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Coding and educational robotics and their relationship with computational and creative thinking. A compressive review

Codificación y robótica educativa y su relación con el pensamiento computacional y creativo. Una revisión compresiva

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Abstract
New technological tools, technology-based services and support are being introduced into our daily lives faster than ever. Among these technological advances robotic technology has increased dramatically in recent years, the same as its inclusion in education. The purpose of the paper is offer a compressive review about computational and creative thinking definitions and its measurement, furthermore, its relationship with coding, educational robotics and the maker movement. The review is based in the most cited papers publish in the last 10 years, retrieved from google scholar and other prestigious databases. The review has showed that with the use of coding and robotics kits there is generally no correct way to solve a challenge, and computational and creative thinking are related to find efficient and good solution to problems. Not having a correct answer but multiple ways of addressing a problem is an experience that many teachers are not familiar with. That is why more scientific research is needed in this regard, in terms of successful interventions that show evidence and good practices that serve as training and guides teachers.
Key words: coding, educational robotics, computational thinking, creative thinking.

Resumen
Nuevas herramientas tecnológicas, servicios basados en tecnología y soporte se están introduciendo en nuestra vida diaria más rápido que nunca. Entre estos avances tecnológicos, la tecnología robótica ha aumentado dramáticamente en los últimos años, así como su inclusión en la educación. El propósito del trabajo es ofrecer una revisión compresiva sobre las definiciones de pensamiento computacional y creativo y su medición, además, su relación con la codificación y la robótica educativa. La revisión se basa en los artículos más citados publicados en los últimos 10 años, recuperados de Google Scholar y otras bases de datos prestigiosas. La revisión ha demostrado que, con el uso de kits de codificación y robótica, generalmente no hay una forma correcta de resolver un desafío, y el pensamiento computacional y creativo está relacionado para encontrar una solución eficiente y buena a los problemas. No

tener una respuesta correcta pero múltiples formas de abordar un problema es una experiencia con la que muchos maestros no están familiarizados. Es por eso que se necesita más investigación científica a este respecto, en términos de intervenciones exitosas que muestren evidencia y buenas prácticas que sirvan como capacitación y guíen a los maestros.
Palabras clave: codificación, robótica educativa, pensamiento computacional, pensamiento creativo.

1. Introduction

The speed of change in our society has accelerated since the birth of the Internet and will accelerate rapidly through the implementation of artificial intelligence (AI) innovations, for example, in health and social care, in transport and education, as well as in the learning analytics. New technological tools, technology-based services and support are being introduced into our daily lives faster than ever. Among these technological advances, especially AI, robotic technology has increased dramatically in recent years. News headlines from major news sources, including the New York Times, CNN, Wall Street Journal and BBC, frequently present several robotic innovations, which is a strong indication of this phenomenon (Yiannoutsou, 2017).

The need for competencies development in rapidly changing societies has been debated throughout the world (Zapata, 2015) and these have been called 21st century skills/competencies or generic/transversal competences. These 21st century competencies describe the wide range of competencies necessary to fully participate in modern societies and support the employability of citizens. However, there are several definitions and connotations related to these competencies. For example, UNESCO (Five Pillars) emphasizes the definition of learning and education for sustainable development. The OECD (DeSeCo) analyzes skills, which meet complex demands, by mobilizing psychosocial resources in different contexts. The EU (lifelong learning, 8 key competences) analyzes the competencies (knowledge, skills and attitudes) necessary for personal fulfillment, active citizenship, social inclusion and employment (Voogt and Roblin, 2012). For example, according to one traditional description, DeSeCo (OECD, 2005), people in the 21st century must be able to use a wide range of tools, including socio-cultural (language) and digital (technological) tools, to interact effectively with the environment, engage and interact in a heterogeneous group, carry out a work oriented to research and problem solving, assume responsibility for managing their own lives and act autonomously. In this environment, both, computational and creative thinking, including the maker movement, are necessary to learn these skills.

The purpose of the paper is offer a compressive review about computational and creative thinking, its measurement, furthermore, its relationship with coding and educational robotics and the maker movement.

2. Research method

A systematic review process as outlined by Jesson, Matheson & Lacey (2011) was applied to gather, synthesise and appraise the findings of studies which explore the relationship between coding and educational robotic to computational and creative thinking, and maker movement (Table 1).

Table 1. Process of systematic review.

Aim	Relationship between coding and educational robotic to computational and creative thinking, and maker movement
Search strategy	Boolean search using: Coding OR programming OR programing (Title), educational robotics (Title), AND computational thinking OR creative thinking (Abstract), OR maker (Abstract)
Inclusion criteria	Research focused on the link between coding and educational robotic to computational and creative thinking, and maker movement. Full text, peer-reviewed, scholarly articles, empirical research.
Exclusion criteria	Studies on: tertiary or university students, programming related outcomes, learning technologies other than coding or robotics and literature reviews.
Quality appraisal	Adapted from Critical Appraisal Skills Programme (CASP) checklist and notes on validity and reliability from Johnson & Christensen, 2016.
Data extraction	Read studies and collect relevant information.
Synthesis of data	Narrate the evidence of educational outcomes related to coding, educational robotic, computational and creative thinking and maker movement from the data extraction which identifies themes, similarities and differences.
Report	Results analysed and summarised in a model created to demonstrate the impact of coding and educational robotic to computational and creative thinking and maker movement development.

