Empowering Vocational Students

Subjects: Education & Educational Research
Contributor: Seppe Hermans, Tom Neutens, Francis wyffels, Peter Van Petegem

Vocational Education and Training (VET) faces significant challenges in equipping individuals for modern workplaces, which increasingly require digital literacy and Computational Thinking (CT) skills. A methodology primarily involves a systematic literature review, resulting in the identification of 29 relevant papers. Through qualitative content analysis, researchers develop a CT integration framework that connects CT practices and integration elements to the engineering design process, while highlighting the VET context. Arguably, the innovative aspect of this framework lies in its core dimensions of harnessing computational power for enhanced efficiency. Raising the question of whether computers can optimize the efficiency and effectiveness of specific tasks is paramount for addressing challenges in technology-rich environments. Therefore, this inquiry merits unwavering attention at every stage of the process. The proposed framework provides educators with a structured approach to identify integration opportunities and help prepare students for multifaceted vocational careers. Furthermore, other key findings underscore the inherently interdisciplinary nature of VET, the growing demand for STEM competencies, and the transformative potential of CT integration. Implications emphasize the need for further research, supportive policies, and practical CT integration.

Keywords: computational thinking ; computing literacy ; STEM ; VET

1. Introduction

In an ever-evolving and highly competitive society, job requirements are undergoing significant shifts to keep pace with rapid technological advancements. Developments in genetics, artificial intelligence, robotics, nanotechnology, and biotechnology, among others, are reshaping the global economy, marking the advent of what the World Economic Forum [1] has termed the Fourth Industrial Revolution.

Within this fast-changing landscape, industry expectations have soared. Being technically and technologically educated today is no longer sufficient to secure future job success [2]. Workers must possess the ability to learn swiftly, adapt, and grasp intricate new technologies [3]. Vocational Education and Training (VET), which equips individuals to enter the workforce, must therefore also be agile and forward thinking in response to these evolving demands. Those entering the labor market require immediate job skills in addition to competencies commonly referred to as 21st-century skills [4][5], but implementing 21st-century skills competences in VET programs is not without challenges [6].

Regarding technological advances and changing job demands, the ability to solve problems in technology-rich environments has been identified as a crucial skill [5][6][7]. Moreover, as the technologies that drive this revolution are predominately digital in nature (e.g., The Internet of Things, big data, cloud computing, artificial intelligence) [8][9], education has shifted its attention to the skills required to understand these technologies and solve problems in technology-rich environments. This set of digital skills can be grouped under the term computational thinking (CT) and are gaining importance in many national curricula [10][11]. Yadav et al. [12] argued that CT is an inseparable part of digital literacy and should be an important competence domain within VET, but much of the educational research concerning this 21st-century skillset fails to address the specific challenges associated with VET. In preliminary literature search, researchers explored several databases, including ERIC, Web of Science, and ACM Digital Library, using the following query: (“Vocational education” OR “VET” OR “Career education”) AND (Publication Type: “Journal Articles”). While each of these search terms generated a substantial amount of material when used individually, researchers observed that combining these specific terms resulted in a notably limited number of publications. Although in the last decade there has been an enormous growth in interest and research on CT in education [10], attention on CT in VET is lacking [10][12]. Moreover, previous research has shown that VET-trained adults score lower on the ability to use digital technology, communication tools, and networks to acquire and evaluate information, communicate with others, and perform practical tasks [2]. Given the role of computing in VET occupations, the competence to solve problems in technology-rich environments is essential.

The literature indicates, however, a growing trend in fostering students' CT in Science, Technology, Engineering, and Mathematics (STEM) [10][13][14]. An integrated STEM approach can serve as a valuable guide for incorporating CT into VET. Internationally, STEM education has garnered significant attention from education ministries due to the recognition of STEM-related competencies as being crucial for economic growth and global workforce competitiveness [15]. Furthermore, STEM education exhibits a natural synergy with VET [16], particularly in technical VET branches such as industrial automation and mechatronics. Even non-technical VET branches intersect with STEM disciplines. For instance, healthcare incorporates medical technology, logistics management utilizes data analysis, and environmental sciences apply scientific principles. Moreover, STEM education is defined as inclusive of society as a whole, aiming not only to provide technical skills for occupations in demand (such as electricians and data scientists) but also to enhance the foundational capacity for life and work in general. As indicated by Siekmann [17], "STEM education aims to improve scientific and technical literacy for all" (p. 6).

