Computational thinking and creativity in K-6 education

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ABSTRACT. Nowadays, computational thinking (CT) and creativity are concerned as core competences in the 21st century for everyone who wants to take a career and work in the ever-evolving digital society. This study presents a systematic literature review (2006-2018) aiming to highlight teaching practices and learning frameworks used to support the development of both computational and creative thinking skills of primary level education students. Over the last years, there is a trend for these competences to be conceived as complementary and synergetic abilities and approaches which should be delivered and promoted together in order to train students to be problem solvers and critical thinkers, by understanding and using the digital technology provided creatively. Since only four solid empirical studies have been found relevant to K-6 education, the efforts made to combine these two thinking skills into teaching practice are still in infancy. The learning frameworks involved students mainly in game programming activities, as well as in programming activities related to art education where students should make use of technological resources, sensor cards and minicomputers. Limitations and recommendations for future research are also provided.

KEYWORDS: *Computational thinking, computing education, creativity, state of the art*

Computational and creative thinking in the 21st century

Living and working successfully in a digitalized society requires skills that are often referred to as 21st century skills (Mäkitalo et al., 2019). Over the last years, CT (computational thinking) and creativity have been considered thinking competences required for tomorrow's citizens. CT is realized as the problem-solving and thinking processes which enables us to look at problems and systems in such a way that we can make good use of computer systems to help us solve or understand them (Berry, 2014).

Creativity, on the other hand, is a vital aspect of any problem solving process tending to lead to creative results. Thus, it is a necessary skill for working and competing effectively in our complex, interconnected, and rapidly changing global society (Miller et al., 2014).
It is also a feature that allows you to be competitive in our modern economic and organizational environment that rewards speed and instantaneous results (Wilf, 2019).
In the field of education, there is a recent interest for the development of CT and creativity to all students throughout the various disciplines beyond STEM (Denning, Tedre, 2019).
These skills are proposed to be delivered together and not to be viewed as separate skills and manifested in isolation of each other (Shell et al., 2014). Therefore, trying to create with technology is critical for everyone in order to have equal access to opportunity in the future (Qureshi, 2018).
In this context, empirical research conducted in pupils of all educational levels is still in infancy and, thus, there are few efforts conducted – specifically in primary education – aiming to provide specific learning frameworks and practices for each student's age for the development and assessment of both their computational and creative thinking.
Therefore, it would have a great interest to examine the various teaching interventions conducted for the achievement of this goal and especially in the primary level.
To this end, the aim of this study is to review the literature related to K-6 education, in an effort to highlight teaching practices and learning frameworks used to support the development of both computational and creative thinking skills of primary school students.
This is the contribution of this paper.
As far as my knowledge, there is not another study attempting to map the situation on this topic. It is hoped that this review paper would set a basis in order to help other educational researchers to design new and more effective didactic approaches and learning frameworks that would support the development of both CT and creativity of primary school students.
The rest of this paper is organized as follows: in sections 2 and 3, a theoretical framework about CT and creativity is presented, while in section 4 the current view of the educational community on the students' benefits, by blending and delivering these skills teaching practice, is highlighted.
The research methodology is reported in section 5 followed by the presentation of the results (Section 6). Finally, in section 7 the conclusions and future work are discussed.

Computational thinking

Jeannette Wing introduced the term "computational thinking" in order to describe the way in which computer scientists think. She defined CT as a core analytical ability that embraces a set of thinking skills "to solve problems, design systems, and understand the humans' behavior, by drawing on the concepts fundamental to computer science" (Wing, 2006, p. 33).
Wing's article provoked educational community's interest. To this end, many discussions and workshops were organized in order to better examine the nature and the incorporation of CT in education.
Wing further defined the term of CT as "the thought processes involved in formulating problems and their solutions so that the solutions to be represented in a form that can be effectively carried out by an information-processing agent" (Wing, 2010).
Accordingly, she also suggested that CT is a core analytical and problem solving competence fundamental for everyone, not just for computer scientists.

