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Guest Editorial: Creating Computational Thinkers for the Artificial Intelligence Era—Catalyzing the Process through Educational Technology

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ABSTRACT: There is an ongoing debate in the literature about the ways of using technology to enhance students' Computational Thinking (CT). This special issue further enriches this debate by investigating how educational technology could be used, and for which purposes, to facilitate learning CT. It includes six papers demonstrating the innovative design of curricula and the use of various technologies to teach CT for students in different educational levels. Based on these papers, this special issue points out that more research is needed to investigate the best educational practices that could be used to teach CT rather than focusing on the technology itself. It also reveals that future work could cover smart learning analytics and precision education to better model students' individual differences, hence effectively supporting learning CT.

Keywords: Computational thinking, Artificial Intelligence, Educational technology, Future education, Competencies

1. What is computational thinking? Unveiling the ambiguity

The digital transformation and the rapid evolution of Artificial Intelligence (AI) have catalyzed the use of machines in our daily activities, where computers and their algorithms have changed the way that we think to better communicate and utilize them (Tlili et al., 2022). The world is becoming more complex and unpredictable, where students should acquire the basic skills to deal with it. The thinking processes associated with the problem-solving approach of Computational Thinking (CT) allows learners to better deal with the complexity and open-ended non-trivial problems posed by the world and its emerging technologies (e.g., AI and big data). Therefore, several research studies advocated considering CT as an essential competence that should be included in all educational levels and in every student's skill set (Grover & Pea, 2018). In his constructivist work with technology, Seymour Papert (Papert, 1980) was the first to introduce CT, which then got more popularity after the researcher Jeannette Wing (Wing, 2006) published a paper in 2006 discussing CT. She argues that:

"Computational thinking 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. ... Computational thinking is a fundamental skill for everyone, not just for computer scientists. To reading, writing, and arithmetic, we should add computational thinking to every child's analytical ability. Just as the printing press facilitated the spread of the three Rs, what is appropriately incestuous about this vision is that computing and computers facilitate the spread of computational thinking." (Wing, 2006, p. 33)

CT can be confusing at it can also be related to several terms like computers and computing (Li et al., 2020) or computer science and programming (Czerkawski & Lyman, 2015). It is therefore important to further clarify these terms to readers. There is a large agreement that computing has contributed to revolutionize science. A key instance of this is the computational science movement in 1980, when several researchers claimed that computing is a new way to conduct science. Due to its significant importance, computing was considered as the "third pillar" of science (Oberkampf and Roy, 2010), the "fourth great scientific domain" (Rosenbloom, 2013), and the "most disruptive paradigm shift in the sciences since quantum mechanics" (Chazelle, 2006). Additionally, while computing has inspired researchers to look at CT, it is still not CT, *per se*. Computing is the study of natural and artificial information processing (Denning, 2007). CT, on the other hand, is much broader than that and focuses on the models and methods of processing information which could be in different formats and shapes, as well as the needed skills for that (Cansu & Cansu, 2019).

CT skills are not unique to computing and can be found in several disciplines (Li et al., 2020). In this context, Ioannidou et al. (2011) pointed out that CT skills are not the same as programming skills, but programming is a good context for helping to think computationally (Israel et al., 2015). Shute et al. (2017) further highlighted that

CT skills and concepts cover: (1) decomposition, (2) abstraction, (3) debugging, (4) iteration, (5) generalization, and (6) algorithms and their design.

Finally, while CT originates from computer science (Wing, 2006), it differs from computer science as it allows users to transfer CT skills to domains other than programming (Berland & Wilensky, 2015), such as everyday activities and problems. The misconception of CT further continued as several people considered it as "thinking like a computer" (Kite & Park, 2020), however, Wing (2006) clearly stated that this not correct raising concerns that thinking like a machine might hinder creative and divergent aspects of CT (e.g., systems thinking, problem decomposition, and abstraction). Therefore, emphasizing the difference between human thinking and computer thinking is essential in CT.