2. How Is CT and STEM Education Related to VET, and Which Connections can Be Identified?

2.1. STEM–VET

This section offers a comprehensive exploration of the STEM–VET intersection. Firstly, both Chondrogiannis et al. [18] and Asunda [19] contribute significantly to the STEM–VET intersection by emphasizing the interdisciplinary nature of VET. Chondrogiannis et al. [18] highlight the inherent involvement of all four STEM subjects in agricultural education, underscoring the importance of STEM integration in VET. Asunda [19] recognizes the relevance of VET programs to STEM-related careers, acknowledging that VET encompasses science, mathematics, and technology components to cater to diverse career paths.

Secondly, including Chondrogiannis et al. [18], Asunda [19], Reiss and Mujtaba [20], and Wannapiroon et al. [21] collectively emphasize the overarching theme that societal and industrial evolution is reshaping the landscape of VET. This transformation is accompanied by a growing demand for STEM-related competencies within the VET domain, encompassing essential skills such as problem-solving, critical thinking, and technological literacy. Chondrogiannis et al. [18] highlight the transformative impact of Education 4.0 in addressing educational gaps and adapting to the evolving demands of agricultural careers. Asunda [19] underscores the increasing need for technical and critical thinking skills in the 21st-century workplace, advocating for STEM integration in VET programs. Reiss and Mujtaba [20] delve into the significance of incorporating careers education into STEM, addressing the limitations of non-specific career guidance in VET. Wannapiroon et al. [21] emphasize the necessity for a mindset shift among vocational educators, promoting innovation and interdisciplinary skills, including STEM, to meet the evolving demands of the industry.

Lastly, a pivotal theme on which both Asunda [19] and Wannapiroon et al. [21] converge is the increasing demand for STEM-related vocations, necessitating a qualitative educational approach to attract and retain students in these fields. Asunda [19] cites the Association of Career and Technical Education, highlighting that infusing STEM concepts into VET curricula enhances students' STEM literacy and encourages them to consider STEM-related careers. In alignment with this perspective, Wannapiroon et al. [21] argue that the hands-on, skill-oriented nature of STEM education makes it a fitting choice for vocational education. They propose that this approach benefits not only foundational subjects but also job-specific ones, reinforcing the notion that a high-quality, pragmatic STEM-focused education better prepares vocational students for successful careers in STEM fields.

2.2. CT–VET

This section delves into the intersection of CT and VET through three key themes. Firstly, CT emerges as a vital 21st-century skill with relevance even in VET contexts. Yadav et al. [12] stress the significance of introducing CT concepts early in education, advocating for its integration, including Information Technology and Computer Science, from primary school onwards. Additionally, Pöllänen and Pöllänen [22] shed light on Finland's National Core Curriculum, where technology integration transcends disciplinary boundaries, highlighting the cross-disciplinary importance of CT in education. These findings underscore CT's role as a universal 21st-century skill, accessible across all educational levels, from primary education to VET, to prepare individuals for an increasingly digital world.

Secondly, the evolving societal and industrial landscape reshapes the demands placed on VET, accentuating the need for CT-related skills. This theme resonates across multiple papers. Chondrogiannis et al. [18] emphasize CT's critical role in addressing the requirements of Agriculture 4.0, characterized by digitalization, IoT, robotics, and AI. They also highlight the synergy between CT, STEM, and Agricultural Education and Training (AET), enhancing the problem-solving skills crucial for future agricultural careers. Yadav et al. [12] point out that individuals with only VET qualifications may find themselves ill-prepared for the rapidly changing 21st-century job market. This drives the imperative for VET programs to incorporate CT and related skills, equipping students with essential technical expertise. Pöllänen and Pöllänen [22] argue that CT is indispensable in the 21st century due to the ubiquity of information, technology, and automation in the workforce. They stress the importance of educational systems in training students with adaptable technical competencies. Additionally, they highlight emerging technologies, digital design tools, and 3D printing, underscoring the necessity of integrating CT into education to bridge the divide between traditional skills and contemporary industry demands.