The main criteria for inclusion was empirical research that explores computational and creative thinking and maker movement within a school coding and educational robotic curriculum. Specific databases were initially searched, these included, Education Source (EBSCO), ProQuest Central, Scielo, Redalyc, Scopus, Springer and Google Scholar. These databases together provided access to an extensive and broad range of education journals and indexed conference proceedings. The initial search included the key words defined (Table 1). This identified a large number of articles focusing on the topic. Therefore, a filter was used to limit the keywords to within the title. It could be possible that not all relevant research would have these words in the title. Other key terms which through a process of trialling terms to optimise results included requiring the terms school OR children AND skill OR thinking in the abstract. Filters were used to include only articles from peer-reviewed sources. No time frame was filtered, any way the focus was the last 10 years, most articles retrieved were published between 2011 and 2019.
The search strategy identified 143 potentially relevant research articles in October 2019. Due to the risk of potentially excluding relevant articles exclusions was made manually through three stages. The first involved reading the title of each article, those that appeared possibly relevant were scrutinised further through the reading of the abstract or preview then a third stage involved reading full articles. The search strategy was undertaken independently by two reviewers to reduce individual bias, and ensure the reliability of the process. Finally, 31 paper were considered for the review, and its results and contributions were synthetized and commented by author in a narration way.
The structure of the review was: comment definitions of computational and creative thinking and maker movement, then measurements of the computational and creative thinking, and finally, how coding with robots, and maker initiatives can develop CT and creativity.

3. Results and discussion

3.1. Definitions framework

Computational thinking

Computational thinking (CT) has gained great attention in the field of education in recent years, especially after the launch of Code Hour in December 2013 in the EE.UU. And England implemented its computer education in 2014 (García-Valcárcel, and Caballero-González, 2019). In a seminal article on computational thinking by Jeannette Wing in 2006, she predicted that computational thinking would be a fundamental skill used by everyone in the world in the mid-21st century, and define CT as a sort of analytical thinking skill, which includes components such as problem solving, system design and understanding of human behaviour based on the concepts of computer science (Wing 2006).
In general terms, computational thinking consists of problem solving using basic concepts, procedures and development of programs and algorithms in computer science,

and can help develop as: creativity, problem solving, abstract thinking, recursion, iteration, collaborative methods, patterns, among others. In this respect ISTE (2018) describes computational thinking as the capacity to develop and utilize strategies to understand and find solutions to problems with the help of technological (computational) methods.

However, there is a more holistic approach to what computational thinking is. This refers to the set of skills and other elements of cognitive and procedural development that we can find in the skills that serve programmers to do their homework, but which are also useful to people in their professional and personal lives as a way of organizing the resolution of their problems, and of representing the reality around them. These complex skills we said that it constitutes a new literacy (Zapata-Ros, 2015) --- or the most substantial part of it --- and an inculturation to handle a new culture, the digital culture in the knowledge society. In this way Zapata-Ros (2015), has determined 15 of these elements, among which there are as diverse as ascending thinking, descending thinking, pattern language or synectics. Without ruling out the classics of "successive approximations or trial error, problem solving and abstract thinking.".

Unplugged computational thinking

Particularly important in this context is what has been called *unplugged* computational thinking (CT), which Zapata-Ros (2019) refers to the set of activities and its educational design, which are developed to encourage children, in the first stages of cognitive development (early childhood education, first tranche of primary education, home games with parents and friends, etc.), skills that can then be evoked to support and enhance a good learning of computational thinking in other stages or in technical, professional or even university training. Activities that are usually done with chips, cards, board games or playground, mechanical toys, etc. And that has been incorporated into the official curricula of some countries and economies such as Singapore and Hong Kong.

The characteristic of problem solving, such as building a robot or developing a code, is a process that consists of different steps (for example, problem formulation - evaluation of ideas - choice of solution - test and evaluation). This process requires critical, creative and computational thinking. In general, critical thinking is the analysis of facts to form a judgment. However, there are various types and situations for critical thinking and there are several different definitions, which generally include rational, skeptical, impartial analysis or the evaluation of objective evidence. And creativity is understanding as a context-related process to generate or recognize ideas, alternatives or possibilities to solve problems individually or in collaboration with others, and can be considered as original, valuable and useful by a reference group.

This definition by accumulation of skills has also been formulated by Professor Shuchi Grover (2018), of Stanford, who also points out the difficulty of defining the CT, and then adopts the position of defining it by breaking down the skills as its component parts. So most of them involve or are skills, but they are always easy to operationalize (they are all central parts of computer science, educators and researchers have found that it is easier to operationalize for the purposes of teaching, curriculum and evaluation design) and above all they are possible to include in an educational design.

These are skills that include powers to operationalize logic (logical thinking), algorithms (algorithm), patterns, abstraction (abstract thinking), generalization (ascending thinking), evaluation and automation. It also means approaches such as "breaking down" problems into subproblems to facilitate resolution (downward thinking), creating computational artifacts (usually through coding); reusing solutions, testing and debugging (trial and error); iterative refinement (iteration). Finally, he points out that the CT “also implies collaboration (collaborative methods) and creativity”. So this definition also by accumulation coincides in ten of the fifteen elements of the previous definition.

There is another basic coincidence and it is that in the Grover article (2018) the relevance of Computational Thinking is pointed out in that it constitutes one more to those already accepted as competences for the digital society. In any case, what both developments have in common is that computational thinking is a point of cultural inflection, a new literacy.

Creative thinking

Creativity plays an important role in human inventive potential in all fields, and its influence controls many spheres of life (Hershkovitz et al., 2019). There is increasing consensus that creativity is an essential skill for the twenty-first century, and, as such, it should be included in the curriculum from an early age. Supplying students with opportunities to engage in creative ways may promote not only their academic success, but also the ways they manage their learning, the affective aspects of their learning, and their attitudes towards learning (Davies et al., 2013; Romero, Lepage, & Lille, 2017).

It is difficult to identify what “creativity” is, however, and there are many conceptualizations. Paul Torrance, over 50 years ago, defined creativity as the process of becoming sensitive to problems, deficiencies, missing elements and gaps in knowledge, identifying problems, seeking solutions, formulating hypotheses, examining the hypotheses and rephrasing them, and then communicating the results (Torrance, 1965).

Torrance suggest that creativity covers four areas: (1) fluency, or the capacity to generate a large number of ideas and directions of thought for a specific problem; (2) flexibility, or the capacity to think about as many uses and classifications as possible for a particular item or subject; (3) originality, or the capacity to think of ideas that are not self-evident or banal or statistically ordinary, but unusual and occasionally even refuted; and (4) elaboration, or the capacity to enlarge an existing idea, to develop and improve it by integrating existing schemes with new ideas.

