Unplugged computational thinking at K-6 education: evidence from a multiple-case study in Spain

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This paper examines the implementation of unplugged tasks across different school settings developing computational thinking skills and cultivating concepts at upper primary schoolchildren in Spain without programming and without using electronic devices. The study is based on qualitative case study design. Across the three case studies, namely three schools -Waldorf-Steiner, conventional and innovative- which follow different pedagogical approaches, several themes and key tasks were emerged for unplugged computational thinking development. The evidence stems from field notes based on observation and transcripts based on semi-structured interviews with 152 participants. We collected 94 lessons in all the three schools and analyzed the field notes by using a predefined coding scheme grounded upon existing frameworks and analyzed the interview transcripts by using thematic content analysis for defining the emerging themes. We conclude that the detected unplugged tasks demonstrate a great potential to develop computational thinking skills and concepts even though the teachers are not fully aware of their development. The study highlights the need of teacher professional development on computational thinking teaching and learning. Also, we stress the need of computational thinking skills, concepts, and tasks integration into curriculum explicitly. Given the paucity of research on unplugged methods and computational thinking development at primary education, this study is promising to uncover some prominent issues for further examination and future research agenda.

Keywords: primary school, computational thinking, skills, concepts, unplugged

Introduction

With the fast-moving development and advancements in technological landscape, digital skills are evolving to be the fundamentals of modern society. To be integrated into the information society, except for the well-known 21st century skills, students should be equipped with computational thinking (CT) skills as well to leverage resourcefully these skills to be adjusted successfully in modern society (Hsu, Chang, and Hung 2018). The Partnership for 21st Century Skills (2019) communicates that students will need an assortment of skills, including creativity, communication, critical thinking, collaboration and problem solving all known as fundamental skills in our globalized society. Gretter and Yadav (2016) assert that practices in computational thinking and media & information literacy share the common goal of making students active citizens and skilled users of digital tools whether through programming and coding or through analytical and critical thinking skills that cover an all-encompassing continuum of 21st century skills, from creativity to critical analysis. Students will enter a workforce forcefully influenced by computing. The attention to computational thinking has raised as the significance of problem-solving skills of abstraction, decomposition, algorithmic design, generalization, and evaluation have grown in importance in schools and workplaces (Voogt et al. 2015).

Despite the fact that computational thinking skills have become fundamental to such a degree that are considered essential literacies, computer science and computational thinking have not been extensively taught in K-12 level. Computer science standards and frameworks are on the way to be integrated into K-12 school curricula (Jacob and Warschauer 2018). Designing CT teaching and learning and merging age-appropriate learning strategies and approaches across various subjects is an area worth studying (Hsu, Chang, and Hung 2018).

Bocconi et al (2016) define some areas needed further research, among others, such as how the teaching, learning and assessment of computational thinking are influenced within different learning conditions, namely without programming, with programming, without electronic media, with electronic media. The role of CT in non-STEM (Science, Technology, Engineering, Mathematics) subjects is promising but still nascent (Grover and Pea 2018). Despite the fact that unplugged approaches decoupled programming, most studies aim at teaching CT skills through unplugged activities in a way similar to programming ones (Brackmann et al. 2017). There is an increasing interest in using unplugged approaches to ease the introduction of CT into non-computing subjects (Weintrop et al. 2016). Using real-life situations and making analogies can be proved useful in CT teaching within non-STEM discplines (Güven and Gulbahar 2020). Therefore, students could be encouraged to engage in Computer Science (CS) through solving real-world problems in interdisciplinary contexts. Additionally, students could develop even advanced CT without using that term at preparatory stages (Yadav, Hong, and Stephenson 2016). This echoes our approach in teaching and learning of CT in unconscious and indirect way, a way that Steiner posits as age-appropriate for children between 6 to 14 years (Steiner 1954). Drawing upon the scarcity in studies that examine non-programming interdisciplinary activities improving CT and the shortage in frameworks about CT unplugged approach at K-6 (Kakavas and Ugolini 2019), we meet the need of a taxonomy of unplugged tasks that could be used as a reference point for CT skills and concepts integration at K-6 education.

In the remainder of the paper, we outline theoretical stances and related studies, we elaborate on the research methodology, we present the data collection and analysis, the results and the emerging taxonomy of CT tasks and then, we discuss the findings. We propose some transformations that could facilitate the explicit and effective implementation of the documented CT tasks in an effort to infuse and develop CT skills and concepts at primary schoolchildren.

