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EXPLORING THE FIELD OF COMPUTATIONAL THINKING AS A 21ST CENTURY SKILL

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Abstract

Computational Thinking, which entails using analytic and algorithmic approaches to formulate, analyse and solve problems, has increasingly gained attention in the educational field in the past decade, giving rise to a large amount of academic and grey literature, as well as to numerous public and private initiatives to implement it. Despite such widespread interest, its successful integration in school curricula is still facing several open issues and challenges. In order to contribute to the field development, we are carrying out a desk investigation to draw a comprehensive overview of recent findings produced by academic research, grassroots initiatives and policy actions addressing the development of computational thinking in primary and secondary school, as well as to highlight major implications for policy and practice. In this paper we describe the project methodology and a classification of the comprehensive corpus of documents collected. We also present a preliminary picture of the field as it is emerging from our analysis.

Keywords: computational thinking, problem solving, computer science education, ICT.

1 INTRODUCTION

Computational Thinking (CT) has increasingly gained attention in the educational field in the past decade, following a short paper by J. Wing [1], who used this expression to indicate "thinking as a computer scientist", i.e., using an analytic and algorithmic approach to formulate, analyse and solve problems. In her article, Wing claimed that CT is a fundamental skill for everyone, not just for computer scientists: "To reading, writing, and arithmetic, we should add computational thinking to every child's analytical ability" [1]. Ten years after this seminal work, over 300 papers on this topic have been published in the academic literature and about 200 in the grey literature, highlighting, among other properties, the added value CT can contribute to fostering critical thinking, problem solving and other 21st century skills.

Despite the widespread interest in developing CT at all levels of education (and especially in compulsory education), and the increasingly large number of public and private initiatives, the successful integration of CT in school curricula is still facing open issues and challenges, such as: Is it possible to define CT as a key skill for the current century? What are its characterizing features? What are its relation to programming and computer science, on the one side, and to digital literacy, on the other? Should CT be included in compulsory education? How should skills in this field be assessed? How should teachers be prepared to best integrate it into their teaching practice?

In order to contribute to answer such questions, and by this means enhance the field development, we are conducting a study entitled "An analysis of educational approaches to developing Computational

Thinking (CompuThink)"[1], designed and funded by the Joint Research Centre – Institute for Prospective Technological Studies (JRC-IPTS) of the European Commission and carried out by the Institute for Educational Technology of the Italian National Research Council together with European Schoolnet, which represents a network of Ministries of Education in Europe. The study aims to provide a comprehensive overview of recent findings produced by research, grassroots initiatives and policy actions for developing CT as a 21st century skill among primary and secondary students.

In this paper we present a picture of the field as it is emerging from the CompuThink study, based on both a characterization of the comprehensive corpus of academic and grey literature collected and on a preliminary analysis of its content. In the next section we describe the project's methodology; than we characterize the literature corpus collected; finally, we briefly sketch the main lines of investigations currently addressed in the field.

