper understanding of the effective integration of these two domains to empower future generations. "This research aims to develop a strategy for implementing AI in business education in higher education to improve students' computational thinking skills." (Rahma *et al.*, 2023).

Objectives of study

- To identify the core themes of CT and EE and their integration.
- To determine the diverse perspectives and definitions presented for CT and EE.
- To analyze the range of educational contexts.
- To examine the various research methodologies and approaches employed in Integrated CT and EE.
- To synthesize the potential interconnections and overlaps between CT and EE.

Literature review

In this study, the researchers surveyed the literature in various databases using keywords such as EE and CT, integration of EE and CT, computational thinking, and EDD. Contemporary educational research has explored various intertwined domains, notably CT, EE, and digital literacy, often within engineering and other disciplines. The sources reveal the diverse research methodologies employed to investigate these areas. Figure 1 shows one method for mapping research papers using the Information Technology (IT) tool "connected papers" for review and further selection of the references.

Wardana and Ayuni (2020) investigated the impact of EE and digital literacy on business sustainability among Indonesian homemakers, employing a self-administered survey and partial least squares structural equation modeling (PLS-SEM) for data analysis. The effectiveness of the "Easy Access" web application for physiotherapy findings was also

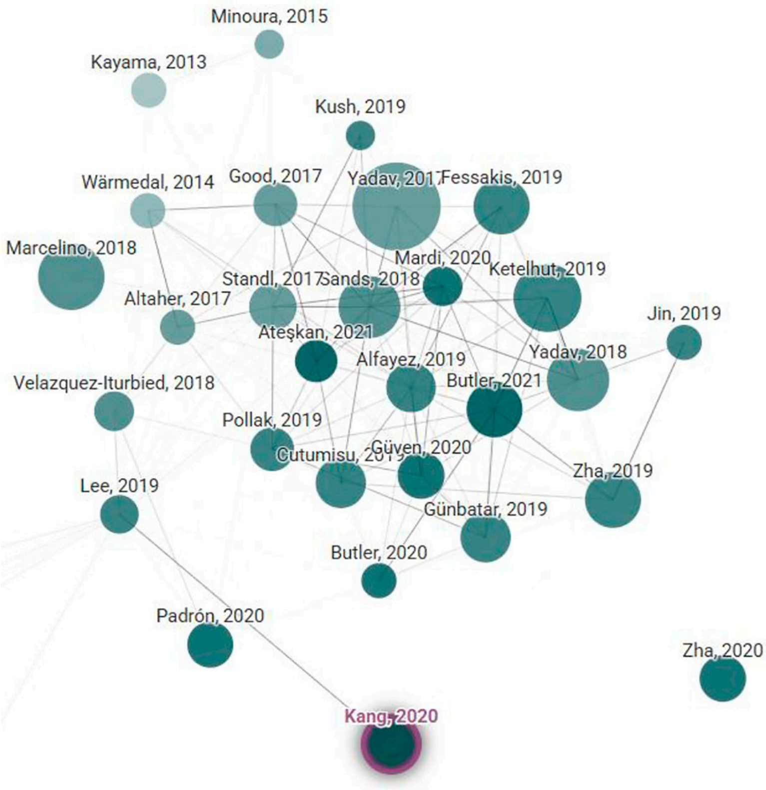

Figure 1. Mapping of the research papers using the IT tool: "connectedpapers"
Source(s): Authors' own work

evaluated through usability tests, generating quantitative data on its efficiency and user-friendliness (Burgsteiner, Spieler, and Messer-Misak, 2015).

Several studies have explored the integration of CT with EE and engineering. "Designing technology EE using CT" (Kang and Lee, 2020) explores how CT can be leveraged to design effective EE for engineers, potentially through capstone courses. Similarly, Philbin (2021a) advocated project-based learning to equip engineers with multidisciplinary skills in technology entrepreneurship, business planning, and technology transfer. "A new framework of entrepreneurship education that combines business model development and CT. It is applied to this framework to a capstone course for social innovation, in which undergraduate students were asked to define a social problem, develop a solution, and finally implement the appropriate products and services using Arduino, Raspberry Pi, sensors, and actuators." (Kang and Lee, 2020).