In this sense, creative thinking is needed when generating and playing with unusual and radical ideas related to the problem or design. Creative thinking can be stimulated by both an unstructured process and brainstorming, as well as by a structured process such as lateral thinking (Fisher, 2005). On the other hand, computational thinking is necessary for solving problems in the context of the design of a code or robot. It is necessary to design algorithms that make computers do jobs and to explain and interpret the world as a complex of information processes. The characteristics of computational thinking are decomposition, pattern recognition or data representation, generalization or abstraction and algorithms (Grover and Pea, 2013).

The associations between CT and creativity have been recently studied (Hershkovitz et al., 2019), and preliminary evidence suggest some interesting links between these constructs. However, exist a gap regarding the relationship between only some types of creativity. Likewise, most of the relevant studies have only focused on aggregated measures of creativity (Roque, Rusk, & Resnick, 2016). Hershkovitz et al. (2019) suggest bridging this gap by operationalizing a “continuous” (rather than aggregated) measure of CT-related creativity, and to test for its associations with a standard measure of creativity.

The maker movement

According to Halverson and Sheridan (2014), the maker movement emphasises active involvement in the use of knowledge and creative design, the production of physical and digital artefacts in maker spaces, and sharing these artefacts with others. Digital tools and devices have made it possible to promote a new kind of entrepreneurial spirit in terms of designing products and providing services for other people.

In the context of school, maker-spaces are often aimed to use for learning of competences, described, for example, in science and technology curriculum. Moreover, working in a maker space is often supposed to support the learning of generic competences or 21st century competences, like creative and computational thinking skills. In order to achieve subject specific and generic competences an appropriate pedagogy is need for supporting the working in the maker space.

Some researchers have go around to the maker movement for a more integrated approach to develop computational and creative tinking skills (e.g., Brennan and Resnick 2012; Brady et al. 2016). Making imply developing an idea with the use or creation of a tangible artefact. Coding is part of the maker movement. Students can connect with people from all over the world to code, for example, robotics, machines, games and a wide array of digital maker projects. Because makerspaces have roots in the hackerspace culture, computing and technology play a key role in problem solving and product development (Cavalcanti, 2013).

Students in a maker space are identified as having a STEM culture, and the keys to the advancement of this culture are learning and working with others. In summary, this movement, especially when include coding and robotics, can develops skill and actitudes like:

- Encourage the use of classroom programming
- Use of programming in schools and institutes using programming to be able to develop creative and computational thinking.
- Make interactive projects that facilitate the learning of any subject without being related to technology.
- Start in the world of electronics and robotics.
- Build electronic components to they liking.

- Interact with the outside world through actuators based on the environmental variables we read through the sensors.

An experience improving the Finnish basic school curriculum through maker-based learning

The maker movement in Finnish education dates to 1866, when craft education was accepted as a compulsory subject in the school curriculum (Rasinen, Ikonen, & Rissanen, 2006). The subject emphasised design, innovation, creativity, and aesthetics, as well as use of science and mathematics knowledge in the design activities. Workshops were established in every school for supporting students design, create, and share useful artefacts. Therefore, there has been a long "maker-tradition" in Finnish compulsory school.

In the past ten years, the challenges of the Finnish education system were discussed in a similar way to Taiwan and Singapore, as described in this introductory section. The discussion was done, for example, in different forums and national projects, such as the National Teacher Education Forum (MEC, 2016), the Basic Education Forum (MEC, 2018), The following questions have guided the discussion (Vahtivuori-Hänninen, Halinen, Niemi, Lavonen, Lipponen, & Multisilta, 2014):

- What types of competences will be needed in future?
- What kinds of practices at school produce these competences?

These questions facilitated also the discussion during the design of the National Core curriculum for Basic Education (NCCBE) (FNBE, 2014). The NCCBE introduced transversal competences, which were grouped in the following categories: taking care of oneself; managing daily life; multiliteracy; digital competence; working life competence; entrepreneurship; participation involvement; building a sustainable future; thinking and learning how to learn; and cultural competence, interaction, and expression. In order to achieve these transversal competences, the curriculum recommend that teachers encourage their students to engage in scientific and engineering practices (cf. Krajcik & Shin, 2015), like:

- critical and creative knowledge practices, such as searching for information and generating new ideas
- collaborative knowledge building, and the use of knowledge in different situations
- constructing and working with abstract or concrete artefacts, like texts and concept maps, Lego robots, and 3D printers, along with digital tools in different learning environments both in and out of school

Consequently, the original idea related to the use of workshop in design and creative activities have resurfaced in the NCCBE.

In addition to describing the transversal competences included in the NCCBE, the goals for these competences were examined through subject-specific aims of the curriculum. This approach was intended to help teachers understand the meaning of the competences and how they should be developed (Halinen, 2018). The science and technology curriculum, as a part of the NCCBE, emphasised core scientific and technological knowledge, with inquiry and design processes being promoted as necessary for learning science. The inquiry and design processes included both critical and creative thinking, which are also considered to be essential transversal competences including computational thinking.

During the inquiry process, critical thinking is needed to identify research questions and connect a specific claim with evidence. Creative thinking is also required when designing an artefact because students must consider unusual and radical ideas related to the design. Furthermore, they need to develop their critical thinking skills while taking into account several points of view related to the design and evaluation of their ideas. Maker activities are also useful for promoting scientific and engineering practices, as they teach students to study both the natural world and the world of design, making them effective for achieving the aims outlined in the NCCBE. Digital tools can be used for building designs that are apt for 3D printers. While engaged in maker activities, students generate innovative ideas, as well as create and develop interesting things in digital and concrete forms, using both new and old technologies. Such activities encourage students to take part in the creation process and start making things on their own (Dougherty, 2013; Martin, 2015).

