Computational Thinking Nurturing Skills and Inspiring Pedagogy for Sustainable Education in the 21st Century

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Abstract. Creativity, Innovation, Information search, problem-solving and data treatment are important not only in developed countries where people use many digital objects in their everyday life. Developing countries are necessary concerned by many aspects of the information society and digital era. Even if a large part of the population still does not access to the internet, because of a lack of reliable infrastructure, the information and knowledge societies are imposing their pace of innovation to the entire world. A more and more complex world is coming. Developing countries also feel the need to educate their people and give them the most of the 21st century skillset in order to face this complexity and the new challenges. For this reason, and because some of these competencies can be taught even without computers, Computational Thinking may nurture these skills even in developing countries.

In this presentation, we try to show how the integration of Computational Thinking with collaborative problem-based learning can cultivate learners how to learn and work on a real (authentic) problem together by bridging computer science main concepts and these skills to some efficient collaborative learning methods. Different recent viewpoints from developing countries are presented to show how they face this challenge in their nation.

Keywords: Computational thinking · 21st century skills · Collaborative problem-solving

1 Introduction

Our society is now built on a global scale. The development of each country has an impact on all others. Information processing allows us to regulate the transportation of people and goods from and to any part of the world, according to the special rules of each destination (political: visa, health: vaccination, financial: money change or withdrawal, cultural or religious: clothes and drinks, etc.) Many parts of everyday lives in many countries are already managed by using information processing (bank operation, medicine acts, commercial operations, media production and broadcast, etc.) Our world has reached such a complexity that computers became necessary to help us in managing more and more shift at all levels (individual, family, institutions, country) in

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many domains: Army, Industry, Shopping. Education is often reluctant to change but the complex transformation of the society requires modification of the curricula to give more and more competencies to the citizen of the 21st century.

For [1], Computational Thinking (CT) is a skillset for everyone: not only for computer scientists and programmers. Many of CT concepts are related to Computer Science: correctness, termination, efficiency, determinism, parallelism [2]. The "Great Principle framework" draws Computer Science by the 7 categories: Computation, Communication, Coordination, Recollection, Automation, Evaluation and Design [3]. An interesting vision of the evolution of computer and education is given in [4] where ICT and Computer Science have evolving roles in the education system. In [5], the 4 roots of Computer science are algorithms, machines, languages and information.

As a current example in a developing country to illustrate the situation in teaching and learning digital competencies, a recent study [6] from a school of education in Cuba reports that: "[…] the current development of computer skills is insufficient, it was detected in the limited domain of work algorithms, as a result of the students who enrol in computer courses at the Young Club have little knowledge of the contents of the subject. They are afraid of the challenges and technological advances, so they tend to refuse to change, to develop and do not feel the need to enter the computer world because they do not consider the benefits they can achieve to develop even more professionally this way" [6].

We argue in this presentation that Computational Thinking (CT), and not only programming activity, can contribute to strengthen some of the important competencies of the 21st century skillsets and also that it may serve pedagogical design. Section 2 gives an overview of 5 frameworks on 21st century learning skillset. Section 3 emphasizes bridges between CT, selected competencies and learning design as presented in Table 2. Section 4 offers viewpoints from different developing countries over 3 continents and discussion and conclusion are briefly given in Sect. 5.

2 21st Century Skillsets: An Overview

More broadly, in the 21st century, many competencies are necessary to live in complex societies. In [7] authors decompose the 21st century learning skillset into three categories (to know, to value and to act) and 9 subcategories as presented in Fig. 1.

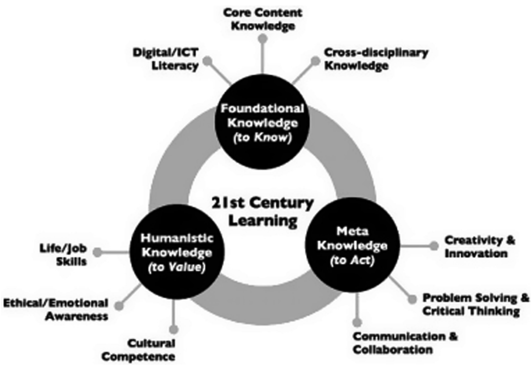

Fig. 1. Synthesis of 15 different 21st century learning frameworks [7]

The Partnership 21st Century Learning framework (P21) developed by Battelle for Kids [8] which are educators, education experts and business leaders who defined skill and knowledge that students require to succeed in their life. The framework is being used by many educators in several countries across the world. Key subjects, i.e. that are essential to student success include English, reading, or language arts, world languages; arts; mathematics, economics; science; geography; history; government; and civics. As presented in Fig. 2, the framework divides skills into three categories: (1) Learning and Innovation skills include creativity and innovation, critical thinking and problem solving, communication and collaboration. The next category is (2) Information, Media and Technology skills including information, media and ICT literacies. The last category is (3) Life and Career skills including flexibility and adaptability, initiative and self-direction, social and cross-cultural skills, productivity and accountability and leadership and responsibility.