Lastly, the integration of CT into VET enriches the learning experience, as evidenced in two research papers. Pöllänen and Pöllänen [22] emphasize the role of technology, programming, and hands-on applications in fostering CT-based learning experiences. Their study illustrates how specific tools can cultivate CT skills within crafts and design education. In a different context, Souza et al. [23] conducted a study on educational robotics in a Brazilian technical high school, showcasing improvements in student performance as a result of CT integration.

3. What Significant Points of Intersection and Potential Advantages Can Be Identified between CT as Nurtured within STEM Education and Its Practical Application and Integration within VET?

Regarding *problem-solving skills*, numerous papers directly link CT to problem-solving. Biddy et al. [24] even note that some teachers struggle to differentiate between CT and traditional problem-solving methods. Paltz and Pedaste [25] conducted a systematic literature review and categorized six original articles on CT [26][27][28][29][30][31]. They concluded that most of the underlying elements attributed to CT can be grouped into three categories related to problem-solving: defining the problem, solving the problem, and analyzing the problem. A similar approach is evident in the work of Yang et al. [32] and Juskevicience [33], who connect the elements of CT to the problem-solving process and design thinking. Several authors [13][14][32][33][34][35][36][37][38] have made a distinct connection between this conceptualization of problem-solving within the framework of CT and problem-solving within the context of STEM.

Furthermore, Weintrop's taxonomy [26] categorizes CT practices into four primary domains: Data practices, Modeling and simulation, Computational problem solving, and Systems thinking. This taxonomy serves as a foundational reference in 16 out of the 23 papers and provides the basis for several frameworks aimed at integrating CT into STEM education, as demonstrated in the works of Juskeviciene [36] and Yang [32]. Several authors [13][14][34] emphasize the significance of incorporating data analysis into STEM work and the direct relevance of CT. Additionally, Hutchins et al. [39] highlights the widespread use of modeling and simulation in STEM, aligning with the conclusions drawn by several other authors [13][32][34][35][39][40][41].

Another recurring theme throughout the literature is the integration of technology. Sivaraj et al. [40] advocate for the pivotal role of technology in STEM, viewing it through the lens of CT and portraying CT to harness technology for innovative solutions to address complex real-world STEM problems. This perspective is shared by several other papers [10][14][37][40][42][43]. The utilization of technology is closely linked to the concept of *Future Workforce Preparedness*, as highlighted by researchers [25][34][36][39][42][44]. They emphasize that industries are undergoing significant transformations due to technological advancements that are mainly digital in nature [1].

Moreover, four distinct studies [14][34][38][45] collectively underscore the profound *pedagogical benefits* of integrating CT into STEM education. Peel et al. [46] demonstrated that combining CT with science content led to significantly higher learning gains in understanding natural selection, suggesting its potential for broader integration in scientific processes. Cheng et al.'s meta-analysis [38] of 21 eligible studies between 2013 and May 2021 revealed a substantial positive effect of CT integration on STEM learning performance in K-12 education. Yin et al.'s experiment [41] confirmed that CT–STEM activities significantly improved both cognitive and affective learning outcomes. Hutchins et al.'s experiment [39] using the C2STEM environment showcased positive impacts on students' learning gains in kinematics and CT, promoting flexible problem-solving strategies and deeper conceptual understanding.

3.1. CT–STEM Integration Frameworks

In their literature review, Wang et al. [13] identified four significant frameworks for defining CT, much like how Paltz and Pedasta [25] categorized five influential works in their own review. It is worth noting that among these conceptualizations, only Weintrop's framework [34] offered a clear focus on STEM. As mentioned earlier, Weintrop's taxonomy of CT practices stands as a cornerstone reference, referenced in 16 out of the 23 papers, and serves as the foundational structure for various other frameworks, e.g., [32][36].

Out of the 23 articles focused on CT–STEM, nine of them present their unique frameworks or guidelines for incorporating CT into one or more STEM fields. researchers categorized these frameworks into three distinct groups: one focusing on levels of integration [47], five on computational practices and integration elements [34][37][39][42][44], and three on design thinking and the problem-solving process [25][32][33].

Regarding *integration levels*, Waterman et al. [19] addressed the challenge of integrating CT skills into already packed school curricula without standalone computer science courses. They therefore categorized their approach into three levels of CT integration:

- Exist: Recognizing existing CT concepts within lessons.
- Enhance: Adding tasks to enrich disciplinary concepts with CT connections.
- Extend: Creating new lessons that use disciplinary concepts as a basis for CT exploration.