Many development and research projects, competitions, and TV series have been supportive of the maker movement. For example, the six-year LUMA-SUOMI programme (2013-2019) (Luma Suomi Ohjelma, 2018[1]), funded by the Ministry of Education and Culture for €5 million euros, is responsible for increasing the quality of science learning and outcomes, including creativity and student engagement in cooperation with teachers, schools, parents, administrators, and stakeholders.

Currently, there are several research projects in Finland focused on developing innovations in education, including maker activities and coding with new block-based programing (e.g. Scratch), that follow the new curriculum. For example, Professor Kai Hakkarainen is leading the Co4-Lab (2018)[2] project, which supports pedagogic development in schools by using long-standing research. Practices of invention pedagogy are developed together with schools through repeated explorative cycles of investigation. The project is committed to the open sharing of pedagogic innovations and seeks collaboration with schools committed to pedagogic development. Co4-Lab also organises inspiring maker and creative school projects in primary and lower secondary schools.

In a competition called *This Is Working – Moving Toy*, only certain materials, specified in the list of materials, can be used in the construction of a moving toy. The toy must be creatively designed from materials recycled in the school, so nothing needs to be purchased. This encourages students to think about the rational use of materials: what is needed, and how to make it. Ideas should be discovered by the children themselves or in

[1] Luma Suomi Ohjelma (2018). LUMA FINLAND program - National Program for the Development of Primary and Lower Secondary Education in Natural Sciences and Mathematics 2014-2019. https://suomi.luma.fi/blogi/

[2] CO4-Lab. 2018. https://www.helsinki.fi/co4lab

cooperation with one another. The competition is organised each year; local competitions are held all over Finland, followed by a nationwide final competition.
In summary, at a strategic level, the maker movement is well-recognised and emphasised in the NCCBE. Several examples of maker-related development and research projects exist, and they continue to support the development of maker-based education with new focus in emergent competencies like computational thinking.

3.2. Measuring computational and creative thinking

Various researchers have explored the assessment approaches for CT (Brennan & Resnick, 2012; Werner, Denner, Campe, & Kawamoto, 2012). However, there is a lack of effective approaches to comprehensively assessing CT, especially since the concept of computational thinking is not very clear, its measurement becomes more difficult. In this sense, two bodies of literature to assess the CT effective are available: one is to seek out an operational definition of CT, and the other is to figure out an appropriate assessment approach. One important challenge in assessing learners' CT is the difficulty in evaluating the problem-solving skill. The ability of identifying, debugging, and solving problems is at the core of being able to fulfill a computational task (Pala & Mıhçı, 2019).
Existing work has often focused on assessing student created artifacts, for instance educational robots, for CT skills in a variety of settings. For example, Koh, Basawapatna, Bennett, and Repenning (2010) established a real-time CT assessment system that stresses semantic analysis of student-created games or simulations and visualizes students' learning in terms of some CT patterns. Similarly, but focus on games, Werner, Denner, Campe, and Kawamoto (2012) tested students' CT learning by implementing three challenges in a 3D gaming environment powered by Alice[3] and examined several factors (parental education, mother languages, high school grades, etc.) and their relationships to students' CT performance.
Particularly, in the use of Scratch environment[4], Seiter and Foreman (2013) proposed a CT assessment framework and confirmed its efficacy by applying it to 150 Scratch projects done by students from grade one through six. Correspondingly, Bers, Flannery, Kazakoff, and Sullivan (2014) evaluated children's written programs after each activity of their curriculum to determine the students' CT learning patterns. Finally, Rodríguez-Martínez, González-Calero & Sáez-López (2019), analyse the potential of programming activities using Scratch for both the learning of mathematical ideas and the acquisition of computational thinking in sixth-grade students, and the results seem to indicate that Scratch can be used to develop both students' mathematical ideas and computational thinking.
As exposed in the above examples, the majority of existing CT assessments focus more on examining student products and artefacts, after they have learned a particular

[3] http://www.alice.org/index.php
[4] https://scratch.mit.edu

programing platform. Others, only take in account some of the elements of CT. This limitation prevents such assessment method from being used as pre/post measure of a specific curriculum, and provide an partial evaluation of CT.

Moreover, many studies give an interpretation of CT as a fundamental ability that can be transferred across platforms. This is particularly important given the proliferation of many coding and robotics platforms for the elementary level (e.g. LEGO family, Creative Hybrid Environment for Robotic Programming, VEX Robotics Design System and Virtual robot's software like RoboMind) and a need for assessment tools that cover many platforms.

Without being exhaustive and focusing on K-12 education Román-González, Moreno-León & Robles (2019) propose an interesting classification that help to understand the wide range of CT assessment tools and its insufficiencies, and can be applied to creativity too, classified depending on their evaluative approach:

CT diagnostic tools: They are aimed at measuring the CT aptitudinal level of the subject. Their major advantage is that they can be administered in pure pretest condition (e.g., subjects without any prior programming experience).

CT summative tools: Their goal is to evaluate if the learner has achieved enough content knowledge (and/or if he is able to perform properly) after receiving some instruction (and/or training) in CT skills.

CT formative–iterative tools: They are aimed at providing feedback to the learner, usually in an automatic way, in order to develop and improve his/her CT skills. Strictly speaking, these tools do not assess the individuals, but their learning products, usually programming projects.

CT data-mining tools: These tools, like the previous ones, are focused on the learning process. Nevertheless, while the formative–iterative tools statically analyse the source code of the programming projects, the data-mining tools retrieve and record the learner activity in real time.

CT skill transfer tools: Their objective is to assess to what extent the students are able to transfer their CT skills onto different kinds of problems, contexts, and situations.

CT perceptions–attitudes scales: They are aimed at assessing the perceptions (e.g., self-efficacy perceptions) and attitudes of the subjects not only about CT, but also about related issues such as computers, computer science, computer programming, or even digital literacy.

CT vocabulary assessment: Finally, these tools intend to measure several elements and dimensions of CT, when they are verbally expressed by the subjects.

