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Connecting moments of creativity, computational thinking, collaboration and new media literacy skills

Xanthippi Tsortanidou
Doctoral School, Open University of Catalonia, Barcelona, Spain

Thanasis Daradoumis
Department of Computer Science, Multimedia and Telecommunications, Open University of Catalonia, Barcelona, Spain and Department of Cultural Technology and Communication, University of the Aegean, Mytilene, Greece, and

Elena Barberá
Department of Psychology and Education Sciences and Doctoral School, Open University of Catalonia, Barcelona, Spain

Abstract

Purpose – This paper aims to present a novel pedagogical model that aims at bridging creativity with computational thinking (CT) and new media literacy skills at low-technology, information-rich learning environments. As creativity, problem solving and collaboration are among the targeted skills in twenty-first century, this model promotes the acquisition of these skills towards a holistic development of students in primary and secondary school settings. In this direction, teaching students to think like a computer scientist, an economist, a physicist or an artist can be achieved through CT practices, as well as media arts practices. The interface between these practices is imagination, a fundamental concept in the model. Imaginative teaching methods, computer science unplugged approach and low-technology prototyping method are used to develop creativity, CT, collaboration and new media literacy skills in students. Furthermore, cognitive, emotional, physical and social abilities are fostered. Principles and guidelines for the implementation of the model in classrooms are provided by following the design thinking process as a methodological tool, and a real example implemented in a primary school classroom is described. The added value of this paper is that it proposes a pedagogical model that can serve as a pool of pedagogical approaches implemented in various disciplines and grades, as CT curriculum frameworks for K-6 are still in their infancy. Further research is needed to define the point at which unplugged approach should be replaced or even combined with plugged-in approach and how this proposed model can be enriched.

Design/methodology/approach – This paper presents a pedagogical model that aims at bridging creativity with CT, collaboration and new media literacy skills.

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Findings – The proposed model follows a pedagogy-driven approach rather a technology-driven one as the authors suggest its implementation in low-tech, information-rich learning environments without computers. The added value of this paper is that it proposes a novel pedagogical model that can serve as a pool of pedagogical approaches and as a framework implemented in various disciplines and grades. A CT curriculum framework for K-6 is an area of research that is still in its infancy (Angeli *et al.*, 2016), so this model is intended to provide a holistic perspective over this area by focusing how to approach the convergence among CT, collaboration and creativity skills in practice rather than what to teach. Based on literature, the authors explained how multiple moments impact on CT, creativity and collaboration development and presented the linkages among them. Successful implementation of CT requires not only computer science and mathematics but also imaginative capacities involving innovation and curiosity (The College Board, 2012). It is necessary to understand the CT implications for teaching and learning beyond the traditional applications on computer science and mathematics (Kotsopoulos *et al.*, 2017) and start paying more attention to CT implications on social sciences and non-cognitive skills. Though the presented example (case study) seems to exploit the proposed multiple moments model at optimal level, empirical evidence is needed to show its practical applicability in a variety of contexts and not only in primary school settings. Future studies can extend, enrich or even alter some of its elements through experimental applications on how all these macro/micromoments work in practice in terms of easiness in implementation, flexibility, social orientation and skills improvement.

Originality/value – The added value of this paper is that it joins learning theories, pedagogical methods and necessary skills acquisition in an integrated manner by proposing a pedagogical model that can orient activities and educational scenarios by giving principles and guidelines for teaching practice.

Keywords Collaboration, Creativity, Computational thinking, Imagination, Low-technology, Information-rich, New media skills

Paper type Conceptual paper

Introduction

Developing students' twenty-first century skills, including creativity, critical thinking and problem solving, has been a dominant concern in our globalized society. Students should take part in the present participatory culture to acquire these skills by becoming creators/prosumers of knowledge rather than being consumers of information (Gretter and Yadav, 2016). Mishra and Yadav (2013) advocated that creativity can be augmented by computational thinking (CT) which constitutes a process of identifying aspects of computation in the world and applying tools and techniques from Computer Science to understand and explain both natural and artificial systems and processes (Voogt *et al.*, 2015). In this context, computational problems can be solved, computational artifacts can be created and students have the chance to express themselves creatively (Gretter and Yadav, 2016). It is noticeable that there is no clear-cut definition for CT and its curricular infusion in education should be tried by finding similarities and relationships in the discussions about CT. Although it draws on concepts of Computer Science, the two concepts are not identical, since CT refers to problem solving processes that are followed when solving complex problems, generalizing and transferring this process to a wide range of problems. The ability to think computationally involves algorithmic thinking and design-based thinking as well. CT practices include the design and development of computational artifacts, models, simulations and artifacts of natural and artificial phenomena collaboratively and the implementation of computing techniques to solve problems. Therefore, computing can take many forms ranging from creating animations to developing websites (Voogt *et al.*, 2015). These products entail imagination since enable artistic, scientific and technical creation (Vygotsky, 2004) and can be evaluated by applying aesthetic, mathematical, pragmatic and other criteria. Students can communicate them through written and oral descriptions supported by graphs, visualizations, diagrams, and so forth. Voogt *et al.* (2015).