With respect to the *design thinking and the problem-solving process*, Juskeviciene et al. [33] linked the CT practices of Weintrop et al. [34] to the design thinking process to create a framework for CT–STEM integration. Similarly, Palts et al. [25] and Yang et al. [32] provide models for developing CT skills in STEM based on the problem-solving process. By doing so, they moved away from relying on decontextualized ideas and practices and instead drew on real-world instantiations of CT by relying on the application of the practices identified in contexts distinct from computer science. Although they build on different CT components, similarities between the frameworks are apparent. They all describe how CT components that focus on forming and solving problems can be mapped on to one or more engineering design processes. Yang et al. [32] point out that the mapping of one CT component onto a specific engineering design process does not mean that this CT will not be used in other processes. The manifestation of CT practices is very much dependent on the specific tasks at hand. According to them the main benefit of mapping CT on the engineering design process is to be able to recognize CT applications and practices in learning STEM content and solving problems.

Moreover, Lee and Malyn-Smith [42] have played a significant role in the development of integration elements. They adopted a holistic approach and introduced five CT Integration Elements (CTIEs) to serve as a bridge connecting CT skills with CT integration fields. These elements encompass understanding complex systems, innovating with computational representations, designing solutions that leverage computational power and resources, engaging in collective sense-making around data, and understanding the potential consequences of actions. Similarly, Hutchins et al. [39] focused on scientific modeling practices [48] to establish integrated domain maps and the acquisition of CT skills.

3.2. Teaching Practices

Both Wang et al. [13] and Ogegbo and Ramnarain [14] conducted reviews of the literature to investigate teaching practices used for integrating CT. While their findings are not entirely congruent, both reviews identified Modeling-Based Learning as a widely utilized practice. However, Wang et al. [13] emphasized the significant application of Problem-Based Learning, which was not noted by Ogegbo and Ramnarain [14].

4. Can the Insights from RQ1 and RQ2 Inform the Development of a Comprehensive Framework for CT Integration within an Integrated STEM Curriculum in VET Programs?

By delving into the inquiry posed by Research Question 1 and Research Question 2, a collection of distinctive and valuable insights has arisen, presenting singular viewpoints regarding the incorporation of CT within Vocational VET, facilitated through the prism of STEM methodologies.

Moreover, Lee and Malyn-Smith's introduction of CT Integration Elements (CTIEs) [42], including understanding complex systems, innovating with computational representations, designing solutions, sense-making around data, and understanding consequences, offers a holistic perspective. These elements can be applied to VET contexts to ensure a comprehensive integration of CT into STEM, catering to the specific needs of vocational students.

As educators in VET, many are potentially already incorporating various CT practices into their existing curricula. Therefore, it is crucial for them to first identify these practices. This aligns well with the categorization of CT integration levels proposed by Waterman et al. [19], which includes categories such as “Exist”, “Enhance”, and “Extend”. This framework can be adapted effectively for VET settings. It enables VET educators to evaluate the presence of CT concepts within their curriculum, enrich these concepts with CT connections, and even design new lessons rooted in CT exploration within vocational subjects. Hence, researchers propose a comprehensive framework that combines the insights from existing theoretical frameworks for integrating CT in STEM to identify CT learning opportunities and help identify and enhance CT in a VET-integrated STEM curriculum.

Distinct parts: the Engineering Design Process (1), CT Practices (2), Leveraging Computational Power (3), Integration Levels (4), and the VET Context (5). In the subsequent sections, researchers will provide detailed explanations and elaborations on each of these components.