The study "Complex thinking as a component in EE and engineering classes: an empirical study" (Alonso-Galicia *et al.*, 2025) aims to compare the development of reasoning-for-complexity competency in entrepreneurship and engineering programs, suggesting that entrepreneurship is a valid discipline for fostering scientific thinking. Research on Indonesian homemakers indicates a significant effect of EE and digital literacy on business sustainability, with CT mediating this relationship (Wardana *et al.*, 2024).

A meta-synthesis (Mills *et al.*, 2024) reviewed research on coding and CT across the curriculum, identifying key features of learning environments, impacts on learning outcomes, pedagogical constraints (such as lack of teacher skills and technology difficulties), and underlying learning approaches. This review highlights the global interest in integrating coding and CT into subjects such as science, mathematics, and history to foster problem-solving and critical thinking.

Other studies have explored specific aspects of CT education. One study examined the impact of short-term training on students' and teachers' self-efficacy in CT, programming, and entrepreneurship, finding significant increases in self-efficacy in these domains (Huruzoğlu, 2019). Another study utilized discourse analysis to examine the future of CT education, moving beyond a purely digital agenda and considering sociocultural aspects (Dolgopolovas and Dagiene, 2021).

Mills *et al.* (2024) conducted a meta-synthesis, an interpretive analytical technique, to examine qualitative findings from multiple peer-reviewed studies on integrating coding and CT across the curriculum. This approach aims to identify broader patterns and provide a more profound understanding than individual studies. Dolgopolovas and Dagiene (2021) employed multimodal discourse analysis to explore narratives and online resources related to the future of CT education, focusing on uncovering underlying meanings and intentions.

The "ComeThinkAgain" (CTA) project utilizes a mixed-methods approach for data collection and evaluation, combining qualitative and quantitative measures analyzed through descriptive and inferential statistics, content analysis, and triangulation (Burgsteiner *et al.*, 2024). Triangulation enhances the validity and reliability of findings by using multiple data sources and methods (Burgsteiner *et al.*, 2024; Greene *et al.*, 1989).

A study aiming to develop a strategy for implementing AI in higher education business education to improve students' CT skills utilized a literature review involving a structured process of identifying, selecting, and analyzing relevant research articles. This often involves searching databases and critically analyzing collected articles on the Application of Artificial Intelligence in higher education business education to improve students' CT (Alexander, 2020; Schlosser *et al.*, 2006).

There are concerns about Artificial Intelligence (AI) and current developments in AI with Computational Thinking. According to Boddington (2017a, 2017b) stated that "AI encompasses a wide range of applications, of very varying natures, which means that there will be complex debates about its benefits and risks. Some of the many and varied current initiatives concerned more specifically with AI and ethics are briefly introduced. There are diverse approaches to tackling ethical issues in AI which may complement the development of codes of ethics." This concern was considered in this study.

Philbin (2021b) utilized a case study to explore key aspects of technology evaluation within EE for engineers. Case studies provide rich contextual understanding and can generate insights that are applicable to broader settings (Cousin, 2005). Several sources have emphasized the importance of conceptual frameworks in guiding research (Alexander, 2020). Furthermore, the development and evaluation of educational tools and interventions are common research themes. The "Easy Access" application (Burgsteiner, Spieler, and Messer-Misak, 2015) and the "ComeThinkAgain-CETS" training and certification system (Burgsteiner *et al.*, 2024) are examples of such initiatives. The impact of training on self-efficacy in CT with short-term duration, programming, and entrepreneurship has also been investigated using a quasi-experimental design with pre- and post-tests (Huruzoğlu, 2019).

Research gaps

One significant gap pertains to the implementation and impact of CT in diverse educational settings and curricula in the country. While there is growing global interest in integrating CT, Mills *et al.* (2024) noted a lack of published systematic reviews examining the evidence of its strategic integration across various curricula. They emphasized the need for research that systematizes the various aspects of learning environments to develop algorithmic expertise and other learning outcomes when coding is embedded into different subjects. Furthermore, Dolgopolovas and Dagiene (2021) point out that existing research may not fully capture non-systemic narratives and perspectives on the future of CT education, as their study was limited to English-speaking participants. They suggest that a broader search in other languages is important for uncovering diverse perspectives on this topic.