2 THE COMPUTHINK STUDY

The literature analysis we are discussing in this paper represents one of the four working packages that constitute the CompuThink project, and certainly the most complex and informative one, due to the wide-angle literature search it is based on. In the overall approach, this desk research is complemented by several semi-structured interviews with policy makers, researchers and practitioners involved in the implementation of relevant policy and grassroots initiatives, so as to collect further data contributing to understand possibilities and implications of introducing CT in K-12 educational contexts. The overall structure of the project is shown in Fig. 1. The project is running from December 2015 to September 2016.
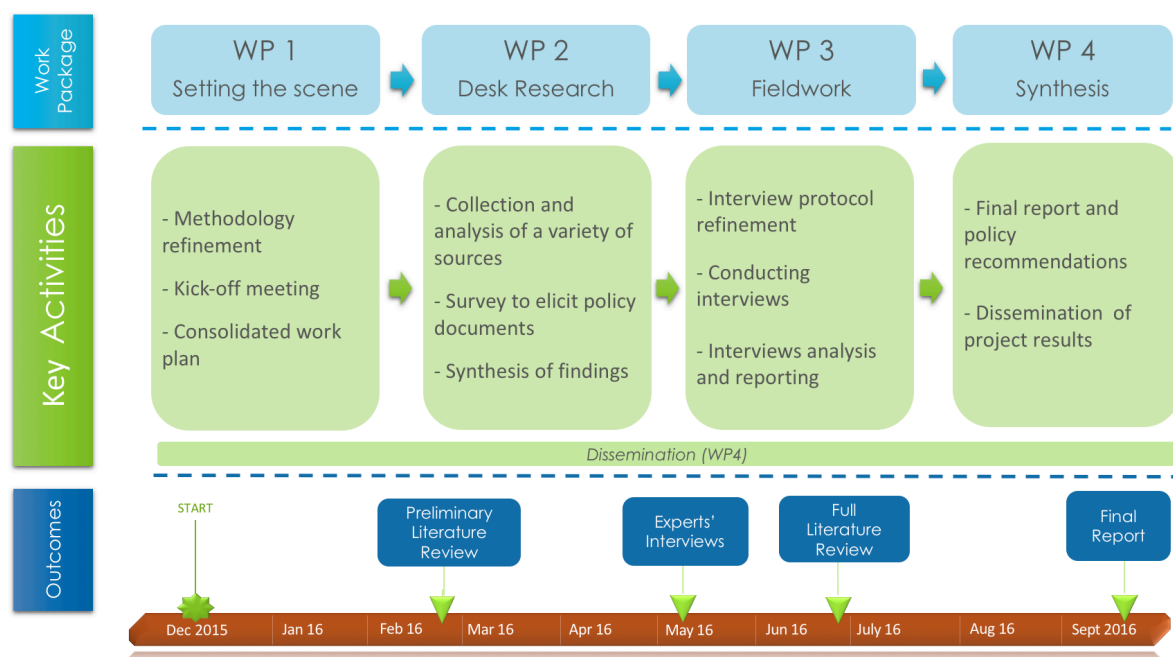

Fig. 1. The overall organization of the CompuThink project.

2.1 The overall approach

Our literature collection and review is based on a structured approach to locate, review, categorize and represent information, consisting of three steps: a) strategic searching; b) literature processing; c) tag-and-map representation.

Step 1. Strategic searching.

The literature review drew from a wide variety and range of sources. In order to reflect the wider definitions, conceptualization and characterizations of CT, a broad selection of bibliography portals and consortia was explored, representing a crossover between various disciplines (mathematics,

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[1] The CompuThink website is accessible at https://ec.europa.eu/jrc/en/computational-thinking

psychology, sciences, computer science, engineering, education, and computer science education research). They included: *Scopus*, *Elsevier Science Direct*, *Web of Science (all Databases)*, *IEEExplore Digital Library*, *ACM Digital Library*, *SpringerLink, Sage Publications*, *EdITLib, Wiley Online Library, Taylor & Francis Online, World Bank Open Knowledge Repository, Emerald, Google Scholar, Eric.* This was complemented by direct search in highly regarded academic journals (e.g. Communications of the ACM, Educational Researcher, Journal of Computational Science Education, Journal of Pervasive and Practical Computing, Journal of Computer Science and Technology, etc.). We also found documents through *snowballing*, by examining the bibliographies of recent literature reviews on CT in compulsory education (e.g. [2]; [3]) and in CT-related fields (e.g. [4]). Backward references in highly cited papers related to CT in compulsory education (e.g. [1], [2]; [6]; [7]; [8]) also provided additional sources of information.

As concerns the grey literature, we queried several databases, such as: Google.com, Academia.edu, ResearchGate, Mendeley, EBSCO. Other data sources were: reviews and evaluation studies in the Department for Education of many countries (e.g. Research Councils UK, iDA Singapore, etc.), and of education-related organizations publishing studies, technology reports, press clippings, blogs and newsletters.

Regarding curricula and guidelines at national level in Europe, relevant documents were collected from the Internet by accessing websites of the relevant Institutions, as well as from a survey of policy documents carried out by European Schoolnet with the Ministries of Education. Additionally, policy documents that relate to the concept of CT at European level (e.g. communications and reports from the European Commission; position papers from European stakeholders active in the field of CT, ICT, digital literacy, e.g. CEPIS; and reports from organizations that work on ICT in education, e.g. British Computer Society) were detected.