UNESCO advocates the complementary relationship between CT and media and information literacy that can provide teachers with a comprehensive set of skills to allow students to creatively produce content (Gretter and Yadav, 2016). Computation, collaboration and creativity are overarching elements of media arts practices and therefore, it is meaningful to consider the new media skills development of crucial importance. More specifically, computation refers to the role of technology and computer programming. Mitch Resnick argues that although programming is an important tool to help development of CT skills, "computational thinking is more than programming, but only in the same way that language literacy is more than writing" (National Research Council, 2010, p. 13). Programming in this context is less about code and more about self-expression (Grover and Pea, 2013), and creativity can be used as a way to tell stories or to create artwork for example. Self-expression means that students can infuse their interests and personal styles into their media artworks. Collaboration emphasizes the social context of media arts practices, since the social participation enables creation and sharing of work and forms peer to peer and mentor to peer forms of collaboration (Peppler and Kafai, 2007a, 2007b).

Media arts include sociocultural theories and the involvement of imagination. The sociocultural theory of constructionism serves the aims of (media) arts education since artifacts design and sharing within a community of learners stimulate social participation and active engagement. Consequently, it is important to stress that not only intellectual skills are developed but also social skills and that bidirectional connection between the individual and the community of learners is emerged (Peppler, 2010). Students have to develop their physical, emotional and intellectual abilities as the basis for obtaining media competency (Hübner, 2015) and toward this direction, it is purposeful to incorporate social and intellectual skills development in the model. The new media literacy skills framework proposed by Jenkins *et al.* (2009) is employed in our pedagogical model, which emphasizes not on mastering the tools use but on intellectual activities performed when someone works with sophisticated technologies (Dede, 2010). In fact these skills, the new media literacy skills, are social skills needed for active engagement in todaýs participatory culture (Jenkins *et al.*, 2009). Furthermore, CT requires intellectual and social abilities as well, and can be considered integral element of media skills acquisition (Gretter and Yadav, 2016).

Greene (2011) highlighted the central role of aesthetics and imagination in the artistic process because they engage students in building, creating and constructing digital or physical artifacts. The artistic creativity integrates "intangible assets" ("creative milieu") and the new media arts aid the artistic, individual and social creativity (Jennings and Giaccardi, 2005). In addition, the curricular infusion of CT in schools is still scarce and studies about how it can be cultivated in disciplines other than Computer Science are needed. CT facilitates students to think not only like a computer scientist, but also like an economist, an artist, a physicist, and so forth (Voogt *et al.*, 2015). Furthermore, media arts as a "metamedium" overlap with sciences, visual arts, animation, film, electronic music, and so forth (National Research Council, 2003) and in this sense, multimodality has significant implications in combining many different modes.

The proposed pedagogical model aims at developing the overarching twenty-first century skills of creativity, collaboration and CT which are presented as macromoments. We call it 3 C multiple moments pedagogical model (see Figure 1). The three macroments are connected and realized through five micromoments: non-technological, sociocultural, imaginative, multimodal and media. These micromoments refer to specific methods which cultivate the corresponding skills and thus, provide the natural avenues for the implementation of the macromoments.

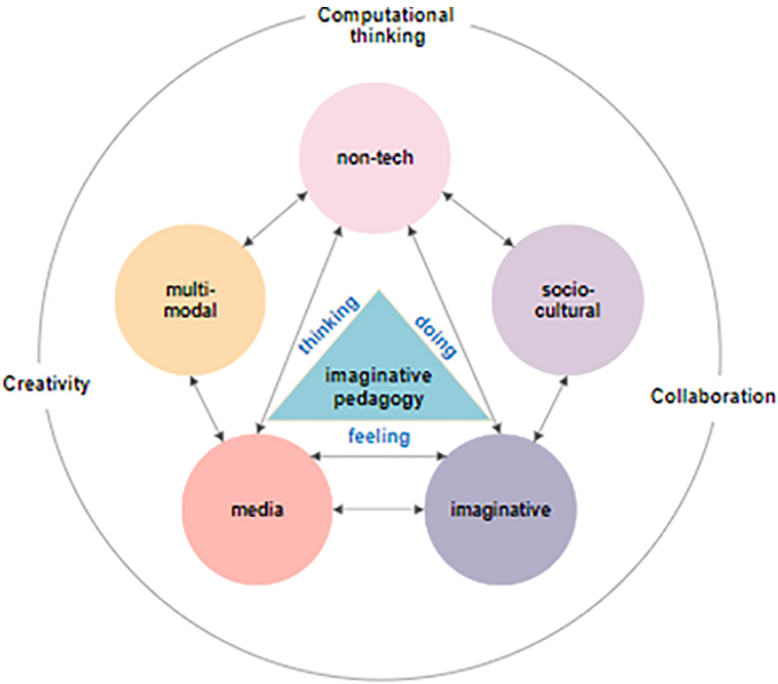

Figure 1. 3C (CT, creativity and collaboration) multiple moments pedagogical model

Imaginative pedagogy is at the center of the model aiming at developing students in a holistic manner, since it unifies the thinking, feeling and doing realms of human nature (Henriksen *et al.*, 2016). The *non-technological micromoment* refers to low technology and computer science unplugged approaches, corresponding to the CT macromoment. The *socio-cultural micromoment* refers to theories that recognize the social context in which the education process is realized and is connected to the collaboration macromoment. The *imaginative micromoment* entails the imaginative methods and tools that can be incorporated in a low-tech, information rich learning environment, matching with creativity. The *media micromoment* refers to media arts practices and new media literacy skills, corresponding to all macromoments. The *multimodal micromoment* spans over all teaching methods and skills accounted for by the 3 C model, involving all three thinking, feeling and doing realms of imaginative pedagogy. As such, it is inherent to the rationale of the model. As we explain in greater detail in the following section, all macromoments and micromoments intertwine, representing more than simple one-to-one relationships between them.