The analysis highlighted gaps in understanding the pedagogical constraints and effective teaching methods for CT and EE. (Mills *et al.*, 2024) identified several recurring pedagogical constraints in their meta-synthesis, including fewer teacher and student skills, knowledge, experience, creativity, technology context difficulties and time constraints. Sarri *et al.* (2020) emphasize that teachers need to be adequately trained in EE to ensure effective delivery and facilitation of learning, suggesting a need for more research on effective teacher training programs and their impact on student outcomes in EE.

The relationship between CT, entrepreneurship, and other skills, such as digital literacy, requires further exploration. While Wardana and Ayuni (2020) found a mediating role of CT between EE and digital literacy on business sustainability among Indonesian homemakers, more research is needed to understand these complex interrelationships in different contexts and with various populations. The CTA project (Burgsteiner *et al.*, 2024) aims to address the challenges of defining and teaching new skills in CT, EE, and green skills. However, the outcomes and effectiveness of its standardized training and certification system (CTA-CETS) have yet to be fully evaluated, as the project is in its initial stages.

Another research gap exists in understanding the long-term impact and sustainability of interventions that foster CT and EE. Huruzoğlu (2019) investigated the impact of training on self-efficacy in CT with short-term programs, programming, and entrepreneurship; however, the lasting effects of such interventions require further study. Similarly, while Bentz (2024) presented a didactically reduced business model canvas incorporating CT for hackathons, the long-term effectiveness of such approaches in fostering sustainable entrepreneurship and problem-solving skills requires further research.

Further research is needed to assess CT. Dolgopolovas and Dagiene (2021) note the ongoing discussion and lack of consensus on the scope of CT. This lack of a clear definition and scope makes it challenging to develop standardized and reliable assessment methods. Mills *et al.* (2024) also highlight that conceptual frameworks for CT are often poorly delineated in research studies, further complicating assessment efforts.

According to Mittelstadt *et al.* (2016), "Algorithms increasingly mediate digital life and decision-making. A review of existing discussions on the ethical aspects of algorithms, a prescriptive map to organize the discussion, and a critical assessment of the literature to identify areas requiring further work to develop the ethics of algorithms are the three contributions to clarify the ethical importance of this mediation."

Research methodology

The researchers surveyed the literature using the Emerald open-access databases, SCOPUS, SCIMAGO, Sage, and Google Scholar. Furthermore, researchers have used IT tools such as "Litmaps" and "connectedpapers" to map relevant papers. To conduct an exploratory study on the synthesis of current research and trends, this literature survey selected and reviewed research papers and project summary reports of relevant sources. Researchers used thematic, discourse, and comparative analyses for the exploratory research method, which was adopted to draw inferences and conclusions. A Comparative Analysis was performed using the IT tool Zotero to identify research gaps.

According to Braun and Clarke (2006), “Thematic analysis stands as a flexible and widely used qualitative method for identifying, analyzing, and reporting recurring patterns of meaning, or ‘themes’, within qualitative data. Its primary focus lies in discerning these patterns across various data sets, moving beyond surface-level observations to uncover deeper insights”. Researchers have used this analytical approach, which is particularly valuable for exploring complex phenomena and gaining a nuanced understanding of CT-integrated EE. Researchers used steps with familiarization, coding, and generating and reviewing themes with naming. Practicing reflexivity through research journals, a clear audit trail of methodological decisions and analytical steps, reliability checks, and resolving discrepancies are the strategies that researchers used for the thematic analysis.

First, the researchers collected and organized relevant papers into specific collections and sub-collections with the thematic process of analysis based on “integrated CT and EE.’ Using Zotero’s PDF reader, key findings, arguments, and data points were annotated and highlighted directly within each paper. Tags and notes are employed to categorize and link specific comparative elements across multiple documents. By filtering or searching these tags and notes, researchers can surface and compare insights from different papers, effectively identifying commonalities, divergences, and unique contributions for their analysis.