Online courses and MOOCs for the development of CT skills, together with other educational resources that promote CT among primary and secondary school students, were detected through the analysis of the best known course providers, such as: Coursera, EdX, Futurelearn, EUN Academy, EMMA, Stanford online courses, OpenLearn, Canvas, Udemy, Udacity, complemented by a web scan.

In all databases, the search was based on a combination of keywords, such as: computational thinking, algorithmic thinking, critical thinking skills, computing curriculum, computational thinking for learning, computational thinking assessment. Special terms such as 'abstraction', 'decomposition', 'algorithm', 'modelling', 'problem solving', etc. were also used.

Step 2. Processing the literature.

The detailed examination of the references collected has been carried out by means of the review matrix approach [9], that facilitates the comparison of different sources in a structured way. In such matrices, reading a line provides a concise summary of the main aspect of a bibliographical reference, while analyzing a column helps comparing how a particular aspect is handled by different sources, hence helping to highlight major findings, emerging patterns, and scarcely addressed elements.

Two preliminary review matrices were developed to start the process, respectively devoted to:

- theoretical/conceptual studies, i.e., existing conceptualizations, definitions and frameworks of CT as a 21st century skill (or set of skills) as emerged from the academic literature and other sources;

- practical implementations, including evaluations of grassroots and policy initiatives for developing CT skills among primary/secondary students.

The creation of two different matrices instead of only a global one is due to the need to highlight slightly different elements in theoretical and applicative studies. It must be pointed out, moreover, that this subdivision does not correspond to the literature division into academic and grey mentioned above, because many times academic papers concern implementation studies, while grey reports may be devoted to a reflection on theoretical and conceptual aspects.

The structure of the preliminary matrices (i.e., number and labels of columns) was then revised by merging and integrating the suggestions of all reviewers on an initial set of papers of different nature, so as to make sure to have a ductile tool apt to collect and represent in concise form the essential points of the variety of bibliographical sources detected. In general, both review matrices were considered easy to use and adequate to the scope by all researchers involved. Each matrix was then organized into four sheets, subdividing the processed papers into "Highly Relevant", "Relevant", "Connected" and "Peripheral", based on the richness of their content and its relevance in relation to

the scope of the study. In the end, we agreed to label the columns in the two review matrices as follow (see Table 1), so as to highlight elements of the reviewed literature that could most suitably help to answer the research questions, aims and objectives of the study:

Table 1. Structure of the review matrices in the CompuThink study.

Matrix 1. Theoretical/conceptual studies	Matrix 2. Implementation studies
– Definition of CT – Context/settings – Concepts/characterizations of CT – Skill (or set of skills) for all – Framework – Relation to programming /coding – Relation to digital literacy – CT for teaching other school subject	– Definition of CT – Context/settings/funding schema – Learning objectives – Pedagogical approaches – Teacher training – Evaluation strategy – Implementation challenges – Supporting measures – Initiator

Step 3. Tag-and-map approach.