Consistent to this view, several researchers attempted to clarify the meaning of CT in the K-12 education level (Voogt et al., 2015).

Computer Science Teacher Association noted that the study of CT enables all students to better conceptualize, analyze and solve complex problems by selecting and applying appropriate strategies and tools, both virtually and in the real world (CSTA, 2011).

Hemmendinger also proposed that CT should be taught to students in order to enable them to solve problems and discover new questions to explore within and across all disciplines (Hemmendinger, 2010).

Sysło and Kwiatkowska view CT as a set of thinking skills that should focus on computing principles rather than on computer programming skills (Sysło, Kwiatkowska 2013). A more precisely definition for K-12 level of education derives from the International Society for Technology in Education (ISTE) and the CSTA that described CT as a "problem-solving process" encompassing specific characteristics (ISTE, CSTA, 2011).

They are as follows: (a) formulating problems in a way that enables us to use a computer and other tools to help in solving them, (b) logically organizing and analyzing data, (c) representing data through abstractions such as models and simulations, (d) automating solutions through algorithmic thinking, (e) identifying, analyzing, and implementing possible solutions with the goal of achieving the most efficient and effective combination of steps and resources, and (f) generalizing and transferring this problem-solving process to a wide variety of problems.

Close to this approach, Grover and Pea provided some extra elements to the above that include: (a) iterative, recursive, and parallel thinking, (b) structured problem decomposition, (c) conditional logic, and (d) debugging and systematic error detection (Grover, Pea, 2013).

Barr and Stephenson noted that CT is an approach to solve problems in a way that can be implemented with a computer, where students become not merely tool users but tool builders. They use various concepts, such as abstraction, recursion, and iteration, to process and analyze data, and to create real and virtual artifacts. CT is a problem solving methodology that can be automated, transferred and applied across subjects (Barr, Stephenson, 2011).

In August 2016, the CSTA (2016) released the [Interim] CSTA K–12 Computer Science Standards. This update to existing CSTA standards refers to Wing's CT definition emphasizing the problem-solving aspects, as well as abstraction, automation, and analysis as fundamental elements of CT (Wing, 2010).

Specifically, it is stated that CT is a problem-solving methodology that expands the realm of computer science into all disciplines, providing a distinct means of analyzing and developing solutions to problems that can be solved computationally. With its focus on abstraction, automation, and analysis, CT is a core element of the broader discipline of computer science" (Wing, 2011, p. 6).

Nevertheless, other researchers view CT from a more general perspective.

Phillips refers to CT as the integration of the power of human thinking with the capabilities of computers, to solve complex problems (Phillips, 2009). Aho defines CT as "the thought process involved in formulating problems so their solutions can be represented as computational steps and algorithms" (Aho, 2012, p. 832).

An interesting definition is also derived from The Royal Society viewing CT as "the process of recognizing aspects of computation in the world that surrounds us, and applying tools and techniques from Computer Science to understand and reason about both natural and artificial systems and processes" (The Royal Society, 2012, p. 29).

Moreover, Voogt and others have approached CT as the "thought processes that are involved when solving complex problems and generalizing and transferring this problem solving process to a wide variety of problems" (Voogt et al., 2015, p. 725).
In addition, García-Peñalvo emphasizes the idea of CT as "the application of high level of abstraction and an algorithmic approach to solve any kind of problems" (García-Peñalvo, 2016, p.2).
Moreover, broadly speaking, Mäkitalo and others refer to CT as "the skills and competences necessary for understanding, controlling, and automating information processes" (Mäkitalo et al., 2019, p. 105). Finally, while Ferragina and Luccio (2018) mention that CT is based on the understanding of the concepts of algorithms and coding, Denning and Tedre (2019) explain that CT is not a set of concepts for programming. Instead, it refers to the way of thinking that is honed through practice, namely the mental skills for designing computations to do different tasks for us, and for explaining and interpreting the world as a complex of information processes.
Based on the above, it seems that CT consists of various thinking skills which have a procedural orientation, emphasizing processes and strategies for solving computational problems where computer has a central role. However, although there is no still clear consensus on a CT definition, for the purpose of conceptualizing CT and integrating it in education, it is considered that the research focus should not be given trying to propose an ultimate definition of CT, but rather try to find similarities and relationships in the discussions about CT (Voogt et al., 2015).