The mixed research methodology was further used with various approaches and techniques in most of the referenced papers. The choice of this methodology was based on the inquiry of “integration of CT in EE” with ethical considerations and outcomes with comparative analysis. Generally, “Contemporary research utilizes diverse methods, including mixed-methods, systematic literature reviews, and case studies” (Burgsteiner *et al.*, 2024; Philbin, 2021a; Wardana *et al.*, 2024; Mills *et al.*, 2024). This Mixed-methods research methodology offered a better understanding of the scope and limits of the references set by the researchers to identify research gaps. This study aimed to develop a strategy for implementing AI in business education to enhance students’ CT skills and employed case study research. This was the main inclusion criterion for the study.

Analysis

Based on the theoretical grounding and exploratory objectives, researchers used mixed comparative and data-driven inductive thematic analysis, which is suitable for exploring new or under-researched areas, such as novel models of CT integration in entrepreneurship education, allowing themes to genuinely surface without imposing preexisting structures. The key criteria for trustworthiness included credibility, transferability, and dependability for the consistency and repeatability of the findings. Comparative Analysis is useful for illuminating similarities and differences across cases to generate transferable knowledge and inform practical applications, particularly in policy and educational design. In this research on CT-integrated EE, this means comparing various cases with curricula, pedagogical models or student outcomes across different institutions or regions.

Several sources have addressed the concept of CT and its definition. The researchers used thematic, discourse, and comparative analyses in this study. The Erasmus+ project “Come Think Again” (CTA), which includes CT Skills (CT) as one of its three pillars, aims to develop a standardized training and certification system (CTA-CETS). This study emphasizes that CT is a fundamental skill for everyone, not just computer scientists. The “Computational Thinking Requirement” report details MIT’s exploration of incorporating a CT requirement for all undergraduates, acknowledging that CT involves more than just computer programming skills and should be an intellectual framework for all disciplines.

This report also notes the diversity in the meaning of CT across different disciplines. Dolgopolovas and Dagiene (2021) analyze the discourse surrounding the future of CT education, highlighting the multimodality of CT as a semiotic entity.

The integration of CT into education was a key theme across multiple sources. Mills *et al.* (2024) present a meta-synthesis reviewing international research on coding and CT across the curriculum, noting a lack of systematic reviews on its strategic integration. The study by Wardana and Ayuni (2020) in "Entrepreneurship Education Digital Literacy" investigates the mediating role of CT between EE and digital literacy on business sustainability among housewives in Indonesia, finding a significant positive relationship. The paper "Designing technology EE using CT" by Kang and Lee (2020) proposes a framework for integrating CT into technology EE, arguing that CT skills can enhance entrepreneurial problem-solving and innovation. Bentz (2024) discusses fostering problem-solving skills through sustainable entrepreneurship and CT in K-12 education.

The CTA project also focuses on EE and Innovation Skills as a core pillar, alongside CT and green skills, aiming for cross-sectoral collaboration and standardized training. Philbin (2021b) emphasizes project-based learning in this context. Kang and Lee (2020) specifically focus on designing technology EE using CT. Huruzoğlu (2019) investigated the impact of training on students' and teachers' self-efficacy in CT, programming, and entrepreneurship.

Pedagogical constraints and approaches are also discussed in this paper. Mills *et al.* (2024) identified pedagogical constraints in teaching coding and CT, including a lack of teacher and student skills, technology issues, and time constraints. Sarri *et al.* (2020) emphasize the need for adequately trained teachers in EE. The CTA project adopts a train-the-trainer approach, inspired by the International Certification of Digital Literacy (ICDL), and utilizes blended learning, MOOCs, and other methodologies. CT assessment is challenging. The MIT report questioned CT's key elements and measurable outcomes of CT. Dolgopolovas and Dagiene (2021) note that the ongoing discussion and lack of consensus on CT's scope make assessment difficult.

Wardana and Ayuni (2020) highlight the interconnectedness of CT, EE, and digital literacy, finding that CT mediates the relationship between EE and digital literacy on business sustainability. Mills *et al.* (2024) also consider a digital literacies lens in the context of coding and CT, emphasizing its role in navigating the digital environment and enabling multiple learning modes.