Theoretical stances and related studies

Wing (2014) renewed the idea of CT in 2006 and revised the term by defining it as a thinking process that formulates a problem and express its solution(s) in a way that a computer—human or machine—can effectively perform it. CT is broadly recognized as a way of thinking encompassing fundamental thinking skills that should be honed during compulsory education alongside of reading, writing and arithmetic and it must be seen just as another language (as and in addition to written and spoken language, science, and mathematics) (National Research Council 2010). Computational thinking is not merely or all around computer science rather it supports problem solving across all disciplines covering the whole human experience (Baek et al. 2008).

CT conceptualization could be expanded through approaches decoupled from programming concepts and practices (Huang and Looi 2020) since coding is not necessary in the teaching of computational thinking and it might discourage students from engaging in computer science (Lu and Fletscher 2009) and that it constitutes a skill set essential to conceptual understanding in any domain (Bundy 2007). The question of what constitutes befitting computing concepts for elementary schoolchildren is still unsolved (Park 2019). Most studies examine CT in secondary schools whereas in primary school context are rare. Kakavas and Ugolini (2019) found in their systematical literature review that there is an increasing attention towards the CT skills integration into elementary education throughout the last five years. They point out as underinvestigated and challenging areas the development of CT in disciplines other than STEM, particularly they found that the exisiting studies focus on CS, robotics and science. Studies are limited regarding unplugged approaches, teaching CT without computers and teaching CT without programming. More specifically, the exclusive focus on coding for CT development is a pedagogical and methodological error because the aim is to teach higher-order/level skills/concepts applicable to various cognitive domains (Voogt et al. 2015).

It is noteworthy to refer some recent theoretical and empirical studies examining unplugged CT integration and development in K-6 schooling. Although their mention and description are not exhaustive, we consider it quite useful and purposeful to outline the landscape even briefly. Bell, Duncan, and Atlas (2016) designed a course in CS/CT for elementary school offering opportunities for cross-curricula teaching at non-STEM subjects. Sabitzer, Antonitsch, and Pasterk (2014) conclude that most teachers are unaware they already teach informatics and discusses hidden issues of informatics within the Austrian primary school curriculum. Tsarava, Moeller, and Ninaus (2018) developed three life-size board games using unplugged approach to introduce children aged 8 to 9-year-old into basic coding concepts and computational thinking processes. Pane and Myers (2001) examined how non-programming fifth graders formulate solutions in natural language using pseudocode to write algorithms. In this way, students leverage their existing natural language skills to develop computational competence by writing algorithms with diverse degrees of accuracy and iteratively refine them to resemble computational syntax. Brackmann et al. (2017) describe activities introducing CT concepts at students aged 10 to 12 years old, like decomposition activity (by breaking down tasks into steps), map activity (using four-directional arrow keys to move objects from one point to another on a map), song activity (converting a song into an algorithm to detect variables, repetition and conditionals) and so forth.

Research methodology

Research purpose

The current study aims at examining specific computational thinking skills and concepts development in non-computerized and non-programming contexts at upper elementary schoolchildren.

The humanistic character of our approach is evident to the following elements: (1) we intent to detect tasks developing CT skills across various academic disciplines, not just STEM, in a real life-based manner sounding Wing´s (2006) CT concepts and (2) CT is seen as a universal skill that should be learned by everyone, not just by computer scientists, and is applicable to every aspect of daily life (Hsu, Chang, and Hung 2018).

The current study promotes the CT development in the first years of compulsory education 'unplugged', 'disconnected' and 'non-computerized' by preventing possible discouragement and early drop-out attitudes related to computer science field later on. The present study intends to uncover a taxonomy of unplugged computational thinking tasks at K-6 education. Our working hypothesis is that, there are more similarities than differences among the three case studies/schools. Given that the diversity in school settings is evident in the pedagogical approaches they follow, we hypothesize that the findings will be rich in the manner they approach the CT skills and concepts development across the academic disciplines but similar as well since we investigate the tasks in unplugged context.

Particularly, we have set the following theoretical propositions:

(1) School A will follow a more stuctured format for CT skills development since the diversity existing in the academic subjects allows for the involvement of almost all the CT skills;
(2) School B will follow a more narrow format for developing CT skills by focusing on specific CT skills;
(3) School C will follow a more flexible format in developing CT skills since the teaching strategies and approaches are not conventional allowing in this way the development of almost all th CT skills.

In a nutshell, the current study intends to shed light on the following key aspects of unplugged CT development in K-6 education: (1) documentation of unplugged CT tasks that develop CT skills and concepts at primary school students by fulfilling three learning conditions: (a) without using electronic devices, (b) without using coding/programming, (c) in non-computing subjects; (2) the tasks identification lead into age/grade-appropriate CT taxonomy maximizing in this way its responsiveness and acceptance by both teachers and students.