Creativity

Creativity is one of the key factors that drive our modern society forward (Wilf, 2019). Thus, the study of creativity and its incorporation in education should be seen as a basic necessity (Córdoba-Pachón, 2018). In fact, scholarly research on creativity is proliferating since a variety of new publication outlets have emerged (Hennessey, Amabile, 2010).
Creativity is a concept that has been defined in many ways by various researches all over the world. Many times, this term is overlapped with the concept of innovation as if they had the same meaning (Stein, 1974). Byron distinguishes these terms mentioning that creativity "is the thinking associated with ideas, imagination, inspiration, intuition and ingenuity", and innovation "the process of coming up with new ideas but more often innovation refers to what happens after someone has been inspired with a creative idea, making creative ideas a reality" (Byron, 2006, p. 2). This begins with communication of the idea and ends with organized teams in various roles working together to bring the idea as efficiently and as quickly as possible to fruition.
To this end, creativity is an active process necessarily involved in innovation (Cambridge Assessment International Education, 2018, p. 53).
E. Paul Torrance has been a pioneer in creativity research and education for more than 50 years (Millar, 1997).
Vidal, describing Torrance's view on creativity, mentions that he sees creativity as a process which can be enhanced or blocked in many ways. He also asserts that creativity is an infinite phenomenon and someone could be creative in an endless manner (Vidal, 2005).
Sawyer provided an individualistic definition of creativity as "a new mental combination that is expressed in the world" – and a sociocultural definition of creativity as "the generation of a product that is judged to be novel and also to be appropriate, useful, or valuable by a suitably knowledgeable social group" (as cited in Deschryver, Yadav, 2015).

An interesting definition of creativity in the domain of education comes from Kampylis and Berki who described this term "as the thinking that enables students to apply their imagination to generating ideas, questions and hypotheses, experimenting with alternatives and to evaluating their own and their peers' ideas, final products and processes" (Kampylis, Berki, 2014, p. 6).

Under different names and as subscribed to in more traditional disciplines (psychology, education, management, etc.), Córdoba-Pachón notes that creativity is being regarded as a new or emerging scientific field or discipline, which could help individuals identify and connect the dots that are in front of us and we cannot or do not want to see (Córdoba-Pachón, 2018).

Moreover, Teresa Amabile mentions that creativity arises through the confluence of the below three components (as cited in Adams, 2005):

- knowledge: all the relevant understanding a person brings to bear on a creative effort;
- creative thinking: relates to how people approach problems and depends on personality and thinking/working style;
- motivation: motivation is generally accepted as key to creative production, and the most important motivators are intrinsic passion and interest in the work itself.

Donald N. MacKinnon has delineated three different kinds of creativity used as a basis for research (MacKinnon, 1975). The first relates to *artistic creativity*, which reflects the creator's inner needs, perceptions and motivations. The second type is *scientific and technological creativity*, which deals with some problem of the environment and results in novel solutions but exhibits little of the inventor's personality. The third type is *hybrid creativity*, found in such fields as architecture that exhibits both a novel problem solution and the personality of the creator.

Creative-thinking skills determine how flexibly and imaginatively people approach problems and tasks. It demands courage to be creative because you will be changing the status quo. Individuals can learn to be more creative and can learn to use creative tools in problem solving (Vidal, 2005). However, it is supported that creativity is not encouraged in school settings – especially in primary school – although school environment is a key aspect for both rational and creative work to be flourished (Goff, 1998).