3.3.Coding with robots to develop CT and creativity

Pala & Mıhçı, (2019) affirm that it is a common belief that one of the most effective ways of developing skills in computational thinking process is through computational programming education. In this line, Lye and Koh (2014) indicate that coding works as a key to computational thinking. Likewise, Sayın and Seferoğlu (2016) indicate that coding, which is as an academic skill, is considered to be a part of logical reasoning and also as one of the skills named "twenty-first century skills".

With programming education, it is detected that students develop abilities such as problem solving, creative thinking, critical analysis, systematic experimenting and continuous learning (Monroy-Hernández & Resnick, 2008). The studies showed that programming education had a direct link with CT, creative thinking and product building skills. In Oluk and Korkmaz's study (2016), a positive relationship was found between programming skills and computational thinking skills. The study also found a parallel increase in students' programming skills and computational thinking skills.

In Europe, we find projects about computational thinking; one is Erasmus+ KA2 "TACCLE3 – Coding. The contents presented through the project's website (http://taccle3.eu/), are an example of successful educational practices and experiences in the process of incorporation and promotion of these skills (García-Peñalvo et al., 2016).

Researchers Karen Brennan (Harvard University) and Mitch Resnick (MIT) have made a significant contribution to the conceptual framework on computational thinking by formulating an alternative model on this style of thinking. The model was proposed within the research project that resulted in the creation of Scratch, a visual programming platform "by blocks" that allows children and young people to create their own interactive stories with animations and simulations in a playful environment. The model of computational thinking formulated by Brennan and Resnick (2012) is based on three dimensions: computational concepts, practices, and perspectives.

The skills to innovate or employ creative, critical and computational thinking cannot be cultivated through educational practice, focusing largely on memorizing knowledge without providing opportunities for students to transfer them to practice and use knowledge in various problem solving situations. There are urgent calls for innovative educational approaches worldwide that can foster the learning of 21st century competences, especially competences needed for innovators including critical thinking, problem-solving, creativity, inventiveness, collaboration and teamwork, and communication skills through transdisciplinary, learner-centered, collaborative, and project-based learning (PBL). These pedagogical approaches have been designed according to learning science research outcomes. Krajcik and Shin (2015), emphasized the following characteristics of these approaches and describe PBL as an example approach:

- PBL starts with a driving question, that is, a problem to be solved and focuses on the learning goals of the curriculum that students are required to master.
- Students are active in learning and explore the driving question by participating collaboratively in scientific and engineering practices, like designing, coding, inquiring and communicating, that are central to expert performance in science and engineering.
- Students create a set of tangible products, like a program code or a robot, that address the driving question. These are shared artefacts are kind of cognitive tools and publicly accessible external representations.

In this regard, many researchers have been investigating the coding and use of robots to support the education and learning of students. Studies have shown that robots can help students develop problem solving skills and learn computer programming, math and science. The educational approach based mainly on the development of logic and creativity in the new generations since the first stage of education is very promising (García-Valcárcel and Caballero-González, 2019). For these purposes, the use of robotic systems is becoming fundamental if applied from the earliest stage of education. In elementary, secondary and k12 schools, robot programming is fun and, therefore, represents an excellent tool for introducing ICTs and helping the development of logical and linguistic skills, and children's creativity.

The landscape of educational robotics and coding is vast, but fragmented inside and outside school environments and situations. In the last two decades, robots have begun their incursion into the formal education system. Although several researchers have emphasized the learning potential of robotics, the slow pace of its introduction is partially justified by the cost of the kits and the different priorities of schools to access technology. Recently, the cost of electronic kits and components has decreased (i.e., LEGO Mindstorms[5], Arduino[6], Raspberry Pi[7], among others), while its capabilities and the availability of hardware and support software have increased (Yiannoutsou, 2017). With these benefits, educational robotics kits have become more attractive to schools.

In this context, several technology providers, teachers, academics, companies that focus on delivering educational material, etc., invest in the creation of different learning activities around robotic kits, to show their characteristics and make them attractive inside and outside of schools. Therefore, an increasing number of learning activities has emerged. These activities share common elements, but they are also very diverse, since they address different aspects of robotics as teaching and learning technology, and their success lies in how well they have identified these aspects and how well they address them.

This is partly due to the fact that robotics is a technology with special characteristics compared to other learning technologies: they are inherently multidisciplinary, which in terms of design of a learning activity can mean collaboration and immersion in different subjects; they are widely used in formal and non-formal learning environments; its tangible dimension causes disturbances, especially in formal educational environments, which are closely related to the introduction of innovations in organizations and schools (that is, from considering orchestrations in the classroom to establishing or not establishing connections with the curriculum, etc.); they are relevant to the new learning practices that now flourish on the Internet, such as the creators' movement, the "Do it yourself" and "Do it with others" communities, etc.

This recent development of cutting-edge educational tools, both software and hardware, has provided opportunities for children to participate in various improved technological

[5] http://www.mindstorms.lego.com/
[6] https://www.arduino.cc
[7] https: / /www.raspberrypi.org

activities, such as "advanced scientific exploration, creating interactive textiles, building simulations and games, programming video games, designing a virtual robotics system, create sophisticated worlds and 3D games through programming, build new types of cybernetic creatures, explore environmental science and geographic information systems" (Blikstien 2013, p. 5) and build robotic inventions. Although such developments have contributed to the popularity of the movement of manufacturers and digital manufacturing, there is still a division in the population of potential users between those who have and those who do not. It is crucial to bring the education of the manufacturer to all classrooms so that everyone has the opportunity to learn from the activities of the manufacturer. For this reason, it is important to identify student learning outcomes through robotics creation activities (Wang, Lim, Lavonen and Clark-Wilson, 2019).