Based on the review matrices described above, a concept map will be produced, so as to provide a visual representation of key notions involved in the definition of the CT field and its introduction in school, together with their relations. This process is also expected to help to identify overlaps, patterns and connections, helping to identify open issue in the field. The global structure of the whole review process is schematized in Fig. 2.
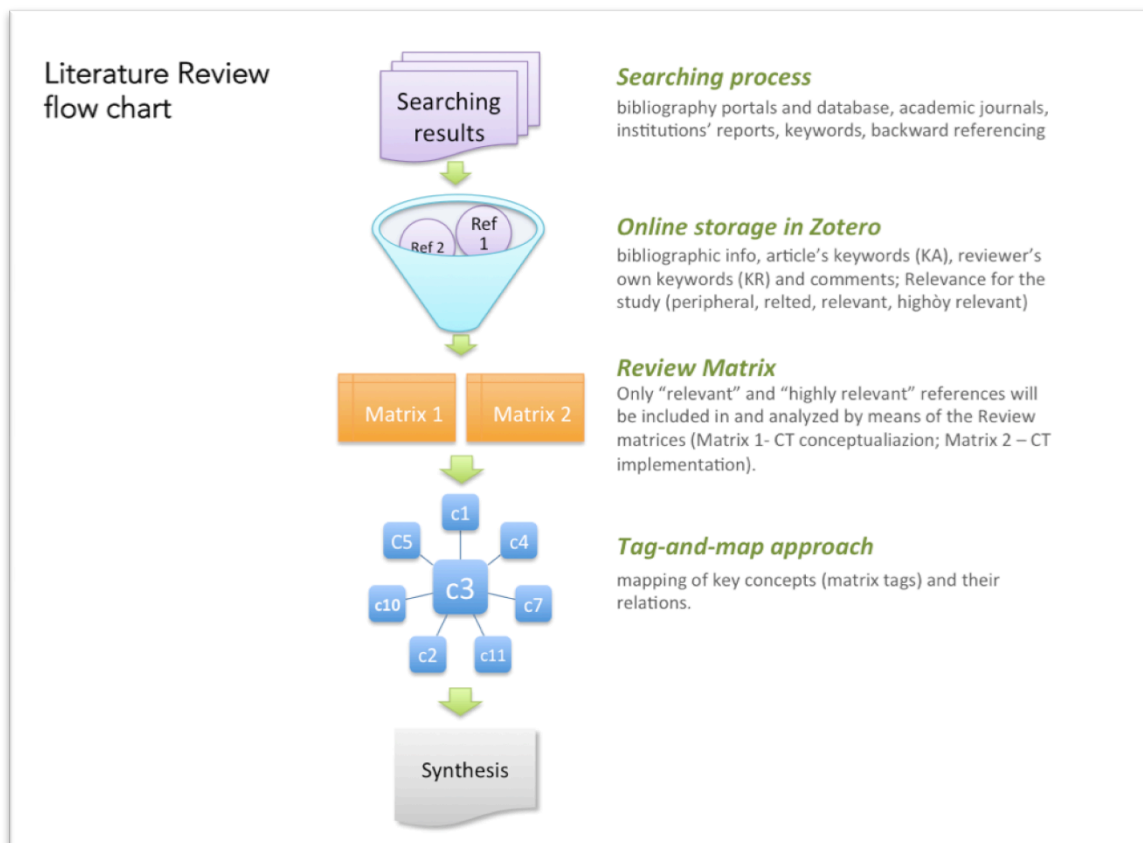
Fig. 2. A schematization of the review process adopted by the CompuThink project.

In order to make sure that the selected literature and documents were analyzed and tagged by the various researchers involved in the project in homogeneous and comparable way, a check of the Inter-Rater Reliability [10] was carried out at the very beginning, as a measure of quality assurance. To this end, after uploading all the collected documents into a Zotero repository (http://www.zotero.org), a set of 15 references of different nature, including both academic and grey literature, have been randomly selected and reviewed in parallel by all researchers involved. The review matrices filled in by all researchers during this process were then compared in order to identify inconsistencies, that were subsequently discussed up to reach a common understanding and build a common perspective on this literature analysis.

3 OUR SURVEY OF THE LITERATURE

3.1 Distribution of the collected documents

Thanks to the wide search process described above, we identified 569 documents, whose nature and publication type can reveal interesting trends in the field even before analyzing their content. We present below their distribution from four different points of view: by *source* (% of academic and of grey references), by *type of reference*, by *topic* and by *year of publication*.