Research design

The present study employed an embedded multiple-case study design to examine which computational thinking tasks were implemented by the teachers in their classrooms and to investigate which specific computational thinking skills and concepts were used within the cases. The multi-case study approach was adopted since it involves data collection at natural settings (i.e. classrooms) through non-participant observations and semi-structured interviews. A multiple case study enables the researcher to provide an in-depth understanding of the implementation of computational thinking skills and concepts across the cases, to explore differences within and among the cases aiming at replicating the findings across them. Since the comparisons are inevitable, it is imperative that the cases were chosen cautiously so that the researcher can predict similar or contrasting results among cases (Yin 2012 ; Baxter and Jack 2008). The study follows the design of an embedded multiple case study (Yin 2003) since each case had two embedded units of analysis/data sources including non-participant observation of teaching practice (first phase) and individual semi-structured interviews on site with teachers (second phase).

The research questions were formulated as following:

(1) How the classroom practice in three different school settings is aligned to CT skills across the academic subjects?

(2) How the classroom practice in three different school settings is aligned to CT concepts across the academic subjects?

(3) Which CT skills are developed by the teachers across the academic subjects?

(4) Which CT tasks are followed by the teachers across the academic subjects?

(5) Which is the converging CT tasks taxonomy that is emerged by the three cases and is applicable to unplugged learning environments across the academic subjects at K-6 schooling?

Context and Participants

The present study was conducted in three schools in the Autonomous Community of Catalonia in Spain. The research took place in three typical schools, the School A corresponds to Waldorf-Steiner private school, the School B represents a public conventional primary school and School C represents a public innovative primary school. The schools were selected based on diversity in pedagogical approaches and acceptance of the study. The sample was a convenience sample of 152 participants – 147 students (79 females and 68 males) aged 10-12 years old and 5 female Hispanic primary school teachers. The vast majority of students come from spanish-speaking countries. More specifically, 129 students come from Spain (88%), 14 from Latin America (9.5%), 2 from Pakistan (1.3%), 1 from Philippines (0.6%) and 1 from Ukraine (0.6%). We have anonymized both schools and teachers to identify the partipants and more details are provided about the three cases in the table below (see Table 1).

Table 1. Basic information about the three case studies

Aspect	**School A**	**School B**	**School C**
Natural Sciences (NS)	9	2	9
Mathematics (M)	3	3	4
Arts (A)	8	2	5
Social Sciences (SS)	19	17	13
Duration	2 weeks	2 weeks	2 weeks
Teachers´ interview	2	1	2
Participating students	48	49	50
Grades	5 th & 6 th		

Ethical considerations

The ethical approval was received by the University's Ethics Committee to carry out the study that respected the issues of confidentiality, the protection of human subjects, especially the minors, and the principle of distributive justice. Firstly, the researchers communicated with the three typical schools by informing about the purpose, duration, instruments, objectives and conditions of the study. Once we ensured the confidentiality of the research without videotaping or audiotaping students, the approval of the study was obtained through signed consent forms by the school principals. Then, the first researcher communicated with the classroom teachers to inform them about the study and her presence at the classroom. The school principals and classroom teachers took on to inform the parents/guardians by asking their consent. Once their consent was obtained and before embarking upon, classroom teachers informed the students about the study. On the first day of the study, the first researcher informed the students about the topic and the conditions of the research by explaining the procedure and by reassuring that all the information would be confidential and anonymous. The first researcher asked students´ consent since the parents´/guardians´ one is not enough according to UNICEF (2002). It was clarified that the participant school would not be identifiable and the names of the interviewed teachers would be pseudonymous. Information about students was obtained regarding only their gender, age, and ethnicity. Before interviewing the classroom teachers, the first researcher obtained their signed consent form. All the information collected during the study remained confidential and was only made available to the researchers. Case study schools and individual interviewees have been anonymized to maintain the anonymity of participants and schools (Resnik 2011 ; Hammersley and Traianou 2012).

Data collection

The data were collected in December 2019 (school A), February 2020 (school C), March (school B) and October 2020 (school B). The data collection was interrupted in

March due to Covid-19 pandemic and was completed in October. Two qualitative methods of data collection were used, interviews and field notes. Information sheets about the research were distributed to directors and teachers who in turn informed the students in advance of fieldwork. Additionally, consent forms were signed by both teachers and directors after the completion of the data collection sessions.

During the first phase, the non-participant observation was performed in total for six weeks. A close-ended observation protocol was designed to capture the teaching practice for two weeks in each case/school. The weekly observations of the classes were documented in field notes at all the academic disciplines apart from physical education and extracurricular activities. We collected 94 lessons from the three cases, particularly 39 lessons from school A, 24 from school B and 31 from school C. The number of lessons is not homogenous due to some festivities that school B prepared. Non-participant observation was chosen to fully understand the on-site teaching practice, to relate and complement the other research instrument. Direct observation can fill gaps that may be resulted from the interviewees´ reluctance to refer everything they experience which they may perceive it as insignificant or irrelevant or even due to ignorance (Birmingham and Wilkinson 2003).