Some research provides evidence that shows the positive changes that occur in students immersed in training courses in programming skills and computational thinking using programmable robots (Chen, Shen, Barth-Cohen, Jiang, Huang and Eltoukhy, 2017; Durak and Saritepeci, 2018). In the Spanish context, for example, programs are increasingly aimed at children in the early stages of education in mathematical content, such as algebra, with the use of robotic devices adapted to children for the successful development of skills computational thinking (Alsina and Acosta, 2018). In Cuba, Matias et al. (2018) describe an experience in the course of Educational Robotics "Learn to play" taught to students of a k12 school with the mBlock software and the mBot kit. Specifically, the programming is described, the different components of the robot, such as: LEDs, buzzers, motors and ultrasonic sensors with which students must interact.

Since computer science is part of robotics manufacturing, it provides the right environment in which students gain computational thinking skills. For example, students demonstrate their abstraction and algorithmic thinking through the algorithm they create, since an algorithm is an abstraction of a process, broken down in orderly steps. These steps are created with sensor inputs, carry out the series of ordered steps and produce outputs to achieve the objective. Students who can create effective algorithms for their problems develop the ability to formulate the steps to effectively use the robotic tool (Bruni and Nisdeo, 2017).

This requires the skills to identify, analyse and implement the solution with the most effective and efficient steps. Experienced programmers can create effective but simple solutions. These skills must be supported by the right provisions, including persistence, tolerance, the ability to communicate and work effectively with others, and the ability to deal with open problems. These provisions can be obtained from your participation in the performance of robotics activities and the learning process. Through robotics manufacturing activities, students gain the necessary confidence to deal with complexity. Very often, students encounter complex problems while doing robotics, which helps students build confidence to persist.

4. Conclusions

Taking steps towards developing a valid and reliable instrument to measure students' CT and creativity thinking is challenging. First, there is a lack of agreement in the field in terms of computational and creativity thinking definition. Many versions of both definitions are vague at the best (García-Peñalvo & Mendez, 2018), and as express this is an important obstacle, for example to the operationalization of CT in concrete assessment items. Additionally, many students have limited programming experience. This creates a need for an instrument that can be administered as pre/posttest and can apply across different programming platforms, and if is the case, different robotics kits. It is needed an instrument on CT based on operationalizable all components of a CT and creativity.
There are educational institutions that have managed to get this issue free, but the problem is that there are no set guides, and it is best to define an itinerary for several years in technology, rather than improvised technology courses on the fly. If solving the problem of technology in a course is complicated, designing an itinerary that covers different ages, for example, from 12 to 18 years old, is very complicated for most centers, because it is difficult to move forward without people that knows the technology.
One way to reduce the barrier for teachers and educators is to connect such learning activities with existing learning standards. However, simply taking robotics activities to classrooms does not automatically generate desirable learning outcomes. With the use of robotics kits there is generally no correct way to solve a challenge. Not having a correct answer but multiple ways of addressing a problem is an experience that many teachers are not familiar with. That is why more scientific research is needed in this regard, in terms of successful interventions that show evidence and good practices that serve as training and guides teachers.

Computational thinking predictable trends and desirable trends

Computational thinking cannot avoid trends that are otherwise marked for technology-supported education. However, there is a margin of variability. Next, we comment experiences of the authors and their commitment to the theoretical corpus of learning and instructional design make them conceive, within that margin, as more favorable trends for more effective learning within the field of social performance and personal development of individuals:

A. ***Learning ecologies of computational thinking.***
Under this denominator various trends are grouped with a common factor: the premise that the context in which learning takes place has an enormous influence on students and their educational development. It is explained in The Ecology of Learning. Several Streams of Research Take a Broad Approach to Understanding the Learning Process and in Media ecology: An interdisciplinary approach to the study of communication by Breslow (2001 and 1986) and Nystrom (1973). This perspective is not new, now the

difference is that it is structured in its approach and takes on a new meaning with the technological learning environments, particularly important now in the computational thinking environments as a cohesive element and interaction of the components that constitute it.

The theoretical construct has its roots in the production of seminal thinkers such as John Dewey, Jean Piaget, Lev Semenovich Vgotsky and Kurt Lewin; and it implies powerful news about how teaching is handled and learning is achieved when it transcends the individual, in its origin, as a cause of its formation, in its projection and in its interactive nature. There we include pedagogical perspectives such as context development and situated learning. To these contributions must be added those of Paper and recently those of Grover (2018) that we have found. But what will be the characteristics of these particular ecologies. It is something that remains to be determined by practice and research.

B. Computational thinking presents a challenge that can be pointed out as the most important.

That is the inclusiveness of all kinds. Its new frontier is Adaptive Artificial Intelligence and recommendation algorithms. In this regard and with learning ecologies, a version of **artificial intelligence** that has to do with **intelligent learning environments** (considered these as an evolution of adaptive environments and context-sensitive environments) and with r**ecommendation algorithms**.

C. Computational thinking as literacy and key competence.

Ephemerally computational thinking will have a strong validity considered as early learning of programming, of coding. But every time they will impose computational thinking modalities that will make sense as a new literacy in a new culture and as a key competence, in the sense that we have described elsewhere, in the line that Grover (2018) and Zapata-Ros (2015) advocate for now: As an accumulation of various related skills because of the meaning attributed to them being useful to this type of thinking, which serves to ***do things and work***. Other collateral or basic initiatives will also come, such as unpplugged, educational robotics or the development of algorithm skills close to AI. But always aimed at developing a computational thinking of these characteristics.

D. In general, the differences between superficial learning and deep learning will be more marked.

In relation to what was commented in the previous section, this characteristic will particularly affect learning in environments of computational thinking, robotics, artificial intelligence, etc. In the Knowledge Society, in a first stage of the Internet and networks, a notable feature of its development has been a boom of banality and relevance. Myths, including educational ones, have proliferated in the network and have affect educational and research institutions, contaminating them in different ways. One in the application of supposed educational principles and procedures derived from it, and another in the nature of the contents themselves.