As there was no exact understanding of CT, several definitions were proposed in the literature accordingly. For instance, one of the most accepted CT definitions is that of Cuny et al. (2010, p. 1) where they considered CT as a thinking process where "…solutions are represented in a form that can be effectively carried out by an information-processing agent." This covers both well-structured problems and ill-structured problems (i.e., complicated real-life problems whose solutions are neither definite nor measurable). The National Research Council of The National Academies (NRC) considered CT as "… a fundamental analytical skill that everyone, not just computer scientists, can use to help solve problems, design systems, and understand human behavior. ... Computational thinking is likely to benefit not only other scientists but also everyone else." Berland and Wilensky (2015) further defined CT as "the ability to think with the computer-as-tool" (p. 630).

While the above-mentioned definitions (as well as those in the literature) are different to a certain extent, all of them agree that CT is a mental skill that everyone should acquire in this digital and AI era, even for non-scientists, where various tools and technologies could be used to facilitate the process.

2. Learning computational thinking and the role of educational technology

Since CT is very important and is considered by UNESCO (2021) as one of the five pillars for guiding AI and education, several countries have started teaching it, as well as its competencies in schools and universities. The need to enhance CT has been taken up at the policy level by national governments, for example in elementary schools in Sweden, as described by Kjällander et al. (2021). Finland and Australia have also joined this movement where they made computing/coding compulsory subjects in primary schools (Rich et al., 2019). Aligned with this international trend, China has deemed CT to be one of the core literacies of information technology curriculum and has included it in the National High School Information Technology Curriculum Standards (Zhang et al., 2023).

Several studies have relied on traditional tools (e.g., Lego) instead of technology, also known as unplugged activities, to teach CT (Zhang et al., 2023). They proved that CT could be taught with cost-effective approaches that are not technology centric. However, these approaches also revealed that there is a need for more sophisticated tools to better guide students in learning CT. For instance, Lee et al. (2020) reported that several STEM classrooms are failing to integrate CT into their curricula. De Jong and Jeuring (2020) revealed that more investigation is needed for new assessment methods to measure students' CT skills. There is, therefore, a need for technology that can keep track of how students learn in each step of the learning process, and analyze their learning log data to identify the learning obstacles faced, hence enhancing the learning process of CT. In this context, learning analytics comes quite effective to achieve this purpose. Additionally, as technology can foster innovative teaching methods, several studies highlighted the importance of using robots (Yang et al., 2020) or visual programming tools (Fagerlund et al., 2021), among others, to teach CT.

Other studies, on the other hand, pointed out that teaching CT requires careful design of the technology which should support multiple combinations, and offer multiple ways to solve a problem (Bers, 2020). The designed technologies need to provide opportunities for creating a computational artifact that can be shared with others and support a growing range of computational literacy skills, from beginner to expert (Bers, 2020). Hamilton et al. (2020) and Pugnali et al. (2017) reported that the issue facing educational technologists is how to select the appropriate tools and practices to teach CT. Therefore, the use of educational technology to teach CT requires careful thinking in terms of the technology to be designed and used, the teaching practices and curricula, and the assessment methods.

Given the aforementioned background, this special issue aims to enrich the ongoing discussion about the use of educational technology to enhance students' CT. Through the six accepted papers, as shown in Section 3, this special issue provides more insights about the effective ways of using educational technology to catalyze CT learning.

3. Contribution of papers to this special issue

The following six papers were accepted in this special issue. Each one of them elicit theoretical and practical knowledge about the use of educational technology to enhance students' CT.

To enrich the ongoing debate in the literature about CT curricula especially in primary and lower secondary education, Paper 1 conducts a systematic review on this topic, where 98 studies were covered. The obtained results revealed that while several technologies exist for age-appropriate CT development, more research is required to design and develop curricula and pedagogies for utilizing these tools effectively to foster young learners' CT skill development.

With limited tools exist about CT assessment of students at an early age, Paper 2 develops *TechCheck*, an assessment of Computational Thinking (CT) for early elementary school children consisting of fifteen developmentally appropriate unplugged challenges that probe six CT domains.

Based on four mathematics domains (arithmetic, random events and counting, number theory, and geometry), Paper 3 designed a series of programming-based learning tasks for middle school students to co-develop CT and the corresponding mathematical knowledge. The obtained results revealed that the dynamic representations and immediate visual feedback afforded by the programming tool are beneficial to student learning.