Overall, the body of relevant literature include 361 academic papers (63%) and 208 grey documents (37%). A wide variety and range of sources were detected. The collected *academic literature* includes refereed journals, magazines, conference papers, books, book chapters, and PhD dissertations. Fig. 3 details the distribution of academic reference within these groups.
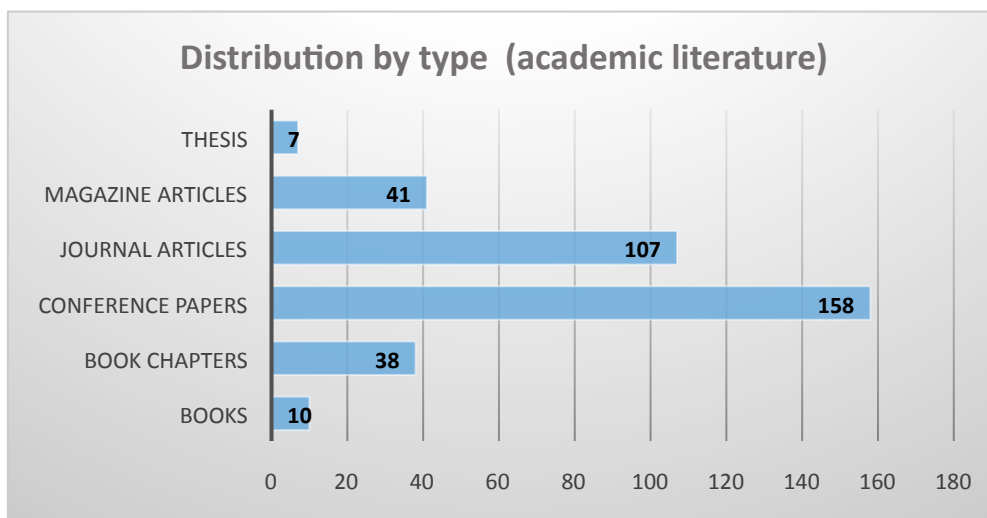

Fig. 3. Distribution of academic references by type

The collected *grey literature* included reports, newspaper articles, blog posts, video recordings, presentations, official documents (such as: curricula, guidelines, position papers, working documents, white or green papers, policy papers, frameworks) and web pages/sites (including: MOOCs, OERs, courses, press clips). Fig. 4 details the distribution of grey references by type.
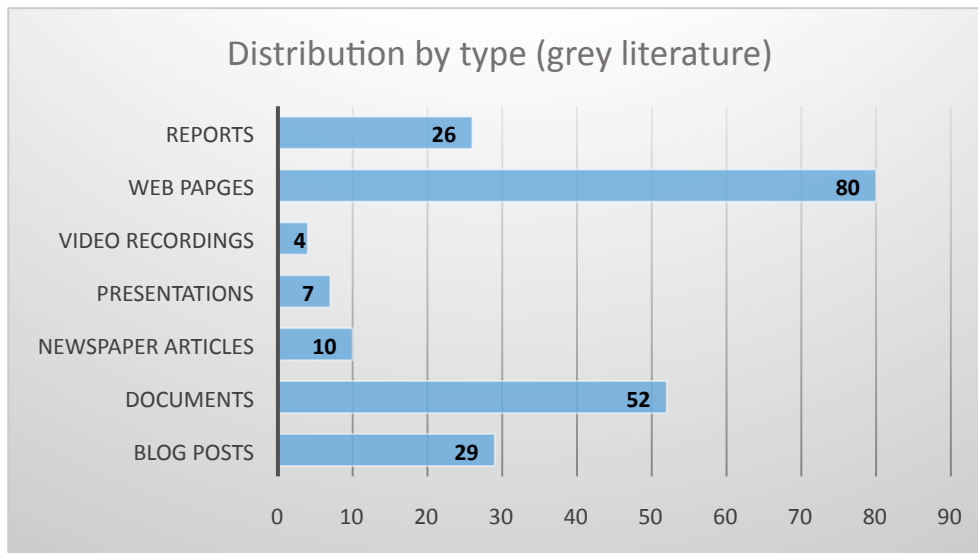
Fig. 4. Distribution of grey references by type