The micromoments of the pedagogical model

In this section, we elaborate on the micromoments that the pedagogical model draws upon. For each micromoment, we describe its essence and figure out linkages with the other micromoments. This model frames possible educational scenarios and activities, aimed at achieving a holistic approach to teaching practices. The holistic approach of the model is encountered in its content and process. Regarding content, the micromoments are comprised of methods and skills that intend to holistically develop the learner. Imagination serves this goal absolutely by using the thinking, feeling and doing realms of human nature. Regarding process, design-thinking approaches compose phenomena in a holistic constructivist manner. A real example explains this holism in the following sections. This model can be applied in tech-free or low-tech learning contexts, where artistic and hands-on activities are central. The role of imagination and creativity is prominent in low technology, information-rich learning environments since the educational process is free from high-tech products. In addition, social interaction and participation are prerequisites for these activities enhancing practical and participation abilities as well (Sun, 2017). Next section presents the model in more detail.

Non-technological micromoment

This micromoment is comprised of both Computer Science Unplugged (CSU) and low-tech prototyping methods. CSU activities promote CT development, which involves problem solving skills; yet, concepts from Computer Science are used to solve real-world problems, independently from using computers (Wing, 2006). CT can be taught through methods that do not use computers or technology and are called CT unplugged methods (Letonsaari, 2018). More specifically, the CSU method exposes children to fundamental computing concepts and presents the kind of thinking that is expected of a computer scientist with the ultimate aim of creating computational models of real world (Sysło and Kwiatkowska, 2015). The CSU pedagogical approach emphasizes on the intellectual and problem-solving nature of computer science. It enhances motivation through challenges and games. Thinking abilities and problem-solving skills are stimulated by trial and error method and hands-on activities with inexpensive materials. Teamwork is promoted and imagination is encouraged through adopting elements of fantasy and storytelling. All these activities can be carried out in classrooms or outdoors (Nishida *et al.*, 2009; Nishida *et al.*, 2008). Some technical elements of the unplugged approach are: simplicity in implementation, active participation, teamwork towards a common goal, or competition towards finding the best or the fastest solution than another group (Nishida *et al.*, 2009).

CT shares elements with creative media use since media design and media production are processes requiring programmatic logic (Jacob and Warschauer, 2018). The creative media use is also encountered at low-prototyping methods. A low-tech prototyping method uses art supplies to create low-tech prototypes of technology and generate models (Alhumaidan *et al.*, 2015) that can be used at educational scenarios (Westerlund *et al.*, 2001). Indeed, “low-tech tools like crayons, watercolors and paper nourish children’s inner capacities and encourage the child to freely move in, directly relate to, and understand the real world” (Cordes and Miller, 2000, p. 74). The low-tech artifacts can be either materials, such as a hammer or a piece of software (computational artifacts), or non-material artifacts, such as a poem, a story, a theory or a scientific experiment. Both types of low-tech artifacts entail and cultivate imagination and can be implemented in several disciplines (arts, computer science, biology, mathematics, and so forth). Students develop technological, social and cognitive skills to construct low-tech artifacts embodying their understanding of concepts that serve as tools for construction, expression and communication of their learning (Brown, 1992).

Sociocultural micromoment

In the proposed pedagogical model, the presence of social interaction between learner and the significant other(s) is paramount and the processing of information plays a primary role in low-tech, information rich learning environments. The human behavior depends strongly on the cultural and social context and exploits the social circumstances (Letonsaari, 2018).

CT is also a non-individualistic act and can be seen as a social, communal practice because we create to share with others. CT should be thought as computational participation, recognized as collaborative, distributed contribution since it is affected by social interaction and context (Kafai and Burke, 2013). Since CT draws upon the cognitive and social realm, it is meaningful to highlight the significant role that sociocultural learning theories play in CT development in terms of information processing, social interaction and participation. Children perceive information and convert it to knowledge through social interaction. Social interaction is necessary element of educational process, facilitating information understanding and elaboration in a changing context (Walter 1994 as cited in Campana, 2018).

The social process is acknowledged as part of information construction because information seeking, use and sharing depend on cognitive information process and social interaction. Social constructivism elaborates on this account advocating that internal knowledge construction is affected by social interactions and the enveloping discourses (McKenzie, 2003; Talja *et al.*, 2005). Vygotsky, a prominent proponent of social constructivism, asserts the social environment importance in children' development and learning. The internalization and transformation of social interactions result in cognition changes (Schunk, 2012). Concerning social interactions, the role of significant other can be taken by teacher, parent, a more skilled/knowledgeable peer or even by materials. In the proposed model, the employment of materials is fundamental, particularly in CSU and low-tech prototyping methods, and contributes to information processing activity (Schunk, 2012). In that sense, the significant other illustrates the concept of scaffolding and Vygotsky's Zone of Proximal Development (ZPD). In practice, scaffolding can take many forms, such as discussion, provision of materials, or designing tasks (Pritchard, 2008). The ZPD differs from learner to learner and reflects the ability of her/him to grasp the logic of scientific concepts (Fosnot and Perry, 1996). Consequently, it is meaningful to take ZPD into account when curricula, activities and materials are developed and provided. Situated learning is another important factor. It points out the importance of connection between people and situations/contexts, stressing that cognitive processes are situated within physical and social contexts. We mentioned previously that CT involves the process of problem solving, transferring and generalizing it to a wide range of problems. Understanding as well as knowledge and skills have more chances to be transferred successfully to other contexts when learning is situated in familiar contexts and learning tasks are authentic and culturally linked (Pritchard, 2008).