Table 1 of the Comparative Framework Matrix for CT Integrated EE Programs shows that researchers should define the specific parameters of comparison, ensure consistency, and focus across cases. The inclusion of "Qualitative Insights/Observations" allows for the direct integration of findings from thematic and comparative analyses into the matrix framework, offering a holistic perspective.

Key findings

Several studies have highlighted the growing importance of CT as a fundamental skill in today's technologically advanced world. "CT for a Computational World" defines CT as a method for critically solving problems, designing innovative systems and understanding human behavior better by drawing on computer science concepts, emphasizing its relevance beyond just computer scientists. The CTA recognizes CT as a central pillar and aims to develop CTA-CETS alongside entrepreneurship and green skills.

Research emphasizes the integration of CT into various educational settings and its impact on learning outcomes. A meta-synthesis by Mills *et al.* (2024) reviewed international research on coding and CT across the curriculum, seeking to systematize the features of learning environments that foster coding expertise and other learning outcomes when coding

Table 1. Comparative framework matrix for CT integrated EE programs

Program/case	CT integration model	Pedagogical approach	Target audience	Entrepreneurial outcomes	Qualitative insights/observations
University CT integrated entrepreneurship program	CT embedded in projects	Problem-based learning, mentorship-driven	Undergraduate STEM	High innovation mindset scores, several startup launches	Themes: "iterative problem-solving," "network building." Discourses: strong emphasis on "disruption" and "market opportunity"
Online CT integrated startup incubator	Dedicated CT course, CT as a cross-curricular theme	Case studies, self-paced modules	Adult learners, aspiring entrepreneurs	Moderate startup success rate, high skill acquisition	Themes: "flexibility," "practical application." Discourses: focus on "lean startup" principles," digital transformation"
High school CT integrated innovation lab	CT embedded in projects	Project-based learning, design thinking	High school students	Increased creativity scores, social impact projects	Themes: "collaborative learning," "real-world impact." Discourses: "design for good," "community solutions"
Community college CT integrated entrepreneurship track	CT as a cross-curricular theme	Experiential learning, local business partnerships	Diverse adult learners	Local business creation, community engagement	Themes: "local relevance," "sustainable growth." Discourses: "community wealth," "inclusive innovation"

Source(s): Authors' own work

is embedded in subjects such as science or history. This meta-synthesis identified several key features of successful learning environments, including the importance of distributed expertise and student-driven learning, supported by timely instruction. Wardana and Ayuni (2020) found a significant positive relationship between EE, digital literacy, CT, and business sustainability among Indonesian homemakers, with CT mediating the relationship between EE and business sustainability and between digital literacy and business sustainability. Kang and Lee (2020) proposed a framework for designing technology EE using CT, arguing that CT skills can enhance entrepreneurial problem-solving and innovation. Bentz (2024) also discusses the importance of fostering problem-solving skills through sustainable entrepreneurship and CT in K-12 education.

EE is recognized as important for developing skills and attitudes that contribute to personal and professional growth beyond starting a business. Philbin (2021a) highlights the use of project-based learning in EE for engineers, focusing on technology evaluation and commercialization. Sarri *et al.* (2020) emphasize the need for adequately trained teachers in EE to ensure effective learning. Mills *et al.* (2024) identified several pedagogical constraints in teaching coding and CT, including a lack of teacher and student skills, technology issues, and time constraints. The CTA project addresses these issues through a train-the-trainer approach, drawing inspiration from the International Certification of Digital Literacy (ICDL) and utilizing blended learning and MOOCs.

A report on MIT's potential CT requirement raised questions about its key elements and measurable outcomes. Dolgopolovas and Dagiene (2021) also highlighted the ongoing discussion and lack of consensus on the definition of CT, which poses challenges for assessment. Finally, a study by Alonso-Galicia *et al.* (2025) compared students perceived mastery of complex thinking in entrepreneurship and engineering programs, suggesting that entrepreneurship is a valid discipline for developing scientific thinking.

"Technological and social change are closely intertwined and may impact many of our key value concepts, including those that may not at first sight be carriers of social and cultural value; in considering AI, we must watch out for such effects" (Boddington, 2017a, 2017b). This is one of the main ethical concerns regarding the application of AI in CT imaging.