By reading the abstracts and scanning the content, it was possible to divide the documents by themes. Each reference was assigned a major theme[2] and classified accordingly in Zotero. For example, a reference concerned with the teaching of programming and CT skills using some particular tool or environment (e.g., Scratch) was categorized as 'learning tools', while the description of a course on some topic strongly focused on the development of CT skills was categorized as 'implementation'. Fig. 5 shows the distribution of the whole body of literature by topic. Such distribution will be subject to some changes when the whole body of literature will be analyzed in detail.
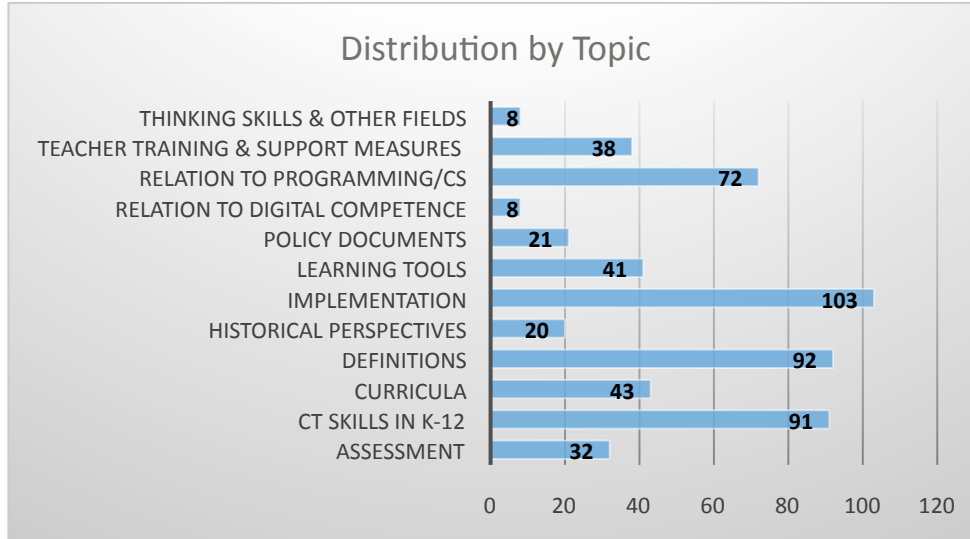

Fig. 5. Distribution of (grey and academic) references by topic

We detected documents in the year range 2006-2015 plus some papers (N=30) from the beginning of 2016. The distribution of the papers along this time period shows a significant increase in recent years (see Fig. 6).

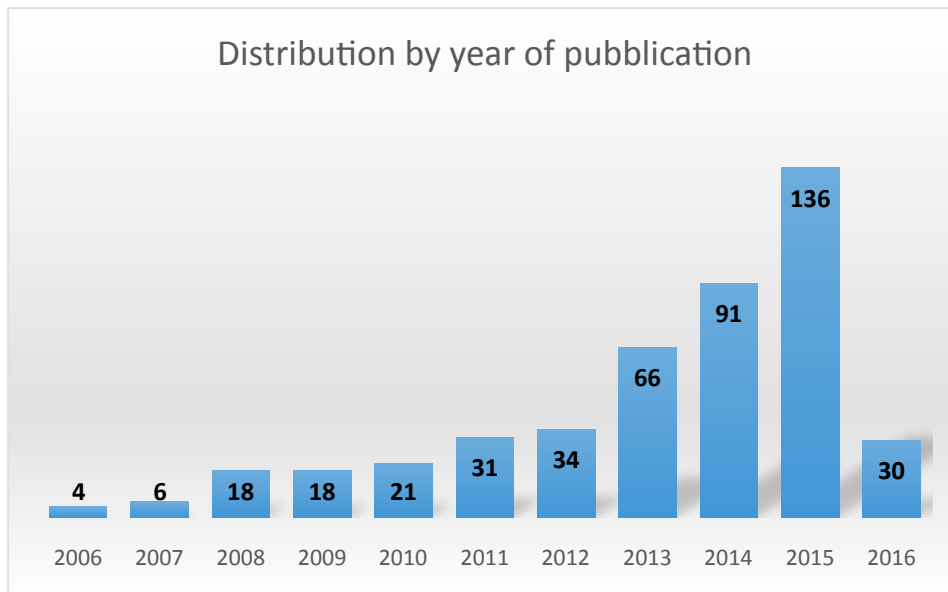[2] Theme categories mainly reflect the research questions of the study.