The suggested model is also rooted in constructionism learning theory, first proposed by Papert (1987). Papert's theory of constructionism advocates that learners physically construct mental models to understand the world around them ("learn by doing approach") and reconstruct their existing knowledge through inquiry-based active learning. The role of materials is also stressed demonstrating that learning is more effective when learners actively create "external and sharable artifacts" supporting in this way the development of concrete ways of thinking (Kafai and Resnick, 1996, p. 4). This learning perspective is fundamentally multimodal in that internal representations and meaning construction occur through engagement with digital, tangible, or even conceptual artifacts, in the real world including sound, text, images, motion and so forth (Papert and Harel, 1991). Two elements of this theory are closely related to imagination: inquiry-based approach and intuitive knowledge. One of the pillars of constructionism learning theory is that learners can be empowered by powerful ideas rooted in intuitive knowledge which they have acquired over a long period of time (Papert, 2000; Bers *et al.*, 2002). Dede *et al.* (2013) argue that CT must be seen in relation to human knowledge, expertise and intuition, implying that imaginative capacities are also involved. Imagination and inquiry are joined through co-design, foreshadowing the importance of design thinking. Steen (2013) draws upon Dewey's ideas on coordinating processes of joint inquiry and imagination. He asserts that co-design, as a process of collaborative design thinking, combines inquiry as a trajectory from the outside to the inside world whereas imagination follows the reverse trajectory, from the inside to the outside world. From this viewpoint, co-design is a reflective process in which instrumentalities (tangible or conceptual) are brought together in a novel manner so that something new is produced. We elaborate on design thinking in greater detail later in this paper, when we explain a real example of how to use our model to guide design instruction.

Imaginative micromoment

Dede *et al.* (2013) argue that CT must be seen in relation to human knowledge, expertise and intuition. It is noteworthy to say that success in CT requires not only computer science and mathematics, but also imaginative capacities involving innovation and curiosity. In this direction, CT can enhance creativity, one of the overarching skills in twenty-first century, because computing extends the human expression and allows the creation of new forms of expression (The College Board, 2012). As we have already mentioned, CT practices include computational artifacts, which are products that draw upon imaginative capacity. Low-tech prototyping and unplugged methods also enhance creativity and capitalize on imaginative capacities since elements of fantasy and imagination are integral. To elaborate deeper on these elements, we propose the adoption of imaginative teaching methods that can serve as a pool of practices facilitating the ability to imagine and create (Nielsen, 2006). Imagination unifies the three mental operations of cognition, emotion and motivation that correspond to the three learning faculties of thinking, feeling and doing (Van Alphen, 2011). The sense of imaginative micromoment can accomplish the vision of children holistic development. We employ the imaginative teaching methods of storytelling, drama/role play, arts, discussion, exploration, ritual and routine, and empathy (Nielsen, 2006). Furthermore, cognitive tools of story, abstract binary oppositions, jokes and humor, sense of mystery, sense of reality, and sense of wonder promote imagination (Egan and Judson, 2009) and can be easily incorporated into CSU and low-tech prototyping methods. The sociocultural sense of creativity is stressed by Sawyer (2012) advocating that creativity is the generation of products that come from and direct at knowledgeable social communities. These products are evaluated for their suitability, usefulness and value at society (Sawyer, 2012) applying aesthetic, mathematical, pragmatic and other criteria (Voogt *et al.*, 2015). The proposed pedagogical model emphasizes on collaboration and the importance of social interaction, participation and active engagement of leaners towards a common goal. Creativity can be an individualistic mental process or collective, when no single participant's contribution determines the creative product. In the case of non-individualistic creative process, distributed creativity or collaborative creativity occurs and corresponds to how collaboration contributes to creativity (Sawyer and DeZutter, 2009). Distributed creativity shares common elements with the collective intelligence skill of media micromoment as well, since the ultimate aim is the collective social creation.

Multimodal micromoment

The creation of digital, tangible, or even conceptual artifacts as integral components of both unplugged and low-tech prototyping approaches entail the engagement of thinking, feeling and doing realms. This is necessary since abstract imagination is specified by transforming mental conceptualization of an idea into real world. This learning perspective is fundamentally multimodal including sound, text, images, motion, and so forth (Papert and Harel, 1991).

The curricular integration of different media through visual, auditory and kynesthetic approaches is a challenge that school curricula have to deal with Kosic (2018). Media arts practice can serve this challenge through the concept of "metamedium". This involves important implications for connecting multiple types of art forms, which includes making and representation (language, visual, spatial, musical, movement, digital, and so on) (Peppler, 2010; Picciano, 2009). In this multimodal learning setting, the educational process involves head, heart and hands learning where the use and development of multiple intelligences and learning styles are encouraged. Gardner's multiple intelligence theory (Helding, 2009) differentiates nine intelligences: linguistic, logical/mathematical, musical, spatial/visual, kinaesthetic, interpersonal, intrapersonal, naturalistic and existential. Multiple intelligences, such as linguistic, kinaesthetic and naturalistic, can be integrated in the imaginative teaching methods we have proposed as fundamental elements in our model. In addition, logical/mathematical and interpersonal intelligences can be involved through CT and collaboration activities, whereas media arts practices can employ spatial/visual, musical and interpersonal intelligences. In this respect, multiple intelligences theory can approach the educational process in a holistic manner, allowing students to reveal their abilities and inclinations.