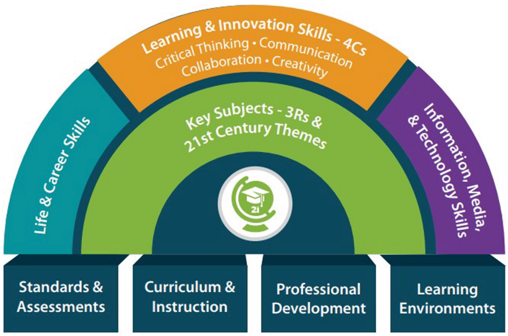

Fig. 2. The partnership 21st century learning framework (P21) schema [8]

Although the P21 Learning framework has gained popularity, a comparable Framework named EnGauge, presented on Fig. 3, was developed in 2003 by the Metiri group and the North Central Regional Educational Laboratory (NCREL) [9]. It proposed four categories of 21st century skills: Digital-Age Literacy (basic, scientific, economic, and technological literacies; visual and information literacies; multicultural literacy; and global awareness), Inventive Thinking (adaptability, managing complexity, and self-direction; curiosity, creativity, and risk-taking; higher-order thinking and sound reasoning), Effective Communication (teaming, collaboration, and interpersonal skills; personal, social, and civic responsibility; interactive communication) and High Productivity (prioritizing, planning, and managing for results; effective use of real-world tools; ability to produce relevant, high-quality products). The framework adds risk taking and effective productivity skills from P21.

Fig. 3. The EnGauge 21^{st} century skills [9]

In 2005, the Organization for Economic Cooperation and Development (OECD) ministries emphasised: "Sustainable development and social cohesion depend critically on the competencies of all of our population – with competencies understood to cover knowledge, skills, attitudes and values." In the Programme for International Student Assessment (PISA), the OECD provided its conception of 21st century skills [10] combining three main categories of skills: Using tools interactively, Interacting in heterogeneous groups and Act autonomously. The highlights of this framework are managing and resolving conflicts skill in the second category. Leadership can be found in "The ability to form and conduct life plans and personal projects" in the third category. The OECD framework is more general than P21.

In 2007, the American Association of Colleges and Universities (AACU) [11] developed and presented their 21^{st} century skills for college graduates who should obtain four categories of the essential learning outcomes. There are Knowledge of Human Cultures and the Physical and Natural World through study in the sciences and mathematics, social sciences, humanities, histories, languages, and the arts; Intellectual and Practical Skills, including inquiry and analysis, critical and creative thinking, written and oral communication, quantitative literacy, information literacy, teamwork and problem solving; Personal and Social Responsibility, including, civic knowledge and engagement - local and global, intercultural knowledge and competence, ethical reasoning and action, foundations and skills for lifelong learning; and Integrative Learning, including synthesis and advanced accomplishment across general and specialized studies. This framework points out the necessity for graduates to have a curiosity about either arts or science and analytics skills such as inquiry and quantitative analysis.

Among the various skillsets referenced here above, we point out in Table 1 hereafter, the important skills shared on which CT may have an impact. And for each of these skills, we show the name of the global category it appears in each framework.

Table 1. Selection of skills from 5 frameworks

Skill	Kereluik's framework	P21	EnGauge	OECD	AACU
Creative thinking	Meta knowledge	Learning and thinking skills	Inventive thinking	–	Intellectual and practical skills
Critical thinking and problem-solving	Meta knowledge	Learning and thinking skills	Inventive thinking + high productivity	Interacting in heterogeneous groups	Intellectual and practical skills
ICT literacy	Foundational knowledge	ICT literacy	Digital-age literacy	Using tools interactively	Intellectual and practical skills
Collaboration	Meta knowledge	Learning and thinking skills	Effective communication	Interacting in heterogeneous groups	Intellectual and practical skills
Communication	Meta knowledge	Learning and thinking skills	Effective communication	Using tools interactively	Intellectual and practical skills
Leadership	Humanistic knowledge	Life skills	High productivity	Act autonomously	Intellectual and practical skills

3 Bridging Skills, Computational Thinking and Learning Methods

People tend to be a good collaborator when they share a common problem with others: the problem makes sense for pupils when it's authentic and realistic in their own environment. Problem-Based Learning (PBL) was initially used in medicine learning [12] but [13] showed that PBL method was widely used not only in medical education but in K-12, college level, and many fields of professional education.