Traditionally, the difference between what they call "deep" and "superficial" learning is based on the fact that deep learning is accepted as learning that goes beyond memorization and reaches a more complete understanding of concepts and ideas, the results of the fundamental decisions that instructors make about how their courses will work (for example, the type of homework and exams that they plan). But currently the border is not only in purely memoristic assimilation, or even in a weak or linear understanding, as opposed to the authentic acquisition of knowledge, which entails attribution of meaning and execution with autonomy of what has been learned, but also encompasses the **critical sense**, the **discernment between the consistent and logical of what is not** or the **metacognition**. It is not only an application to humans of a concept, deep learning, which was defined thinking about machines, but a way of learning that goes beyond memorization and the application of trivial patterns in learning.

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5. References

Alsina, A., & Acosta, Y. (2018). Iniciación al álgebra en Educación Infantil a través del pensamiento computacional: Una experiencia sobre patrones con robots educativos programables. *Revista Iberoamericana de Educación Matemática, 52*, 218-235. https://bit.ly/2PC1hLt

Bell, P., Hoadley, C.M., & Linn, M.C. (2004). Design-based research. In M.C. Linn, E.A. Davis, & P. Bell (Eds.), Internet environments for science education (pp. 73-88). Mahwah, New Jersey, Lawrence Erlbaum Associates.

Blikstien, P. (2013). Digital fabrication and ‘making in education”: The democratization of invention. In J. W. H. C. Buching (Ed.), FabLabs: Of makers and inventors. Bielefeld, Germany: Transcript Publishers.

Brennan, K., & Resnick, M. (2012). New frameworks for studying and assessing the development of computational thinking. In Proceedings of the 2012 Annual Meeting of the American Educational Research Association (AERA) (pp. 1-25). Vancouver, Canada.

Breslow, L. (1986). Media ecology: An interdisciplinary approach to the study of communication. Paper presented at the Association for Integrative Studies Conference, Bowling Green, Ohio

Breslow, L. (2001). The Ecology of Learning Several Streams of Research Take a Broad Approach to Understanding the Learning Process. http://web.mit.edu/fnl/vol/142/breslow.htm

Bruni, F., & Nisdeo, M. (2017). Educational robots and children's imagery: A preliminary investigation in the first year of primary school. Research on Education and Media, 9(1), 37-44. https://doi.org/10.1515/rem-2017-0007

Chen, G., Shen, J., Barth-Cohen, L., Jiang, S., Huang, X., & Eltoukhy, M.M. (2017). Assessing elementary students' computational thinking in everyday reasoning and robotics programming. *Computers and Education,* 109, 162-175. https://doi.org/10.1016/j.compedu.2017.03.001

Davies, D., Jindal-Snape, D., Collier, C., Digby, R., Hay, P., & Howe, A. (2013). Creative learning environments in education. A systematic literature review. Thinking Skills and Creativity, 8, 80–91. doi:10.1016/J.TSC.2012.07.004

Dougherty, D. (2012). The Maker Movement. Innovations, 7(3), 11–14.

Durak, H.Y., & Saritepeci, M. (2018). Analysis of the relation between computational thinking skills and various variables with the structural equation model. Computers & Education, 116, 191-202. https://doi.org/10.1016/j.compedu.2017.09.004

Fisher, R. (2005). *Teaching children to think*. Cheltenham: Nelson Thomes Ltd.

FNBE (2014). The National Core Curriculum for Basic Education. Helsinki: FNBE National Board of Education. Retrieved from http://www.oph.fi/ops2016

García-Peñalvo, F. J., & Mendes, A. J. (2018). Exploring the computational thinking effects in pre-university education. Computers in Human Behavior, 80 (2018) 407-411. Doi: https://doi.org/10.1016/j.chb.2017.12.005

García-Peñalvo, F.J., Rees, A.M., Hughes, J., Jormanainen, I., Toivonen, T., & Vermeersch, J. (2016). A survey of resources for introducing coding into schools. Proceedings of the Fourth International Conference on Technological Ecosystems for Enhancing Multiculturality (TEEM'16) (pp.19-26). Salamanca, Spain, November 2-4, 2016. New York: ACM. https://doi.org/10.1145/3012430.3012491

García-Valcárcel, A., y Caballero-González, Y.A. (2019). Robotics to develop computational thinking in early Childhood Education. Comunicar, n. 59, v. XXVII, 63-72. DOI: https://doi.org/10.3916/C59-2019-06

Grover, S. & Pea, R. (2013). Computational Thinking in K–12 A Review of the State of the Field. *Educational Researcher*. *42*. doi:10.3102/0013189x12463051

Grover, S. (2018). The 5th 'C' of 21st century skills? Try computational thinking (not coding. Retrieved from EdSurge News: https://edtechbooks.org/-Pz

Halinen, I. (2018). The new educational curriculum in Finland. In M. Matthes, L. Pulkkinen, C. Clouder, & B. Heys (Eds.), Improving the quality of childhood in Europe, 7, 75-89. Brussels: Alliance for Childhood European Network Foundation. Retrieved from http://www.allianceforchildhood.eu/files/Improving_the_quality_of_Childhood_Vol_7/QOC%20V7%20CH06%20DEF%20WEB.pdf

Halverson, E.R. & Sheridan, K. (2014). The maker movement in education. Harvard Education Review, 84(4), 495-504.

Hershkovitz, A., Sitman, R., Israel-Fishelson, R., Eguíluz, A., Garaizar, P., & Guenaga, M. (2019). Creativity in the acquisition of computational thinking, Interactive Learning Environments, 27:5-6, 628-644, DOI: 10.1080/10494820.2019.1610451

International Society for Technology in Education - ISTE. (2018). Computational Thinking For All. Retrieved from https://www.iste.org/explore/article Detail?articleid=152

Jesson, J. K., Matheson, L., & Lacey, F. M. (2011). Doing your literature review: Traditional and systematic techniques. Thousand Oaks, California: Sage.

Johnson, R. B., & Christensen, L. (2017). Educational research: Quantitative, qualitative and mixed approaches (6th Ed.). Thousand Oaks, CA: Sage.