Results

The results of the comparative analysis of the identified parameters are listed in Table 2. This table provides an overview of (CT) as an intellectual framework beyond programming, which is crucial for problem-solving in a digital world. Entrepreneurship Education (EE) cultivates growth and innovation. Research highlights the synergy between CT and EE, enhancing business sustainability and entrepreneurial problem-solving. Initiatives like CTA integrate these skills, while pedagogical constraints like teacher skills and assessment are also considered.

Discussion

One prominent area of discussion in several studies is the definition and significance of CT. Multiple sources emphasize that CT is more than just computer programming skill. A report from MIT highlights the view that CT encompasses an intellectual framework applicable across all disciplines, not merely a specific skill. It involves "Computational modes of Analysis," "Algorithmic reasoning," "Data abstraction," and "Designing Computational solutions to theoretical and practical problems." The literature review by Grover and Pea (2013) also notes the preference for the term "CT" over "Computational Literacy" in research and practice. This broader understanding of CT suggests its potential relevance and application in diverse fields of study and professional endeavors.

Table 2. Results of the identified parameters of the comparative analysis

Parameters	Results
Computational thinking (CT) definition and significance	CT is recognized as a fundamental skill for solving problems, designing systems and understanding human behavior, extending beyond programming to be an intellectual framework applicable across disciplines
	The Erasmus+ project "ComeThinkAgain" (CTA) positions CT as a central pillar, aiming to develop a standardized training and certification system (CTA-CETS) for it
	There is an ongoing discussion and lack of consensus on the precise definition and measurable outcomes of CT, posing challenges for its assessment
Integration of CT into education and learning outcomes	A meta-synthesis of international research on coding and CT across the curriculum identified key features of successful learning environments, including distributed expertise and student-driven learning supported by timely instruction
	Many studies reviewed position CT for problem-solving, creative, and critical thinking as key learning outcomes
Synergy between CT, entrepreneurship education (EE), and digital literacy	CT mediates the significant positive relationship between EE and business sustainability, and between digital literacy and business sustainability, as observed among Indonesian homemakers
	CT skills can enhance entrepreneurial problem-solving and innovation, with frameworks proposed for designing technology EE using CT
	Fostering problem-solving skills through sustainable entrepreneurship and CT is important in K-12 education
	Entrepreneurship is considered a valid discipline for developing scientific thinking, comparable to engineering programs in fostering complex thinking
Entrepreneurship education (EE) focus and pedagogical approaches	EE contributes to personal and professional growth by cultivating skills and attitudes beyond mere business creation
	Project-based learning is a key approach in EE for engineers, focusing on technology evaluation and commercialization
	The "ComeThinkAgain" (CTA) project includes EE and innovation skills as a core component for cross-sectoral collaboration
Pedagogical constraints and solutions in CT/EE education	Recurring pedagogical constraints in teaching coding and CT include a lack of teacher and student skills, technology issues, and time constraints
	The CTA project addresses these constraints through a train-the-trainer approach, drawing inspiration from the international certification of digital literacy (ICDL) and utilizing blended learning and MOOCs
	Adequately trained teachers are emphasized as essential for effective EE delivery
Impact of educational interventions on Self-Efficacy	Short-term training has been found to significantly increase student and teacher self-efficacy in CT, programming, and entrepreneurship, with increases potentially sustained over time

Source(s): Authors' own work

The CTA project fosters strategic collaboration between higher education, vocational training, enterprises and research organizations. It is developing a CTA-CETS covering CT Skills, EE and Innovation Skills, and Social Responsibility, Sustainability and Green Skills aligned with European reference frameworks such as DigComp, EntreComp, and the European Sustainability Competence Framework. A train-the-trainer approach utilizing blended learning, MOOCs, and micro-certifications was central to the project's implementation and evaluation through a mixed-methods approach. "CT resembles a new philosophy that approaches not only scientific problems but also the challenges of everyday life. In recent years, CT has become a fundamental skill for all. Observing that, the educational community has been interested in the design of appropriate teaching and pedagogical strategies by incorporating procedures for cultivating and developing CT during the learning process." (Kotini and Tzelepi, 2015).