Collaborative Learning (CL) involves groups of students working to solve a problem, complete a task or create a product [14]. CL is different from a traditional group learning in that CL is a well-organized method for learners to harmonize and to work along together with their own capabilities and expertise on tasks, not just dividing the assignment into pieces and assign to every single member. The Jigsaw Classroom [15] is one of the many approaches based on these concepts. In this method, a problem is given to many home groups in which, each team member is responsible for one part of the problem. Then, each member of all home groups will meet other pupils in specialized expert groups to solve their common specialized part of the problem. Then, home groups meet again to try to assemble the different partial solutions in order to solve the initial global problem.

CT could be involved in many ways of 21st-century skills' learning since it is required to think systematically. The algorithm is one of the main concepts encouraging learners to be able to solve the problem and improve their action step by step. For this reason, CT is an excellent introductory course for an experimental approach: hypothesis -> experiment -> validate or not.

Since the early stages, education must be efficacious on the method of information search. The Jigsaw could be a good way for example if expert groups have to find the missing part of the information. This method can also inspire students: naïve initial solutions may be discussed with experts to find or build a better one. In CT, this is called the optimization process.

Table 2. Bridges between selected skills, computational thinking and learning design

Selected skills	Computational thinking	Learning design
Problem-solving: complexity of a real-world authentic problem can be decomposed into smaller ones and solved by different specialized teams	"Computational thinking is a way humans solve problems; it is not trying to get humans to think like computers" [1] The decomposition can lead to specialized processes to treat the pieces of the whole problem (data or process)	**Problem-based learning** [12]. Jigsaw [16] is a collaborative learning method that implements this idea of decomposition and specialization
Information management: Managing data, information, knowledge and cultural heritage	Data (bit, Boolean, pixel, character, table, image …) representation, storage, access, and treatment are the basics. CT is the ability to "use big amounts of data to speed up computation; to see data as code or code as data" [1]. CT helps to define Boolean expressions like information search criteria. To reduce the information space by adding keywords or cutting branches. This is an evolving process (try and check until find and validate)	Learning is building knowledge upon previous data, experience, knowledge, information, using all accessible sources. **Inquiry learning** relies on information management. This can be applied individually or collaboratively. The collaborative version would promote peer-to-peer teaching and interactions
Critical thinking: reasoning and being able to take distance with arguments. Each position is supposed to be validated by an authority, personal experience or by empirical data	"CT is thinking in terms of prevention, protection, and recovery from worst-case scenarios through redundancy, damage containment, and error correction" [1]. Considering	The **debate** is one of the many learning activities that needs critical thinking. The socio-cognitive conflict [17] is more generally the suitable situation that needs critical thinking ability. The

(*continued*)

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Selected skills	Computational thinking	Learning design
	the validity and optimality of a solution is also CT. Curiosity: to look inside the black box. From early stages, pupils have to discover, understand and experiment that technical objects that are emerging in our everyday lives, are not magical but follow algorithms, limited rules that organize their processes and behaviours. These considerations may help critical thinking	cognitive conflict also arises when the theory needs to be confronted with experimentation. **Project Based Learning** may often lead to such confrontation
Creativity, Innovation: Think globally and act locally. Don't reinvent the wheel but cite its inventors, so that you may invent tomorrow's world	In a programming learning context, [17] show how the Scratch network of publicly available projects give opportunities to the Scratchers to develop their creativity: "Creativity and learning are deeply social practices […] "I can do different things when I have access to others" This enhances the need for collaboration and communication	Constructionism [18] is a well-known learning theory implemented in methods by "learning by making". Physical space and materials may be limited by physics laws where virtual ones may relax some constraints **Design thinking**: a method that may be used in the learning context
Collaboration and Communication: For authentic real size complex problems, collaboration became the major way to tackle them and communication is the necessary ingredient for collaboration	Sharing ideas and applying them to new contexts (by shifting various levels of abstraction), we can find solutions for parts of a problem. Computational thinking promotes multilevel abstraction and transfer of solutions. This can be achieved only by collaboration and communication. Information and Language are 2 of the 4 pillars of Computational thinking for [5]	**Learning** is a **social process.** "One learns alone, but never without the others": Learning needs an individual engagement and a community as context. Interaction, communication and collaboration are promoted by many learning methods. The **Jigsaw** may be one of them