Media micromoment

Our pedagogical model makes use of the new media literacy skills framework proposed by Jenkins *et al.* (2009) which emphasizes not on mastering the tools use but on intellectual activities (Dede, 2010). Jenkins *et al.* (2009) assert that the new media skills are social and cultural skills necessary in todaýs participatory culture since the focus has shifted from "individual expression to community involvement" (p. 7). Students have to develop their physical, emotional and intellectual abilities as the basis for obtaining media competency (Hübner, 2015). All these abilities require the participation of CT (intellectual pillar), imagination and creativity (physical, emotional, intellectual pillars, corresponding to doing, feeling and thinking realms) and collaboration (emotional pillar). Consequently, the new media literacy skills unify all the skills we intend to integrate in our model.

More specifically, play is a new media skill which is closely related to CT because it involves experimentation with the environment, as a problem-solving process. Performance is a media skill which is related to improvisation and discovery, elements that need imagination and creativity. Simulation is a skill related to CSU and low-tech prototyping methods, because real-world models/artifacts are created to interpret real world processes. Appropriation is a skill that can entail the combination of imaginative teaching methods with media arts practices. Multitasking is a skill which is encountered throughout the educational process. Distributed cognition is a skill that refers to tools that expand humans mental capacities, such as a calculator, a ruler, and can complement the creation and refinement of artifacts. Collective intelligence is a skill related to the whole design thinking process, when students have to solve a problem and each members contribution is pivotal for finding the best solution through sharing and comparing knowledge and experience. Judgment is a necessary skill in information-rich learning environments and is related to the reliability and validity of the information sources that are used. Transmedia navigation is an ability which is closely related to storytelling and multimodality since a story can be encountered in different modalities. Networking is a skill that concerns information searching, synthesizing and disseminating and is connected with work sharing in a social community. Finally, negotiation is an important skill in terms of collaboration, social interaction and participation.

CT, collaboration and creativity are significant aspects of media arts practices. These practices involve complex forms of multimodality such as visual (media images), audio, animated movement, written and kinaesthetic/interactive forms. The engagement with media arts facilitates the acquisition of new media literacy and artistic expression (Peppler, 2010). Learners use their creativity for their self-expression through media and arts practices and value the aesthetic qualities of them (Kellner and Share, 2007). Particularly, CT in the context of media arts practices is less about code and more about creativity or self-expression and include telling stories or creating artwork. Collaboration promotes the social context of media arts practices and its importance for learning and motivation through creating and sharing work (Peppler and Kafai, 2007a, 2007b).

Using the model to guide design instruction

In this section, we elaborate on how the described micromoments can come into force. All the three skills, CT, collaboration and creativity, are inherent components of low-tech prototyping, CSU and media arts practices aiming at problem solving, imagination and social skills development. We unify all these micromoments' relationships and interrrelationships through the proposed model, bringing together the skills that twenty-first century students have to possess in a holistic manner. In principle, the proposed model engages thinking, feeling and doing by tying together multiple micromoments in a holistic manner. Learners engage the thinking realm when they use their imagination for the conceptualization of an idea and their creativity when they put this idea into practice. This realm is related to Papert's theory of constructionism. More specifically, it considers that intellectual abilities and the development of concrete ways of thinking (Kafai and Resnick, 1996, p. 4) are promoted through the CSU approach, problem solving and CT. The feeling realm is engaged when learners have to create a collective work with others and share it within their community, using their imagination in low-tech prototyping methods and artifacts co-construction. This distributive creativity involves the social and emotional life of learners within the context of community of peers, illustrating the presence of social constructivism. This realm also reflects one of the pillars of constructionism learning theory in that learners are empowered by powerful ideas rooted in intuitive knowledge (Papert, 2000; Bers *et al.*, 2002). The doing realm employs Papert's theory of constructionism and is based on the "learning by doing approach" in that learners physically construct mental models to understand the world around them and reconstruct their existing knowledge through inquiry-based active learning (Papert, 1987). This theory finds its implementation through CSU and low tech prototyping methods. Kinaesthetic skills are also of equal importance with intellectual and social/emotional skills and are integral part in tangible products creation. To foster the applicability of the model, we suggest a methodology for structuring and guiding its implementation in the teaching practice. Firstly, we frame the model by employing the design thinking process (Scheer *et al.*, 2012; Carroll *et al.*, 2010; Shute *et al.*, 2017). We have decided to follow the process of design thinking as a methodological tool because it is an excellent fit with the targeted skills. Secondly, we suggest some guidelines for macromoments and micromoments implementation and we demonstrate their practical application by giving a real example originated from a teaching practice in a primary classroom.

Design thinking process as a methodological tool

Problem solving is the common denominator between design thinking and CT. Design thinking requires learners to solve problems as designers (Razzouk and Shute, 2012). Problem solving in CT can take many forms, from solving practical to theoretical and conceptual problems (Shute *et al.*, 2017). Design thinking encompasses the whole concept of new competences that twenty-first century students have to acquire: resolving complex real-world problems by analyzing and evaluating them in a solution-oriented manner. Design thinking also fosters the ability to imagine without boundaries and limitations, which is an essential part of learning so that students develop creative confidence (Carroll *et al.*, 2010). Additionally, design thinking effectively serves twenty-first century learning by facilitating interdisciplinary projects and approaching complex problem-solving processes in a holistic constructivist manner. Essentially, design thinking is a constructivist learning design since learning is promoted through experience, complex problem solving, and teamwork (Scheer *et al.*, 2012; Carroll *et al.*, 2010).