A meta-synthesis by Mills *et al.* (2024) reviewed international research on coding and CT across the curriculum, aiming to systematize the features of learning environments that foster coding expertise and other learning outcomes when coding is embedded in subjects such as science or history. This study also discusses the pedagogical constraints encountered when teaching coding and CT. Mills *et al.* (2024) identified several recurring constraints, including a lack of teacher and student skills, knowledge, experience, and creativity, as well as technology-related difficulties and time constraints. The CTA project attempts to address these challenges through a train-the-trainer approach, drawing inspiration from the International Certification of Digital Literacy (ICDL) and utilizing blended learning and MOOCs.

A particularly insightful discussion emerges at the intersection of CT and EE. Wardana and Ayuni (2020) found a significant positive relationship between EE, digital literacy, CT, and business sustainability among homemakers in Indonesia, with CT mediating the relationship between EE and business sustainability, as well as between digital literacy and business sustainability. Kang and Lee (2020) proposed a framework for designing technology EE using CT, arguing that CT skills can enhance entrepreneurial problem-solving and innovation. Bentz (2024) also emphasizes fostering problem-solving skills through sustainable entrepreneurship and CT in K-12 education. Philbin (2021a) highlighted project-based learning in EE for engineers, focusing on technology evaluation and commercialization, suggesting practical applications of entrepreneurial thinking in technical fields. Alonso-Galicia *et al.* (2025) further contribute to this discussion by comparing students perceived mastery of complex thinking in entrepreneurship and engineering programs, suggesting that entrepreneurship is a valid discipline for developing scientific thinking, on par with STEM fields.

However, the discussion also reveals the ongoing challenges and future directions of CT education. The MIT report raised fundamental questions regarding the key elements and measurable outcomes of CT. Dolgopolovas and Dagiene (2021) highlighted the ongoing discussion and lack of consensus on the definition of CT, which poses challenges for assessment and future development. Their discourse analysis suggests that the evolution of CT education is influenced by various implicit interests and political motivations, emphasizing the need to consider epistemic, semiotic and sociocultural aspects. They also noted that metaphorical aspects can be important drivers in the constitutive development of CT.

Research implications

This study has research implications for practice, longitudinal studies, assessments, and ethics. In practice, for curriculum designers, research suggests strategically integrating Computational Thinking (CT) and Entrepreneurship Education (EE) across various subjects to foster problem-solving, critical thinking and innovation, extending beyond STEM. Project-based learning and capstone courses are effective in developing multidisciplinary skills and entrepreneurial action. Curricula should align with established European frameworks, such as DigComp and EntreComp. It is imperative to address pedagogical constraints, such as insufficient teacher skills, knowledge, and time for teacher training. Implementing "train-the-trainer" approaches utilizing blended learning, e-learning, and MOOCs can enhance teacher capabilities. Notably, even brief targeted interventions significantly increase teachers and students' self-efficacy in CT and entrepreneurship.

This study highlights a significant gap in understanding the long-term impact and sustainability of interventions that foster CT and EE. While some studies show immediate positive effects on self-efficacy, further research is needed to determine the lasting effects of short-term training and other pedagogical approaches on developing sustainable entrepreneurial and problem-solving skills for longitudinal studies. Regarding assessments, a crucial implication is the need for clearer conceptual frameworks and a greater consensus on the scope and definition of CT. This lack of clarity complicates the development of standardized and reliable assessment methods for CT skills. Future research should focus on establishing well-delineated frameworks to enable more effective and consistent assessment.

This study highlights the importance of integrating Social Responsibility, Sustainability, and Green Skills within CT and EE curricula, aligning with frameworks such as the European Sustainability Competence Framework. Regarding equity in access to CT education, research implies a need to address pedagogical constraints, such as insufficient teacher and student skills, knowledge, and technology difficulties, which can perpetuate educational disparities4. Further investigation is needed into the sociocultural aspects influencing CT education and the ethical implications of algorithmic decision-making, particularly concerning AI tools, such as virtual coaches for entrepreneurs.