To this end, instead of trying to provide a general definition of creativity, it is easier if the scientific interest will focus on studying creativity in relation to problem solving tasks (Vidal, 2005), since it is associated with various fields including arts, economics and education (Kaufman, Beghetto, 2009). Specifically, to make this possible, in the field of education, teachers can support creativity by:

- Role modeling creative habits by exemplifying creative traits such as curiosity and the development of creative skills;
- Appreciating the critical importance of questions, both their own and those asked by students;
- Treating mistakes as learning opportunities and encouraging learners to take sensible risks in the classroom;
- Giving learners sufficient time to complete their work;
- Scaffolding tasks carefully to provide the appropriate level of challenge (Cambridge Assessment International Education, 2018).

In this way, students could develop their creativity and, therefore, cultivate their cognitive flexibility, communicate easily, be intellectually curious, let their impulses flow freely (MacKinnon, 1975), make assumptions, recognize patterns, make connections and see problems and situations in new ways (Hermann, 1996).
Finally, if students start to realize that there is not just an exclusive answer to many questions – both in school and in daily life – then their creative confidence will grow and they will set the foundation of their personal creative abilities, that they will build up throughout their lives (Cambridge Assessment International Education, 2018).

Computational and creative thinking

Nowadays, there is a tendency for CT to be the 5th C of 21st core century skills with critical thinking, creativity, collaboration and communication which have seen increasing recognition as fundamental ingredients of school curricula (Grover, 2018). In other words, it means that teaching and learning practices blending two or more of the aforementioned skills are effective for students who will live and work in a complex, interconnected and rapidly changing world. In particular, in the field of education, there is a recent interest for the cultivation of computational and creative thinking skills for students through appropriate learning frameworks/environments and teaching practices (Tzankova, Filimowicz, 2019), since they are universally applicable thinking skills that everyone would be eager to learn and use.
The combination of these competences is one of the top priorities in Computer Science education, as well as in other STEM and non-STEM disciplines (Shell et al., 2014). The new computing program of study in England is a prime example referring – in the first sentence – that: "A high quality computing education equips pupils to use CT and creativity to understand and change the world" (English Department of Education, 2013).
Thus, the blending of CT with creative thinking should not be conceived as a set of dichotomies, but rather as complementary or symbiotic abilities and approaches (Miller et al., 2014).
CT tools expand the knowledge and skills that one has available thereby broadening the array of knowledge that one may creatively apply to a problem. Similarly, creative skills enhance the development of CT (Shell et al., 2014).
Moreover, Romero and others underline that the creative use of digital technologies to solve diverse problems is related to CT as a set of cognitive and metacognitive strategies in which students are engaged in an active design and creation process and mobilized computational concepts and methods (Romero et al., 2017).
To this end, creative and computational thinking should be taught together without being considered or manifested in isolation of each other, in order to train students to be problem solvers and critical thinkers (Deschryver, Yadav, 2015). This statement could be enhanced if it is taken into account that both of the aforementioned competences share common thinking abilities such as abstraction, critical thinking, patterns' identification and generalization, modeling, data analysis and synthesis, transformation, etc. To make the dynamics of this combination more understandable, Yadav and Cooper give the example of the Stochastic Music by the musician/composer Iannis Xenakis in the early 1950s (Yadav, Cooper, 2017). In order to accelerate the stochastic calculations, Xenakis started learning and practicing on programming. His programs not only computed the composition of the orchestra (percentages of each section), but also the assignment of a note to particular instrument.

Thus, the understanding and use of computing and computational concepts, deep knowledge of a discipline (e.g. music principles), as well as creative skills and expression allow individuals to create computational artifacts and/or solve problems.

However, empirical research conducted in pupils is still at an early stage, as few studies have been conducted – mainly in higher education – aiming at the cultivation and assessment of both computational and creative thinking acquired by the students through well-designed activities and the use of appropriate learning environments. Millwood and others note that CT is best developed through creative project work, where the solutions designed use computing technology, permitting dynamic and interactive outcomes through making (Millwood et al., 2018). They also mention that new technologies – such as the BBC Microbit – have made such creative projects well within the reach of a playful primary child. Mehrota used unplugged activities in an after-school program to introduce children not only to CT concepts (like sequential logic, conditionals or flowcharts) but also to creative thinking (changing perspectives, associational and analogical thinking) and storytelling (Mehrota, 2016). During this program students created a puppet show that incorporates some programming and creative thinking elements, to make a fun and interactive final show.