Here, we explain the design thinking process and how it reflects the three realms of thinking, feeling and doing. Particularly, design thinking includes five phases: understanding and observing, synthesizing, ideating, prototyping and testing. The phases follow an iterative cycle. This means that it is possible to repeat the whole process or certain phases or even move from one phase to any other at any point of time; doing so, knowledge is updated and adapted to the context.

The understanding and observing phase involves understanding of the context of the problem as well as of the challenges, feelings and thoughts of others, thus corresponding to the feeling and thinking realms. The second phase of synthesizing involves the definition of the problem and its context so that learners proceed with powerful ideas generation and actionable problem solutions, involving the thinking and feeling realm. The third phase of ideating engages the imaginative capacities of learners towards the transformation of ideas into meaningful insights for solving the problem which, in turn, can lead to actionable solutions. This phase is related to the feeling and thinking realms, since social interaction leads to information processing and collective imagination to a common solution. During the fourth phase of prototyping, abstract imagination and mental concepts of solutions to the problem become tangible and testable through experimentation reflecting the doing realm. The last phase, testing, tries out the feasibility and applicability of the imagined solution to refine the final idea (Scheer *et al.*, 2012; Carroll *et al.*, 2010). Scaffolding is crucial in all the phases for their successful completion, illustrating the implementation of Vygotsky's Zone of Proximal Development (ZPD). Discussion, provision of materials or designing tasks are forms of scaffolding (Pritchard, 2008) that can be part of all the phases.

Pedagogical guidelines

Here, we present guidelines and fundamental principles that can facilitate the implementation of the proposed pedagogical model. Based on the multiple macro/micromoments, these principles provide the basis upon which a teacher can use the model to guide the teaching practice. These principles are the following:

- The internalization and transformation of social interactions impact on information processing and knowledge construction (*social participation/collaboration*).
- CT, collaboration and creativity ultimately lead the learners to holistic development since each skill and all together reflect the intellectual, feeling and doing pillars (*holistic approach*).

- The role of the significant "other", which can take many forms such as teacher, parent, a more skilled/knowledgeable peer, or materials, can extend learner*s* abilities through discussion, material or activity (*scaffolding*).
- The curricular integration of visual, auditory and kinaesthetic approaches, the utilization of thinking, feeling and doing pillars and the meaning making and representation in multiple forms approach the teaching practice holistically (*multimodality*).
- Experiential learning situations, which facilitate knowledge construction, can be provided by external and sharable artifacts creation (*inquiry*).
- Intuitive knowledge generates powerful ideas and involves CT (*imaginatio*n/ *creativity*).
- Learners internalize the world through imagination and externalize it through inquiry. The reflective process can coordinate them to that end (*co-design*).
- The shift from individual expression to community involvement alters the skills, from CT to computational participation and from creativity to distributed/collective creativity (*participatory skills*).
- The incorporation of teaching practices that promote thinking in different disciplines, other than Computer Science and Mathematics, can be achieved by engaging the aesthetic qualities and inner capacities of learners (*arts*).
- Problem-solving constitutes both the ultimate aim and the instrumentality of fundamental twenty-first century skills' acquisition, which can be attained collaboratively (*collective problem-solving/ CT*).

The common denominators of any teaching practice that intends to follow our pedagogical model are CT, collaboration, creativity, and ultimately new media literacy skills development. It is not necessary to follow all the elements that each micromoment includes, but even if a teaching practice does not adopt all the elements, the above principles are steadfast and applicable to every teaching practice that follows the current model. The nature of the problem, theoretical or practical and the nature of the artifacts, material or non-material, tangible and conceptual or digital are the most important factors that determine the accompanied methods and skills. For example, if the means used is a non-material artifact such as a poem, obviously the accompanied methods and targeted skills will not be the same as in the case of a material artifact such as a windmill. Though in both cases the design thinking process is common, the change of phases or the iterations may be different, so this process is adapted to the nature of the problem and the situation of it.

A real example

It is noteworthy to say that the following case study is a real example of teaching practice that comes from a public school. Since public schools function under the pressure of prescribed curricula, different types of schools, not so attached to given curricula, could follow different or innovative teaching practices. This was observed during a pilot study conducted in June 2019. We explain the case study by following the phases of design thinking process and we elaborate on micromoments that are encountered. The example concerned a two-hour project that implemented logical/mathematical intelligence and was completed by students aged 9 and 10 years old during the Indrés lesson. Essentially, this lesson aimed at fostering the most dominant multiple intelligences of students who were divided into three different classrooms every week for two hours according to their inclination, that is to inter/intra-personal intelligence classroom, logical/mathematical intelligence classroom and arts classroom, incorporating musical, spatial/visual and kinaesthetic intelligences. Students were free to choose what classroom wanted to attend each week.