Conclusion

This study provides insight into addressing the challenges posed by digitization, production innovations, and climate change by fostering strategic collaboration between Higher Education, Vocational Education and Training, enterprises, and research organizations regarding core themes of the CT integrated curriculum of entrepreneurship development. The CTA project aims to develop, implement, and evaluate cross-sectoral CTA-CETS for CT Skills, EE and Innovation Skills, and Social Responsibility, Sustainability and Green Skills. In the context of CT-integrated EE, "the interdisciplinary pedagogy can guide business schools to improve the quality of programming-related modules, enhance students' performance, and prepare them for future careers" (Luo and Adelopo, 2025).

The importance of CT as a fundamental intellectual framework for all graduates extends beyond programming skills to encompass algorithmic reasoning, data abstraction and the design of computational solutions. This aligns with the "CT for a Computational World" view, which posits that understanding and applying CT is crucial for young and working adults in an increasingly computational world. This study defines CT as a method of solving critical problems, innovatively designing systems, and understanding human behavior, drawing on computer science concepts, considering it a fundamental skill for everyone, and thus exploring the diverse perspectives on the integrated CT with EE. "Students' Software (SW)-centred social adaptation ability refers to understanding computational thinking and solving complex problems using the SW programming language." (Bae and Choi, 2025).

The integration of CT with other disciplines, particularly entrepreneurship, is a recurring theme in the literature. This study argues for empowering K–12 students by fostering problem-solving skills through sustainable entrepreneurship and CT. Wardana *et al.* (2024) demonstrated through a study of Indonesian homemakers that EE and digital literacy significantly and positively affect CT skills and business sustainability, with CT mediating this relationship. This suggests that CT is a crucial link between entrepreneurial knowledge and the ability to sustain businesses in the digital age. The design of technology EE using CT in higher education emphasizes the importance of capstone courses in bridging the gap between engineering and entrepeneurship. "One of the benefits of CT for non-programmers is that the formulated problem can be passed on to information-processing agents, such as third-party companies or freelancers, who can create the solution." (Nuar and Abd Rozan, 2019, December) EE benefits engineers by acquiring transferable skills relevant to technology evaluation and commercialization through project-based learning. It was analyzed in various contexts.

The development of CT skills is also linked to self-efficacy. Short-term training can significantly increase student and teacher self-efficacy in CT, programming, and entrepreneurship, and this increase can be sustained over time. "Developing scientific thinking in entrepreneurship training could strengthen the capacities and skills of students in educational institutions." This underscores the importance of targeted educational interventions in fostering confidence in these critical areas (Alonso-Galicia *et al.*, 2025). According to Fayolle and Gailly (2008), "there is a need to reconsider entrepreneurship education in its wide diversity, both from an ontological and pedagogical point-of-view. The range of theoretical choices, objectives, publics, pedagogical methods and institutional context should be approached through the lenses of multiple teaching models and learning processes, which can be structured around a general framework.'' A meta-synthesis of research on coding and CT across the curriculum identifies key features of learning environments, their impact on learning outcomes, pedagogical constraints and the underlying learning approaches. Their findings emphasize the need for distributed expertise, student-driven learning with explicit instruction, early teaching of problem-solving skills and balancing predictive thinking.

The integration of CT into EE shapes ethical reasoning by exposing future innovators to algorithmic bias, necessitating a proactive focus on fairness and XAI. Algorithmic thinking can perpetuate societal inequalities if not ethically guided, impacting critical entrepreneurial decisions in areas such as hiring and finance. Excluding under-resourced schools from CT programs risks widening the digital divide, exacerbating academic and economic disparities, and limiting access to high-paying jobs for marginalized students. To mitigate these issues, CT education must be rooted in the principles of human rights, transparency, accountability and nondiscrimination. This requires designing inclusive systems, using diverse data sets, fostering human oversight and integrating ethical frameworks from the outset of venture development to ensure responsible innovation and equitable opportunities.

A thematic and comparative analysis perspective on the future of CT education suggests moving beyond the purely digital agenda to consider broader epistemic, semiotic and sociocultural aspects. The development of tools such as virtual coaches also indicates efforts to support novice entrepreneurs through AI-driven assistance.

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