Juuti, K., & Lavonen, J. (2006). Design-Based Research in Science Education. Nordina 3(1), 54-68.

Koh, K. H., Basawapatna, A., Bennett, V., & Repenning, A. (2010). Towards the automatic recognition of computational thinking for adaptive visual language learning. In 2010 *IEEE symposium on visual languages and human-centric computing, VL/HCC 2010* (Leganes, Madrid, Spain, 21-25 Sept. 2010) (pp. 59e66). USA: IEEE.

Krajcik, J., & Shin, N. (2015). Project-based learning. In K. Sawyer (Ed.), The Cambridge handbook of the learning sciences. (2nd ed., pp. 275-297). New York, NY: Cambridge University Press.

Martin, L. (2015). The promise of the Maker Movement for education. Journal of Pre-College Engineering Education Research (J-PEER), 5(1), 30-39. doi: 10.7771/2157-9288.1099

MEC (2016) Opettajankoulutuksen kehittämisohjelma [Development program for teachers' -re- and in-service education]. Retrieved from https://minedu.fi/artikkeli/-/asset_publisher/opettajankoulutuksen-kehittamisohjelma-julkistettiin-opettajien-osaamista-kehitettava-suunnitelmallisesti-lapi-tyouran

MEC (2018). Peruskoulufoorumi luovutti esityksensä peruskoulun kehittämislinjauksiksi [The Basic School Forum published the developmental plan for the basic school]. Ministry of Education and Culture. Retrieved from http://minedu.fi/artikkeli/-/asset_publisher/peruskoulufoorumi-luovutti-esityksensa-peruskoulun-kehittamislinjauksiksi

Monroy-Hernández, A., & Resnick, M. (2008). Empowering Kids to create and share programmable media. Interactions, 15(2), 50–53.

Nystrom, C. (1973). Towards a science of media ecology: The formulation of integrated conceptual paradigms for the study of human communication systems. Unpublished doctoral dissertation, New York University

OECD (2005). *Definition and selection of competencies (DeSeCo): Executive summary.* Paris: OECD Publishing. Retrieved from http://www.oecd.org/pisa/35070367.pdf

Oluk, A., & Korkmaz, Ö. (2016). Comparing students' scratch skills with their computational thinking skills in terms of different variables. I. J. Modern Education and Computer Science, 8(11), 1–7.

Pala, F.K & Mıhçı, P. (2019): The effects of different programming trainings on the computational thinking skills, Interactive Learning Environments, DOI: 10.1080/10494820.2019.1635495

Rasinen, A., Ikonen, P. & Rissanen, T. (2006). Are girls equal in technology education? In M. J. De Vries and I. Mottier (Eds.), International handbook of technology education: Reviewing the past twenty years (pp. 448-459). Rotterdam: Sense Publishers.

Rodríguez-Martínez, J.A., González-Calero, J.A., & Sáez-López, J.M. (2019): Computational thinking and mathematics using Scratch: an experiment with sixth-grade students, Interactive Learning Environments, DOI: 10.1080/10494820.2019.1612448

Román-González M., Moreno-León J., & Robles G. (2019) *Combining Assessment Tools for a Comprehensive Evaluation of Computational Thinking Interventions*. In: Kong SC., Abelson H. (eds) Computational Thinking Education. Springer, Singapore

Román-González, M., Pérez-González, J.-C., & Jiménez-Fernández, C. (2017). Which cognitive abilities underlie computational thinking? Criterion validity of the Computational Thinking Test. *Computers in Human Behavior*, 72, 678e691. https://doi.org/10.1016/j.chb.2016.08.047.

Romero, M., Lepage, A., & Lille, B. (2017). Computational thinking development through creative programming in higher education. *International Journal of Educational Technology in Higher Education*, 14:42 DOI 10.1186/s41239-017-0080-z

Torrance, E. P. (1965). Scientific views of creativity and factors affecting its growth. Daedalus, 94(3), 663–681. doi:10.2307/20026936

Vahtivuori-Hänninen, S. H., Halinen, I., Niemi, H., Lavonen, J. M. J., Lipponen, L., & Multisilta, J. (2014). A new Finnish national core curriculum for basic education and technology as an integrated tool for learning. In Niemi, H., Multisilta, J., Lipponen, L. & M. Vivitsou (Eds.), Finnish innovations and technologies in schools: A guide towards new ecosystems of learning (pp. 33-44). Rotterdam: Sense Publishers.

Voogt, J. & Roblin, N.P. (2012). A comparative analysis of international frameworks for 21st century competences: Implications for national curriculum policies. *Journal of Curriculum Studies, 44*(3), 299-321. doi:10.1080/00220272.2012.668938

Wang, TH., Lim, K.Y.T., Lavonen, J., & Clark-Wilson, a. (2019). International Journal of Science and Mathematics Education, 17(Suppl 1):1. Doi: https://doi.org/10.1007/s10763-019-09999-8

Werner, L., Denner, J., Campe, S., & Kawamoto, D. C. (2012, February). The fairy performance assessment: Measuring computational thinking in middle school. In Proceedings of the 43rd ACM technical symposium on computer science education (pp. 215e220). ACM.

Wing, J. M. (2006). Computational thinking. Communications of the ACM, 49(3), 33–35.

Yiannoutsou, N., Nikitopoulou, S., Kynigos, C., Gueorguiev, I., & Fernandez, J. A. (2017). Activity plan template: a mediating tool for supporting learning design with robotics. In Robotics in Education (pp. 3-13). Springer, Cham.

Zapata-Ros, M. (2015). Pensamiento computacional: Una nueva alfabetización digital. RED. Revista de Educación a Distancia, 46. Retrieved from http://www.um.es/ead/red/46/zapata.pdf

Zapata-Ros, M. (2019). Pensamiento computacional desenchufado. Education in the knowledge society (EKS), (20). https://repositorio.grial.eu/handle/grial/1690