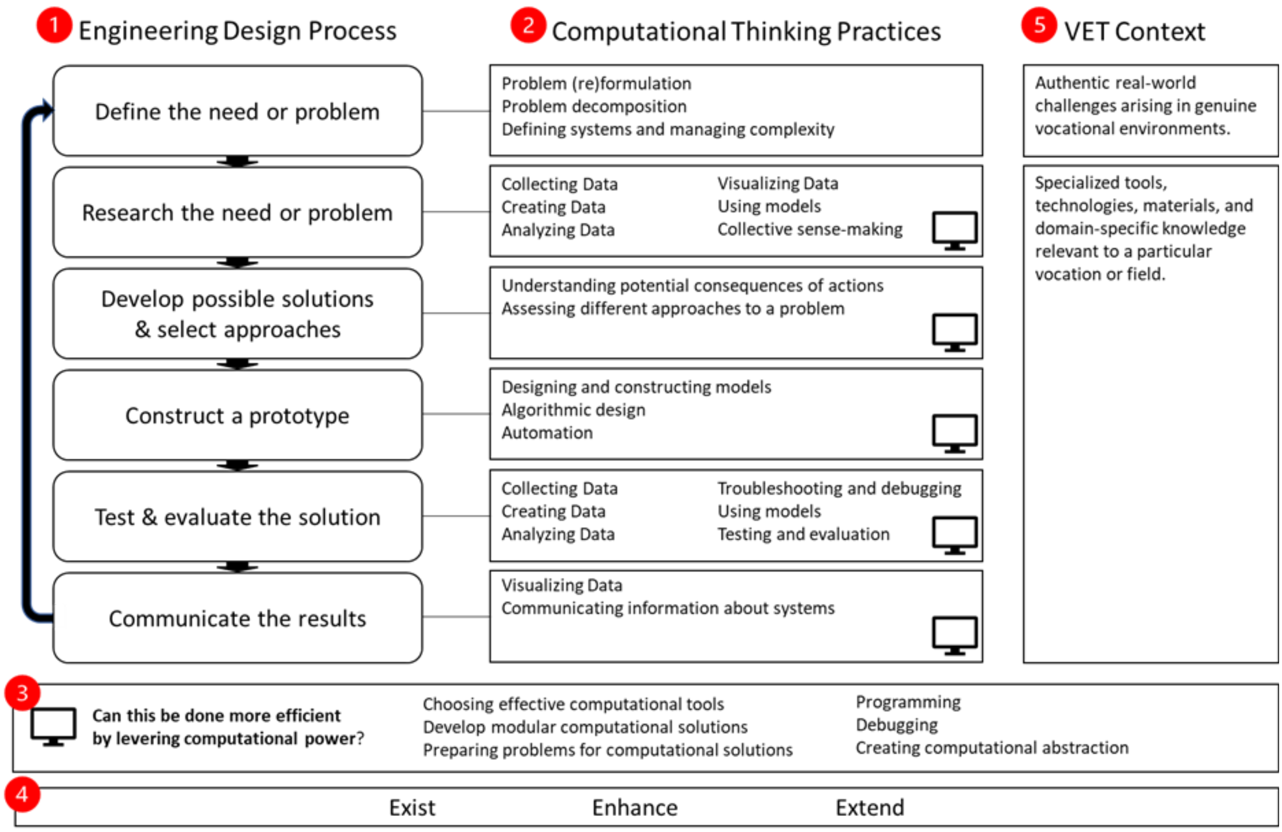

Figure 1. Combining CT and engineering design to identify and enhance CT in a VET-integrated STEM curriculum.

4.1. Engineering Design Process

Through literature review, researchers identified problem-solving and the engineering design process as common practices across various contexts. Recognizing their significance, researchers have positioned them as cornerstones of framework. This provides a structured framework for students to apply scientific principles and mathematical concepts to solve real-world problems. Moreover, it is particularly relevant in VET as it aligns with the practical, hands-on approach typically emphasized in VET.

Although several models can be found, researchers based steps of the engineering design process on those suggested by Hynes [49]. They examined the understanding and teaching of the engineering design process by middle school teachers. These steps include: Identify and define problems (1), Research the need or problem (2), Develop possible solutions (3), Select the best possible solutions (4), Construct a prototype (5), Test and evaluate the solutions (6), Communicate the solutions (7), and Redesign (8).

4.2. Computational Thinking Practices

researchers drew upon examples from Palts and Pedaste [25], Yang et al. [32], and Juskeviciene et al. [36] to align CT practices with specific phases of the problem-solving cycle, particularly within the context of the engineering design process. To structure approach, researchers leveraged Weintrop's CT taxonomy [34], which encompasses data practices, system thinking practices, modeling and simulation practices, and computational problem-solving practices. Additionally, researchers enriched this framework with CT integration elements from the work of Lee and Malyn-Smith [42], including understanding complex systems, innovating with computational representations, designing solutions that leverage computational power and resources, and engaging in collective sense-making around data, while also considering the potential consequences of actions.