Since developing students' CT through active interactions between instructors and students is more difficult in large online than in small face-to-face classes, Paper 4 uses e-mentoring via social network services (SNS) in developing students' CT during large-scale online courses. The obtained results revealed that the most influential e-mentoring activities for students' CT development were informational and technical support in a group and informational support in a private environment. It was also found that female students benefited more from SNS-based e-mentoring than male students, and they also engaged in more types of e-mentoring activities than male students.

Inspired by the research evidence in the literature on the potential positive effects of reflection in complex CT problem-solving by regulating cognitive activities, Paper 5 designs a reflection-guided visualized mindtool strategy to address CT development challenges. Additionally, relying on the powerful insights that could be generated from behavioural analysis, it applies Lag Sequential Analysis (LSA) to analyse student's learning behaviours of CT. The results revealed that students who used the reflection-guided visualized mindtool strategy exhibited more key behaviours of facilitating CT problem-solving (e.g., generalizing the knowledge, re-designing the algorithm scheme, and evaluating the feasibility of their proposed schemes).

Finally, Paper 6 harnesses the power of learning analytics and game-based learning to develop a personalized educational game *Penguin Go* that could facilitate children's personalized learning experiences for K–5 computing education. It reveals that Sequential Data Analytics (SDA) can inform what in-game support is necessary to foster student learning and when to deliver such support in gameplay.

Paper 1: Integrating Computational Thinking into School Curricula of Compulsory Education: A Systematic Review of Recent Literature.
Authors: Panagiotis Kampylis, Valentina Dagienė, Stefania Bocconi, Augusto Chioccariello, Katja Engelhardt, Gabrielė Stupurienė, Vaida Masiulionytė-Dagienė, Eglė Jasutė, Chiara Malagoli, Milena Horvath and Jeffrey Earp.

Paper 2: A Normative Analysis of the TechCheck Computational Thinking Assessment.
Authors: Emily Relkin, Sara K. Johnson and Marina U. Bers.

Paper 3: Integration of Computational Thinking with Mathematical Problem-based Learning: Insights on Affordances for Learning.
Authors: Zhihao Cui, Oi-Lam Ng and Morris Siu-Yung Jong.

Paper 4: The SNS-based E-mentoring and Development of Computational Thinking for Undergraduate Students in an Online Course.

Authors: Yeonju Jang, Seongyune Choi, Seonghun Kim and Hyeoncheol Kim.

Paper 5: Effect of a Reflection Guided Visualized Mindtool Strategy for Improving Students' Learning Performance and Behaviors in Computational Thinking Development.
Authors: Xiao-Fan Lin, Wenyi Li, Jing Wang, Yingshan Chen, Zhaoyang Wang, and Zhong-Mei Liang.

Paper 6: A Framework for Applying Sequential Data Analytics to Design Personalized Digital Game-Based Learning for Computing Education.
Authors: Zhichun Liu and Jewoong Moon

4. Conclusion and future research

This special issue revealed that developing CT curricula will facilitate the access and development of CT tools/technology that could be used in education, calling for more research in this regard, especially that each educational level has different subjects and knowledge to learn, while students in each educational level have different acquired skills.

It also revealed that while educational technology could enhance teaching and assessing students' CT, the focus should not be solely on the technology itself, but more on the educational approaches to be used with the technology. Therefore, there is a need for developing principles and guidelines about the best practices of using educational technology for enhancing students' CT. In particular, more research is needed to investigate the effective and responsible use of technology in CT education. In this context, smart learning analytics could empower both teachers and students by, for instance, revealing students' learning trajectories while addressing a particular CT topic, concept, or practice. Therefore, future research could focus on this direction, as well as on harnessing the power of big data and AI to promote the effective and safe learning of CT.

Finally, this special issue highlights that students' individual differences (e.g., age, gender, competency) should be considered when learning CT using educational technology. In this context, precision education, which aims to detect students' individual difference, could provide opportunities to overcome the one-size-fits-all approach and provide personalized experiences. In this context, Yang et al. (2023, p. 97) stated that "through precision education, teachers can understand students' learning situations by diagnostic system, extract data and establish a learning prediction model, then design adaptive learning activities for different types of students with one-of-a-kind treatment and prevention." Future studies could also investigate this line of research.

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