Regarding the context of the example, students were divided into three groups. Each group had to solve a problem and once it was resolved, the next group took on the problem resolution of the previous group. At the end, all the students would have completed all the problems successively. The problem-solving process was considered complete when a real-life model was designed and constructed. The role of the teacher during this process was to facilitate the educational process by intervening when necessary, solving doubts and queries and organizing the timely completion of each problem so that all the students could engage with all the problems. Finally, the group that would have completed the tasks more accurately and correctly would win a prize, a statuette. Three statuettes were given, one for each successful artifact.

Design thinking process that describes the example methodologically

We describe the educational process of the example based on the design thinking methodology. More specifically, the example follows five phases:

Phase 1: *Understanding and observing*

During this phase, the teacher explains that each group has to solve three different problems through experimentation and model construction. The problems are a damaged windmill, a non-functional current circuit and a defective solar panel. The students have to understand what makes the system non-functional and explain what elements are defective or missing and why these elements are the reason for this defect. Then, they should find solutions to solve these bugs, try out the possible solutions and ultimately describe the correct solution accurately. This process is related to the decomposition of the problem by breaking down the parts of the problem and identifying the steps that they have to follow to solve the problem.

Phase 2: Synthesizing

This phase involves the final definition of the problem and sharing of ideas to find the correct source of defect. The students write individually in a paper what they think about the sources of the problem and then they share their thoughts. The teacher replies to queries and gives prompts to students to keep on investigating the possible sources through discussion and generating powerful ideas so that they proceed with actionable problem solutions.

Phase 3: Ideating

During this phase, students have already discussed the possible sources of the problem and they intend to find the most possible explanations of it with the help of the teacher, excluding the weak explanations, discussing and doing the trial and error method. Students maximize the engagement of their imaginative and thinking abilities towards corresponding possible defects with possible impacts on model function.

Phase 4: Prototyping

This phase includes the conceptualization of possible problem sources and the imaginative resolution, which are transformed into a real-world solution through drawing. Students draw individually the model and think how it should be to function properly by stressing the missing and defective elements. The teacher confirms or explains in detail if the imagined solution is correct or not. The most accurate drawing (conceptual artifact) is choosen after negotiation among the students and teacher*s* advices to be the tangible and testable model.

Phase 5: Testing

During this phase, students transform their conceptual artifact into a tangible and testable one through experimentation. The model construction is done with inexpensive materials (blocks and other manipulative) to check its feasibility and applicability. In this phase, the aim is to refine the final solution and develop a theory that will explain: why the model was non-functional (problem sources), how they found the solution by recording specific steps (process of collecting the possible solutions), and why it works in contrast to the non-functional model (reasons for tangible artifacts functionality).

After the end of the process, the three groups present their artifacts and the accompanied theory at the whole classroom. The teacher decides which group followed the most scientific, accurate and correct procedure to explain and solve each problem. The winner group gains one of the three statuettes (one for each problem).

When the students have completed all the problems resolution, the four pillars of CT are coming up: they have identified the sources of bugs in a non-functional model by breaking it down in smaller pieces to understand its parts in greater depth (decomposition pillar); each one of the possible sources of defect was analyzed individually, so after the three problems resolution, the identification of similar bugs is much easier (pattern recognition pillar); students were able to reach possible explanations and solutions through social interaction and feedback from peers and teachers advice, focusing on significant details and excluding irrelevant or weak explanations and solutions (abstraction pillar); the problems were solved by following specific steps or rules of similar logic in all the three problems (algorithms pillar) (Brackmann *et al.*, 2016).

Joining the dots: skills developed from the application of the multiple macro/micromoments model

The application of the multiple macro/micromoments model reveals some of the traits of the unplugged approach, imaginative teaching methods and new media literacy skills. In particular, students have the opportunity to develop the following media literacy skills:

- A problem that should be resolved without computers (Wing, 2006) entails the sense of wonder and sense of reality through experimentation and the imaginative teaching method of exploration (*play skill*).
- Students are expected to think like a scientist and designer with the ultimate goal of creating a model of real world (Sysło and Kwiatkowska, 2015) (*simulation skill*).
- Motivation is high since the procedure is challenging and students work together striving to find a more accurate and complete solution than other groups (Nishida *et al.*, 2009) (*collective intelligence*).
- Imaginative and thinking abilities are stimulated during the problem-solving process (Nishida *et al.*, 2009; Nishida *et al.*, 2008) when students have to imagine the model and conceptualize its function by drawing it like a designer (conceptual artifact) and when they have to simulate its function by constructing it like an engineer (tanglible artifact) (*performance and distributed cognition skills*).
- Inexpensive materials used in both artifacts feed children inner capacities and encourage them to understand the real world (Cordes and Miller, 2000) and generate models (Alhumaidan *et al.*, 2015). Understanding and respecting the thoughts of others and sharing ideas through social interactions also indicate the employment of the empathy imaginative teaching method within this community of learners (*collective intelligence and negotiation skills*).

- The ultimate objective is to compose a theory reflected by the two artifacts/low-tech prototypes, a non-material/conceptual (drawing) and a material/tangible (real-world model), which are unified to illustrate the developing theory (*transmedia navigation skill*).
- The teacher as facilitator of the educational process scaffolds students so that to extend their abilities through the imaginative teaching method of discussion and through the provision of appropriate materials. Additionally, peer support and feedback are indicators of Vygotský*s* Zone of Proximal Development presence. Social participation and interaction affect collective information processing towards the problem solution, illustrating the implementation of social constructivism (*negotiation skill*).
- The employment of inquiry (finding the most accurate solution with "learning by doing" approach) and imagination (conceptualizing the problem with a drawing and realizing its function into real world through a tangible model construction) are indicators of Papert's constructionism theory (Kafai and Resnick, 1996) (*performance skill*).
- The learning perspective followed in this example is multimodal in that the internal representations and meaning construction are externalized through artifacts construction (Papert and Harel, 1991). Media arts implications are encountered through artifacts construction involving meaning making and representation through language and manipulative (Peppler, 2010; Picciano, 2009). Learners express themselves and value the aesthetic qualities of their scientific artworks (final products) that represent their understanding (Kellner and Share, 2007) (*collective intelligence, simulation, distributed cognition, visualization skills*).