4.3. Leveraging Computational Power

While many CT practices remain applicable independently of computers, “Leveraging computational power” underscores the crucial connection between CT and computer science. The elements within this framework, including choosing effective computational tools, preparing problems for computational solutions, developing modular computational solutions, programming, debugging, and creating computational abstraction, draw from Weintrop’s [50] taxonomy and Lee and Malyn-Smith’s integrative elements [42]. They prompt the question of whether computers can enhance the efficiency and effectiveness of specific tasks, exemplifying the concept of leveraging computational power in problem-solving.

4.4. Integration Levels

As Waterman et al. [47] noted that CT skills and practices are already present in existing approaches and can simply be called out or elaborated upon, this aspect was included to emphasize that integrating CT is a matter of identifying CT practices or learning opportunities in existing lessons that can then be enhanced or extended.

4.5. VET Context

While this framework holds potential beyond the confines of VET, it is critical to underscore the unique benefits that VET provides. VET stands out by offering a direct pathway to engaging with real-world challenges encountered in actual vocational settings. It grants learners access to an array of specialized tools, technologies, materials, and domain-specific knowledge that are directly relevant to their chosen vocations. In VET, the relevance of specific vocational contexts cannot be overstated; thus, the integration of domain-specific knowledge into the learning process is essential for effective problem-solving.

Domain-specific knowledge plays a pivotal role in the problem-solving process by offering the foundational background, concepts, and terminologies necessary to navigate and comprehend problems unique to a particular field. This specialized knowledge equips learners with the ability to identify, frame, and address problems in a manner that is pertinent and directly applicable to their vocational domain. Furthermore, when domain-specific knowledge is woven together with CT practices, it significantly boosts learners’ capabilities in utilizing computational tools and methodologies with greater efficacy. For instance, in a vocational course focusing on automotive technology, learners might employ simulation software to model and analyze engine performance. This process not only involves the application of computational simulations (CT practice) but also a deep engagement with automotive systems (domain-specific knowledge). Such an approach exemplifies how integrating domain-specific knowledge with CT practices not only enriches the learning experience but also ensures that learners are adept at applying theoretical knowledge to practical, real-world problems in their field. This integration is paramount in preparing students for the complex demands of their future careers, making them more adept and versatile professionals.

References

1. Hämäläinen, R.; Cincinnato, S.; Malin, A.; De Wever, B. VET Workers’ Problem-Solving Skills in Technology-Rich Environments: European Approach. Int. J. Res. Vocat. Educ. Train. 2014, 1, 57–80.
2. Boateng, C. Restructuring vocational and technical education in Ghana: The role of leadership development. Int. J. Humanit. Soc. Sci. 2012, 2, 108–114.
3. Wagiran, M.; Pardjono, M.; Suyanto, W.; Sofyan, H. Vocational Education Development Framework in 21st Century. In Proceedings of the 2017 International Conference on Technology and Vocational Teachers (ICTVT 2017), Yogyakarta, Indonesia, 28 September 2017; Atlantis Press: Amsterdam, The Netherlands, 2017.
4. Spöttl, G.; Windelband, L. The 4th industrial revolution–its impact on vocational skills. J. Educ. Work 2021, 34, 29–52.
5. Mutohhari, F.; Sutiman, S.; Nurtanto, M.; Kholifah, N.; Samsudin, A. Difficulties in Implementing 21st Century Skills Competence in Vocational Education Learning. Int. J. Eval. Res. Educ. 2021, 10, 1229–1236.
6. Novalinda, R.; Giatman, M.; Fajra, M. Problem-based learning: 21st century vocational education. Int. J. Multi Sci. 2020, 1, 12–19.
7. Alias, S.Z.; Selamat, M.N.; Alavi, K.; Arifin, K. Industry 4.0: A systematic review in technical and vocational education and training. J. Psikol. Malays. 2018, 32, 66–74.
8. Schwab, K. The Fourth Industrial Revolution; Currency: New York, NY, USA, 2017.