Fig. 6. Distribution of (grey and academic) references by year of publication

3.2 Analyzing the documents' content

All together, the literature analysed so far reveals a wealth of commitment, initiatives and ideas related to CT in primary and secondary education. Two trends emerge in particular, namely: the definition and characterization of CT, which has been evolving after Wing's initial proposal [1] yet preserving initial nature of this concept; the description of many successful activities which are being designed and carried out to introduce CT to younger and older students. Many documents also debate the potential advantages of introducing CT in education, because it can enable children and young people to think in a different way while solving problems, to analyze everyday issues with a different perspective [11], to develop the capacity to discover, create and innovate" [12], to understand what technology has to offer [13]. Acquiring such important skills is expected to have a beneficial influence on economic recovery and future jobs [14].

A wide variety of skills related to CT acquisition are suggested by different authors, such as: problem solving, examining data pattern and questioning evidence [15]; collecting, analyzing and representing data, decomposing problem, using algorithms and procedures, making simulations [16]; using computer models to simulate scenarios [17]; dealing with open-ended problems and persist in challenging cases [18]; reasoning about abstract objects [19].

A mutual influence between CT and coding/programming is recognized. The acquisition of CT does not to necessarily need computer programming [20], being a (conceptual) approach to problem solving that uses strategies such as algorithms, abstraction and debugging [21]. However, programming illustrates in concrete terms otherwise-abstract concepts and can therefore be an effective and practical way to foster the development of CT skills [22].

On the other hand, Digital Literacy, which is usually identified with the ICT school subject, is seen to differ from CT, even though connected to it [23], [24].

As concerns CT implementation in school, most of the papers analyzed represent serious and effective attempts to develop practical learning activities apt to foster some of the skills and competences that characterize CT. Some authors (e.g., [25]) give emphasis to the development of CT characterizing skills, such as abstraction, yet referring to computer science instead of to CT. As concerns the kind of activity proposed, most authors refer to programming tasks, yet often carried out with learning environments/tools (e.g., Scratch) that do not require coding in a textual language. The objective of the proposed programming activities is mostly the development of games, that are considered excellent situations in which abstraction (of moves and actions) can be understood and meaningfully used. Some attention is also given to introduce CT to girls (e.g., [18]), by proposing activities closer to girls' tastes and hence more motivating to them. As concerns the school levels considered, most implementations concern high school, but also middle school (e.g., [26]) and primary

school (e.g., [27]) are considered. Teacher preparation and support measures to facilitate CT implementation in schools are also object of attention by some authors (e.g. [28], [29]), by they are often neglected in papers focused on implementation proposals or experiences.

A number of methodologies and tools for assessing the acquisition of CT skills in compulsory education emerged from the literature. Brennan & Resnick [7] describe three approaches to assessing the development of CT, namely: analyzing a portfolio of projects, artifact-based interviews and scenario design. Skill transfer to other contexts is another form of assessment currently being investigated, as, for example, the capability of transferring computational understanding built in a visual programming environment to a textual one [30]. CT assessment practices, however, appear to be still under-investigated, in particular as concerns what kind of assessment can elicit students' problem solving and CT skills in authentic contexts.

4 CONCLUSIONS

The picture that emerges from this analysis shows a dynamic field in which the number of projects and experiences has been rapidly growing, along with a widespread interest for a more accurate understanding of the nature of computational thinking and its contribution to 21st century skills [31]. Most of the aspects that are relevant in order to answer to the research questions of our project are addressed by (at least) some document in either the academic or grey literature, which suggests that the field is developing in many directions and no aspect of it is completely neglected. Big differences, however, are evident in the distribution of the documents by topic; two relevant aspects, in particular, appear under-investigated, namely the development of suitable assessment approaches as well as the creation of specific teacher training programs and support measures. These on the other hand, are key points that are crucial for a successful development of CT education. Unless more attention will be given to these aspects by researchers, policy makers and practitioners, it is very unlike that CT education will actually be take off, become effectively part of school curricula and contribute to the innovation of formal education.

Another interesting element that is emerging from our study is the large variety of skills that are seen by different authors as part of CT. This might represent a critical point for the field development, leading to a too wide, and therefore vague, characterization of its nature, another potential obstacle to an effective introduction of CT in education.

Spotting possible inconsistencies and gaps in the literature in this field is one of the major aims of our project. The above analysis and reflections show that this aim is actually being fulfilled.

ACKNOWLEDGMENTS

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