Conclusions and further research

The proposed model follows a pedagogy-driven approach rather a technology-driven one since we suggest its implementation in low-tech, information-rich learning environments without computers. The added value of this paper is that it proposes a novel pedagogical model that can serve as a pool of pedagogical approaches and as a framework implemented in various disciplines and grades. A CT curriculum framework for K-6 is an area of research that is still in its infancy (Angeli *et al.*, 2016), so our model is intended to provide a holistic perspective over this area by focusing how to approach the convergence among CT, collaboration and creativity skills in practice rather than what to teach. Based on literature, we explained how multiple moments impact on CT, creativity and collaboration development and presented the linkages among them. Successful implementation of CT requires not only computer science and mathematics, but also imaginative capacities involving innovation and curiosity (The College Board, 2012). It is necessary to understand the CT implications for teaching and learning beyond the traditional applications on computer science and mathematics (Kotsopoulos *et al.*, 2017) and start paying more attention to CT implications on social sciences and non-cognitive skills. Furthermore, there is room for research on how imaginative capacities can facilitate, foster and even predict the CT acquisition in various disciplines. However, there is some research work reporting that imagination is essential in computing, explicit guidelines and experimental applications that show how it can be achieved in practice are scarce. Drawing upon this scarcity, we based our pedagogical model on imagination and on pedagogical approaches that can empower it in relation to unplugged CT and collaboration. CT in this model is seen as a cognitive variable involving problem-solving process disconnected from computer programming. Though an unplugged approach can introduce young students into CT requiring the least amount of cognitive demand and technical knowledge (Kotsopoulos *et al.*, 2017), further research is necessary to define the point at which the unplugged approach should grant its position to the plugged-in approach so that to keep on developing CT skills in a more sophisticated manner (Brackmann *et al.*, 2017).

Brackmann *et al.* (2016) assert that the application of unplugged CT activities should be evaluated in relation to cognitive development improvement to empirically confirm that the CT incorporation into the basic education curriculum is necessary. Even though the combined approach of creativity, CT and collaboration is proposed, empirical studies are still scarce. What is needed is to infuse these skills into school curricula with evidence-based findings across different disciplines and grades, from preschool to higher education. Additionally, the current literature lacks in assuming connections among CT, collaboration, creativity and new media literacy skills. Characteristics of new media literacy skills are inherent elements of CSU and low-tech prototyping methods such as play, collective intelligence and simulation. Therefore, future research should focus on how new media literacy skills are developed through CSU and low-tech prototyping methods, how they can feed back into CT development and whether new media literacy skills can predict the successful CT, creativity and collaboration acquisition. Another interesting direction for future research is the area of learning styles. Kotsopoulos *et al.* (2017) state that many different types of projects support the different abilities, interests and learning styles of students. Future research can be oriented on this field by investigating whether learning styles can predict the engagement level, performance or even the success of students in CT and which learning styles model is the most appropriate to accompany this skill.

Though the presented example (case study) seems to exploit the proposed multiple moments model at optimal level, empirical evidence is needed to show the practical applicability of it in a variety of contexts, not only in primary school settings. Future studies can extend, enrich or even alter some of its elements through experimental applications on how all these macro/micromoments work in practice in terms of easiness in implementation, flexibility, social orientation and skills improvement.

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About the authors

Xanthippi Tsortanidou is a PhD candidate at Open University of Catalonia. She holds a Master in Curriculum Development from the University of Thessaly in Greece. Her research interests include learning design and pedagogies, ICT and collaborative learning. Xanthippi Tsortanidou is the corresponding author and can be contacted at: xtsortanidou@uoc.edu

Thanasis Daradoumis holds a PhD in Computer Science from the Polytechnic University of Catalonia. He combines his role as an Associate Professor at the University of the Aegean, Department of Cultural Technology and Communication with his collaboration at the Open University of Catalonia within the Department of Computer Science, Multimedia and Telecommunications. He is also researcher at the Internet Interdisciplinary Institute (IN3) as well as at the eLearn Center (eLC). His research interests are emotional intelligence, alternative (Holistic) education, learning analytics, e-learning, collaborative, affective and adaptive systems, CSCL. He has been advisor of over 20 MSc theses and 8 PhDs. He has published over 110 Scopus-indexed papers, from which over 20 are articles in *ISI-JCR* journals. He is a member of the editorial board of several international conferences and journals; he has also coordinated or participated in various National and European R&D projects.

Elena Barberá holds a PhD in Psychology (1995) and doctorate extraordinary award for the University of Barcelona (Spain). She is currently Director of the Education and Technology PhD program and she is Full Professor at the Department of Psychology and Education Sciences at the Open University of Catalonia. Her research activity is focused on learning regulation and assessment, learning strategies and processes of teaching and learning in virtual contexts.

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