In Table 2, we showed that CT, that can be studied from an early age, can be used to cultivate many facets of important skills and especially those presented in Table 1.

Furthermore, while enhancing learning by CT, learners can acquire leadership skill step by step which are: first level – planning, learners learn by thinking how to create a thing in steps, second level – solving a complex problem by splitting it into small pieces and the last level - parallel and distributed programming, how to properly assign tasks to processors or operators.

4 Application Examples

4.1 How Much Computational Thinking Is Considered by Educators in Latin America?

In February 2019, the conference entitled "*Pedagogía 2019: Encuentro internacional por la unidad de los educadores*" took place in Cuba. There were more than 2200 participants from 37 countries. The event official language was Spanish, but contributions were accepted also in English, Portuguese or French. The conference was split into 12 parallel sessions covering many aspects of Education at large. Each session produced its own proceedings. Among the 1550 articles in the proceedings, the vast majority was written in Spanish. We analysed the 17146 pages of the 12 conference proceedings, looking for occurrences of "*pensamiento computacional*" or "*pensamiento algorítmico*". Even if many countries consider computational thinking crucial to be taught in their schools, these expressions occur in only 5 articles among 1550 in 3 (among 12) chapters of these conference proceedings (Table 3).

Table 3. "Computational thinking" occurrences in "*Pedagogía 2019*"

Article	Title	#Occurrences
ESU	Current grand challenges of the pedagogical innovation in higher education [19]	1
TIC004	ICT strategy to strengthen problem-solving competence through computational thinking [20]	12
TIC140	Scratch in Education [21]	1
TIC141	Activities to develop skills using Scratch [22]	3
CED009	Didactic model for the development of algorithmic thinking in the systems engineering program [23]	6
Total	Pedagogía 2019 [24]	23

The first occurrence is in the conference of a University Rector in the chapter "Higher Education: challenges facing the 2030 Agenda" (ESU). This unique occurrence of CT is situated in the introduction in the following argument (translated):

"Information and knowledge societies generate new possibilities and challenges. They change the role of the teacher. The policy of technologies for a State becomes crucial. The use of technologies is the new school's alphabet. The distinction between knowing and learning helps us define the specificities of institutional spaces dedicated to education. Memory ceases to be a requirement after a long period in the realm of education. **Computational thinking** advances between fears, ignorance and uncertainties. Biology, genetic engineering and information technology become the disciplines of the future."

In the next 3 articles, belonging to the TIC chapter (ICT), we find contributions measuring the impact of the use of digital tools (EVA or Scratch) on problem-solving competencies for learners (in high school for the first and in primary school for the other two). Moreover, they emphasize positive shifts in more general learning attitude. In the conclusion of [21, 22], we can read:

"The Scratch is a development option for students and teachers can open doors to the healthy and intelligent enjoyment of technological means available to the school and the student. It is a tool to teach thinking logic, to learn and to show everyone that technology can be used not only as users but also as producers of content and games necessary for these ages. Scratch is a door to the development needs of the 21st century, of the world and to place Cuba in an international curricular standard, with the simplicity, modesty and intelligence that our development conditions demand" [21].

The last one, included in the CED chapter (Educational Science) presents a project design which aim is to define a didactic model in a school of engineers on systems.

4.2 Teaching CT in Thailand: An Example

The research in teaching CT through mobile technology and robotics by Phetsrikran et al. [25] is one example of a CT's application in Thailand. The study was conducted with grade 7 and 8 pupils in a provincial school in Thailand with 20 pupils. The research's purpose is to teach CT using technology such as robots and mobile technology. Pupils were divided into four groups with five team members. The brief introduction was given how to use the robot and command the robot with block coding via mobile device under less than five minutes. Then pupils had 2 h to solve as much tasks and puzzles as possible with at least assistance from an instructor. The result of the study is not only pupils improved CT skills but they gained better social interaction and enhanced collaborative skill.