9. Li, Y.; Schoenfeld, A.H.; diSessa, A.A.; Graesser, A.C.; Benson, L.C.; English, L.D.; Duschl, R.A. Computational Thinking Is More about Thinking than Computing. J. STEM Educ. Res. 2020, 3, 1–18.
10. Grover, S.; Pea, R. Computational thinking in K–12: A review of the state of the field. Educ. Res. 2013, 42, 38–43.
11. Yadav, A.; Good, J.; Voogt, J.; Fisser, P. Computational Thinking as an Emerging Competence Domain. In Competence-Based Vocational and Professional Education; Springer: Cham, Switzerland, 2017; pp. 1051–1067.
12. Wang, C.; Shen, J.; Chao, J. Integrating computational thinking in STEM education: A literature review. Int. J. Sci. Math. Educ. 2022, 20, 1949–1972.
13. Ogegbo, A.A.; Ramnarain, U. A systematic review of computational thinking in science classrooms. Stud. Sci. Educ. 2022, 58, 203–230.
14. Kennedy, T.; Odell, M.R.L. Engaging Students In STEM Education. Sci. Educ. Int. 2014, 25, 246–258.
15. Akgunduz, D.; Mesutoglu, C. Science, Technology, Engineering, and Mathematics Education for Industry 4.0 in Technical and Vocational High Schools: Investigation of Teacher Professional Development. Sci. Educ. Int. 2021, 32, 172–181.
16. Siekmann, G. What Is STEM? The Need for Unpacking Its Definitions and Applications; National Centre for Vocational Education Research (NCVER): Adelaide, SA, USA, 2016.
17. Chondrogiannis, E.; Symeonaki, E.; Papachristos, D.; Loukatos, D.; Arvanitis, K.G. Computational Thinking and STEM in Agriculture Vocational Training: A Case Study in a Greek Vocational Education Institution. Eur. J. Investig. Health Psychol. Educ. 2021, 11, 230–250.
18. Asunda, P.A. Standards for Technological Literacy and STEM Education Delivery through Career and Technical Education Programs. J. Technol. Educ. 2012, 23, 44–60.
19. Reiss, M.J.; Mujtaba, T. Should We Embed Careers Education in STEM Lessons? Curric. J. 2017, 28, 137–150.
20. Wannapiroon, P.; Nilsook, P.; Techakosit, S.; Kamkhuntod, S. STEM Literacy of Students in Vocational Education. Int. J. Technol. Educ. Sci. 2021, 5, 527–549.
21. Pöllänen, S.H.; Pöllänen, K.M. Beyond Programming and Crafts: Towards Computational Thinking in Basic Education. Des. Technol. Educ. Int. J. 2019, 24, 13–32.
22. Souza, I.M.; Andrade, W.L.; Sampaio, L.M. Educational robotics applications for the development of computational thinking in a brazilian technical and vocational high school. Inform. Educ. 2022, 21, 147–177.
23. Biddy, Q.; Chakarov, A.G.; Bush, J.; Elliott, C.H.; Jacobs, J.; Recker, M.; Sumner, T.; Penuel, W. A professional development model to integrate computational thinking into middle school science through codesigned storylines. Contemp. Issues Technol. Teach. Educ. 2021, 21, 53–96.
24. Palts, T.; Pedaste, M. A Model for Developing Computational Thinking Skills. Inform. Educ. 2020, 19, 113–128.
25. Wing, J.M. Computational thinking. Commun. ACM 2006, 49, 33–35.
26. Barr, V.; Stephenson, C. Bringing computational thinking to K-12: What is involved and what is the role of the computer science education community? ACM Inroads 2011, 2, 48–54.
27. ISTE; CSTA. Operational Definition of Computational Thinking for K-12 Education; ISTE: Washington, DC, USA, 2011.
28. Brennan, K.; Resnick, M. New frameworks for studying and assessing the development of computational thinking. In Proceedings of the 2012 Annual Meeting of the American Educational Research Association, Vancouver, BC, Canada, 13–17 April 2012.
29. Selby, C.; Woollard, J. Computational Thinking: The Developing Definition; University of Southampton: Southampton, UK, 2013.
30. Moreno-León, J.; Román-González, M.; Robles, G. On computational thinking as a universal skill: A review of the latest research on this ability. In Proceedings of the 2018 IEEE Global Engineering Education Conference (EDUCON), Santa Cruz de Tenerife, Spain, 17–20 April 2018.
31. Yang, D.; Baek, Y.; Ching, Y.-H.; Swanson, S.; Chittoori, B.; Wang, S. Infusing Computational Thinking in an Integrated STEM Curriculum: User Reactions and Lessons Learned. Eur. J. STEM Educ. 2021, 6, 4.
32. Juškevičienė, A. STEAM teacher for a day: A case study of teachers' perspectives on computational thinking. Inform. Educ.-Int. J. 2020, 19, 33–50.
33. Weintrop, D.; Beheshti, E.; Horn, M.; Orton, K.; Jona, K.; Trouille, L.; Wilensky, U. Defining computational thinking for mathematics and science classrooms. J. Sci. Educ. Technol. 2016, 25, 127–147.