Furthermore, Romero and others introduced CT in the context of higher education creative programming activities. They attempted to engage undergraduate students in a creative programming activity using Scratch (Romero et al., 2017).

Moreover, other researchers designed and deployed appropriate creative thinking exercises with linkages to concepts in computer science and CT, with the premise that students can leverage their creative thinking skills to "unlock" their understanding of CT.

Thus they view both creative and CT as cognitive tools that expand the knowledge and skills that one can apply to a problem. In this way, they should be able to make CT more generally applicable to STEM and non-STEM disciplines where students may have creative thinking skills but lack understanding of computing concepts (Miller et al., 2014; Shell et al., 2014). Finally, Tzankova and Filimowicz, trying to answer the question of "What computational creativity means?", provide an anthology with a set of courses in order to face the challenging problem about finding texts that address pedagogy, curriculum, and educators' professional development in the richly diverse fields of computation and creative making (Tzankova, Filimowicz, 2019).

Based on the above, the merging of both computational and creative thinking in teaching practice is a priority, since they are core competences that should be provided to students from all educational levels. CT equip students with competitive skills to do well in modern digital society, while at the same time creative thinking is a vital aspect of any problem solving process. Thus, the combination of these two thinking skills should be delivered together through enrichment and well-designed activities and approaches that engage students, thus provoking their interest and expanding their ability to face and solve various complex problems of daily life.

Methodology

Aim of the study

The aim of this study is to highlight teaching practices and learning frameworks used to support the development of both computational and creative thinking skills among primary level education students.

Data collection

This paper is a part of a broader review study attempting to answer the way that CT has grown in elementary level education students (K-6) (Kakavas, Ugolini, forthcoming).
That study reviewed papers published in scientific journals, book chapters, proceedings of international conferences symposiums and workshops for the years beginning in January 2006 and ending in December 2018. Ten electronic databases – relevant to education, technology and social science – were searched (e.g. ACM, Springer, ERIC, Taylor and Francis, etc.) using the keywords "computational thinking".
After defining specific criteria applied in that systematic literature review, 53 papers were found to be relevant to the inclusion criteria. To be included in the review, papers had to: (a) explicitly refer to the term "computational thinking" in title, abstract or keywords of each paper, (b) be written in English language, and (c) focus on CT and primary level education students by presenting empirical data emerged from methodologically strong empirical studies.
Subsequently, the 53 papers were analyzed into categories according to the research questions set corresponding to the objective of the review paper.
To this end, only four articles focused on the cultivation of CT, while also emphasizing the development of students' creativity through appropriate learning frameworks and activities.

Results

After the analysis of the papers, it was observed that the majority of the interventions conducted took into account the modern social, constructivist and constructionism views of learning (Jonassen, 1999; Harel, Papert, 1991; Vygotsky, 1974). Although these studies could promote CT primarily as an enabling problem solving approach and creative thinking as an enriching problem solving approach and vice versa, however, the following four studies focused on the cultivation of students' CT while taking into account the development of students' creativity as well as other 21st century cognitive skills.
In particular, Allsop explored the ways that the CT process can be evaluated in a classroom environment (Allsop, 2018). Thirty students aged 10-11 years, from a primary school in London took part in a game-making project using the Scratch and Alice 2.4 applications for eight months. Learners' CT skills were evaluated from three aspects: computational concepts, metacognitive practices, and learning behaviors, which were discussed as the main elements of the CT process. Evaluation of children's completed games exhibited that students – working in pairs – were able to use programming constructs including sequences, loops, parallelism, conditionals, operators and events. Moreover, data analysis of the children's problem solving sheets, observation records, informal conversations and semi-structured interviews presented that planning, monitoring, and evaluation were the main metacognitive skills that the children applied and developed through metacognitive practices when making computer games. Furthermore, the findings of this study showed that the children used different modes of conversation to make decisions, evaluate and regulate their activities. The findings of the data also displayed that learning behaviors such as collaboration, communication, persevering, problem solving and creativity were visible whilst children were coding their games.
In addition, Lamprou and others developed and evaluated the project "Scalable Game Design Solothurn" to primary and secondary level of education students (Lamprou et al., 2017).