In Thailand's public policy level, the new discipline in K-12 schools based on CT's concept namely "Computing Science" [26] was launched in May 2018. The objectives of this discipline are defined by levels of pupils in the school. The first level targets to pupils from grade 1 to 3, they learn solving simple problems using the troubleshooting steps, basic skills in using information and communication technology and protect their personal information. Next level, pupils from grade 4 to 6 learn to search for information effectively and evaluate reliability, deciding on information, using logical reasoning to solve problems, using information and communications technology in collaboration, understanding their rights and duties, and respecting the rights of others. Inputting primary data into the computer system; analysing, evaluating, presenting data and information with correct purposes; using computational thinking skills to solve real-life problems and write simple computer programs to solve problems, using information and communication technology knowingly and socially responsible are skills that pupils from grade 7 to 9 will be cultivated. The last level for pupils from grade 10 to 12 who will learn about applying of knowledge in computing science, digital media, information and communication technology to gather real-life data from various sources and knowledge from other sciences in order to create new contribution, understanding the change of technology that affects life, career, society, culture and safely use with ethics. Several learning concepts are applied in the classroom like peer-to-peer learning, creative-based learning, collaborative learning and real-life problem-based learning. Self and peer assessments are applied to evaluate pupils with summative assessment such as learning portfolio and subjective and objective tests.

4.3 Africa: 2 Examples

A first famous example that rid the world through social networks is the story of this Ghanaian teacher teaching word processor with (only) a chalkboard [27].

This story became famous especially when the Microsoft Corporation decided to help this teacher by a donation. However, as this teacher says: this was not possible because of the curriculum that imposes that students understand how to charge the system and configure the computer before any use of it. This example shows many interesting aspects. First, the passion and energy of this teacher to do his job. Second, the importance he puts in the ability to use a word processor. Third, the mismatch between this important need and (a) the material he can use and (b) the institutional constraints.

The second example on this continent is quite old. It is the story of a Swiss association "African puzzle" [28] that installed computer classrooms in Benin and proposed a truck for a mobile computer classroom. It deals with cooperation from a European country to help a developing country to access to the computer in order to develop ICT and related competencies. In this second example, we can see the importance of human exchange between association members (donators) and local teachers and technicians (receivers). Beyond technical problems due to lack of infrastructure, we can see such initiatives as impressive. They give unique opportunities to many pupils to experience moving a mouse and clicking on it to see the result on a real computer, not only on a video or a chalkboard.

There are also more positive examples of creativity using cultural handicraft abilities to produce (street) art from recycled material like for example: the African robots project [29] in Cape Town. Another impressive demonstration of engineering competencies in Africa (Kenya) is the first fly experience of the passenger drone project described in [30].

5 Discussion and Conclusion

The skills selected in Table 1 are important not only in developed countries where people use many digital objects in their everyday life. Developing countries are necessary concerned by many aspects of the information society and digital era because they are crossing frontiers and oceans: data and information on a natural phenomenon like a tsunami or earth quacks, meteorological forecast, migrations, transportations, global market, political shifts on the international scene. For this reason, and because it can be taught even without computers, CT may nurture these skills in order for the people to get more capacity to face new complex challenges. Especially in so-called developed countries, we are ingenious to build smart solutions for the next generation of smart houses, cities, aircraft and so on, but when we go back home by using one car per worker, we are still unable to collaborate and solve rush hours' traffic. Even if we face this problem every day as a citizen, we are still not able to solve it as a community.

In developing countries, we may consider this problem by using the experience of so-called "developed countries". For example, access to the internet is seen for educators in developing countries as a mine of information and knowledge. But we can also witness the time the children in developed countries are wasting in front of online dummy games! This should help us to design better curricula in schools in order to make learners more critical thinkers.

However, the problem to be solved, or the context of this problem, should be reachable by the learner. As a counterexample, this Ghanaian teacher on ICT that teaches Word processor by drawing the MS Word interface on a chalkboard [27]. Does it make sense if students never can use a computer to validate their learning? If they never confront theory to practice, an algorithm to a machine by an execution? In this presentation, we tried to show how the integration of computational thinking with collaborative problem-based learning can cultivate learners how to learn and work on a real (authentic) problem together. We also present some examples of Computational Concepts that can be connected to teaching methods and we suggest to use them to strengthen the skills selected among the various 21st century skillsets.

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