34. Lee, I.; Grover, S.; Martin, F.; Pillai, S.; Malyn-Smith, J. Computational Thinking from a Disciplinary Perspective: Integrating Computational Thinking in K-12 Science, Technology, Engineering, and Mathematics Education. J. Sci. Educ. Technol. 2020, 29, 1–8.
35. Juškevičienė, A.; Dagienė, V.; Dolgopolovas, V. Integrated activities in STEM environment: Methodology and implementation practice. Comput. Appl. Eng. Educ. 2021, 29, 209–228.
36. Jocius, R.; O'Byrne, W.I.; Albert, J.; Joshi, D.; Robinson, R.; Andrews, A. Infusing Computational Thinking into STEM Teaching: From Professional Development to Classroom Practice. Educ. Technol. Soc. 2022, 24, 166–179.
37. Cheng, L.; Wang, X.; Ritzhaupt, A.D. The Effects of Computational Thinking Integration in STEM on Students' Learning Performance in K-12 Education: A Meta-Analysis. J. Educ. Comput. Res. 2023, 61, 416–443.
38. Hutchins, N.M.; Biswas, G.; Maróti, M.; Lédeczi, Á.; Grover, S.; Wolf, R.; Blair, K.P.; Chin, D.; Conlin, L.; Basu, S.; et al. C2STEM: A system for synergistic learning of physics and computational thinking. J. Sci. Educ. Technol. 2020, 29, 83–100.
39. Sivaraj, R.; Ellis, J.A.; Wieselmann, J.R.; Roehrig, G.H. Computational participation and the learner-technology pairing in K-12 STEM education. Hum. Behav. Emerg. Technol. 2020, 2, 387–400.
40. Yin, Y.; Hadad, R.; Tang, X.; Lin, Q. Improving and Assessing Computational Thinking in Maker Activities: The Integration with Physics and Engineering Learning. J. Sci. Educ. Technol. 2020, 29, 189–214.
41. Lee, I.; Malyn-Smith, J. Computational Thinking Integration Patterns Along the Framework Defining Computational Thinking from a Disciplinary Perspective. J. Sci. Educ. Technol. 2020, 29, 9–18.
42. Herro, D.; Quigley, C.; Plank, H.; Abimbade, O.; Owens, A. Instructional Practices Promoting Computational Thinking in STEAM Elementary Classrooms. J. Digit. Learn. Teach. Educ. 2022, 38, 158–172.
43. Pérez, A. A Framework for Computational Thinking Dispositions in Mathematics Education. J. Res. Math. Educ. 2018, 49, 424–461.
44. Rich, K.M.; Spaepen, E.; Strickland, C.; Moran, C. Synergies and differences in mathematical and computational thinking: Implications for integrated instruction. Interact. Learn. Environ. 2020, 28, 272–283.
45. Peel, A.; Sadler, T.; Friedrichsen, P. Using Unplugged Computational Thinking to Scaffold Natural Selection Learning. Am. Biol. Teach. 2021, 83, 112–117.
46. Waterman, K.P.; Goldsmith, L.; Pasquale, M. Integrating Computational Thinking into Elementary Science Curriculum: An Examination of Activities that Support Students' Computational Thinking in the Service of Disciplinary Learning. J. Sci. Educ. Technol. 2020, 29, 53–64.
47. Sengupta, P.; Kinnebrew, J.S.; Basu, S.; Biswas, G.; Clark, D. Integrating computational thinking with K-12 science education using agent-based computation: A theoretical framework. Educ. Inf. Technol. 2013, 18, 351–380.
48. Hynes, M.M. Middle-school teachers' understanding and teaching of the engineering design process: A look at subject matter and pedagogical content knowledge. Int. J. Technol. Des. Educ. 2012, 22, 345–360.
49. Weintrop, D.; Coenraad, M.; Palmer, J.; Franklin, D. The Teacher Accessibility, Equity, and Content (TEC) Rubric for Evaluating Computing Curricula. ACM Trans. Comput. Educ. 2019, 20, 5.