This project both trained teachers and exposed students to CT concepts through the two CT Tools: AgentSheets and AgentCubes online (2-D and 3-D game and simulation programming environments). Results showed that teaching CT through Scalable Game Design is not only feasible in the primary school level but also enjoyable, with AgentSheets and AgentCubes online proving to be sustainable and effective tools for the implementation of Computer Science Education on this school level.

Participating teachers also stated that game programming using AgentSheets/AgentCubes online promotes children's creativity and that they would recommend Scalable Game Design to their colleagues. Their observation could also be reinforced by students' statements mentioning that they appreciated the opportunity to freely use their imagination, be creative and work independently on their own projects/games.

Furthermore, the study of Wong and Cheung investigated the impact of programming with CT on creative thinking, critical thinking and problem solving, known as twenty-first century skills (Wong, Cheung, 2018). Drawing on the theory of constructionism, the students (grades 4-6) were given the opportunity to create digital artefacts in Scratch and Kodu in the form of a game-based project. This was intended to cultivate students' problem solving and critical thinking skills, as well as to enhance their creativity, since children were freely allowed and encouraged to remix their programs and further personalize them.

The quantitative analysis showed an improvement in the students' creative thinking, critical thinking and problem-solving skills after the intervention. The significant gains in creative thinking were particularly higher across three grade levels than the other two constructs. The results were verified by the qualitative analysis, which revealed that students perceived that the CT programming curriculum not only equipped them with knowledge in programming, CT concepts and computer operation, but also enhanced their thinking skills, problem solving skills and creativity through the process of designing and creating their own games.

Authors also noted that the level of creativity expressed by students might depend on the freedom provided in the programming requirements.

Finally, Sáez-López and Sevillano-García developed a project for primary students (6th grade) in order to evaluate the integration of CT in art education making use of technological resources, sensor cards and minicomputers, with a student-centred pedagogical approach (Sáez-López, Sevillano-García, 2017).

The students worked with Scratch and Raspberry Pi (a microcomputer in the size of a credit card, linking guitar with Sctatch interface), creating a series of projects via programming by blocks and later using the hardware and the other components.

The results of the study showed that these activities allowed children's computational development by playing and creating music, since working with coding and devices brings an additional advantage in the development of CT and digital competence.

The results also showed an increase in students' creativity and artistic competence related to the ability to create music from the activities and technological resources used in the technological intervention.

Overview of CT's and creativity's implementation in primary education

The aim of this review paper is to provide a snapshot of the current research and work around the teaching practices and learning frameworks used to support the development of both computational and creative thinking skills of primary level education students.
It was first obtained that blending both computational and creative thinking in teaching practice is a priority in educational community, since they are concerned as core problem-solving thinking skills that should be acquired by all literate population in the 21st century.
It also appeared that the efforts that have been made to combine these two thinking skills into teaching practice are still in infancy. In particular, with regard to primary education, four sound empirical studies have been conducted, aiming to deliver CT and creativity together through appropriate learning frameworks.
Three of them engaged students in game programming activities, while the other one involved them in programming activities related to art education where students should create a series of projects making use of technological resources, sensor cards and minicomputers.
To this end, future studies should address how students' CT concepts and practices could be cultivated and evaluated across the school grade levels in the context of creativity and vice versa. Of course, it would have great interest to be investigated how this combination could be applied in subjects beyond STEM, as well as without the use of programming even in unplugged activities. These studies could contribute to the literature in order for computational and creative thinking to be effectively integrated together in curricula for preparing today students to live in the future digitally evolving world.

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