During the second phase, in-depth individual semi-structured interviews were conducted with five teachers to explore which CT skills they use and give some representative examples of their practice. This instrument allows flexibility and encourages reflection and further discussion. Semi-structured interview was selected to supplement the observation protocol by providing a more complete picture of the school's pedagogical orientation from the teachers´ point of view (Birmingham and Wilkinson 2003). The audio-recorded interviews lasted from 20 to 30 minutes and were conducted at a time convenient for the interviewees. Interview data were transcribed verbatim into Word documents. The interview questions were: (1) Which computational thinking skills are appropriate for this age group? (2) Which of the computational thinking skills do you use at your teaching practice? (3) Can you describe examples and tasks that incorporate these skills into your daily classroom practice?

Data analyses

Case study methodology was followed since "*the case study offers a framework for investigating complex social units containing multiple variables. Grounded in a real life context, the case study as a holistic , life-like account offers insights and illuminates meanings that expand the experiences of its readers*" (Merriam 1985, 210). Qualitative case study research is a flexible method formed by the study design, epitomes and the selection of methods (Merriam and Tisdell 2015). Stake (1995) explained that within cross-case analysis are single cases constituting a collection of cases that share commonalitites and are categorically related. Merriam (1985) stated that as the number of cases increases, the findings become more compelling. We used thematic content analysis (Braun and Clarke 2006) to identify unplugged computational thinking tasks by detecting CT skills and concepts that were used within the cases and to examine commonalities across the cases. We followed the steps that Braun and Clarke (2006) have formulated for thematic analysis: familiarization with the data, generation of initial codes by annotating transcripts, themes search, themes review, themes definition and naming and analytical report production. They also distinguish between a deductive top-down analysis driven by theoretical frameworks and an inductive bottom-up analysis driven by data, not grounding upon theoretical stances. We used a deductive, theory-driven approach to analyse the field notes coming from the observations to identify teachers´ tasks compatible with the pre-defined codes (Table 2, first and second columns). We used an inductive, data-driven approach to analyze the transcripts coming from the semi-structured intreviews with teachers for searching additional CT tasks that may were not identified previously and to detect codes, themes and categories emerging from the data on a case by case basis. Similarities and differences, convergences and divergences, emerged across the cases.

In line with the multiple-case study research design, data sets were analysed in two levels. The first was the individual case level, within-case analysis, whereby the data from the two embedded sources –field notes and interview transcripts– were analyzed by following the thematic content analysis, merged and triangulated to provide an in-depth understanding. The second level concerns the cross-case analysis allowing the identification of similarities and differences among the three cases, whereby we merged the data to end up with convergent findings. Both analyses were facilitated by ATLAS.ti.

Firstly, a within-case analysis was conducted to examine how the teachers develop computational thinking skills and concepts in their classrooms before proceeding to cross-case analysis. Data from each case study were analyzed separately to ensure an in-depth understanding before cross-case analysis took place (Merriam 1998). The field notes were analyzed deductively according to 25 predefined codes (see Table 2, second column) coming from three frameworks (Bell, Witten, and Fellows 2015 ; Kakavas and Ugolini 2019 ; Kordaki and Kakavas 2017) by weaving CT skills and concepts. The transcripts of the interviews were analyzed inductively. The codes were categorized to constitute themes and categories. The analysis led to the development of 9 codes, 6 themes and 2 categories (see Table 2).

Secondly, we made use of a cross-case analysis (Merriam 1998) to investigate the similarities and differences among the CT tasks used in each case study and to identify common enablers and barriers across the cases. We combined both inductive and deductive codes to detect patterns among the cases. The observation field notes and interview transcripts were analysed and a structured coding scheme was developed (Table 2). Observation and interview data from each case/school was coded firstly separately and then, a cross-case analysis was focused on similarities and differences identification across the cases.

Table 2. Coding scheme

Predefined codes deductively coming from field notes/observations (25 codes)		**Emerging codes inductively coming from transcripts/semi-structured interviews (9 codes)**
CT skills (7)	**CT concepts (18)**	**(A) Enablers:** (a) age < age-responsive skill (b) grade < grade-appropriate method (c) school approach < school-related method < school-related tool (d) subject < subject-related method < subject-related tool < subject-related skill **(B) Barriers:** (a) age < age-unresponsive skill (b) teachers´ misunderstandings < teacher-related issue
abstraction logical thinking algorithmic thinking decomposition generalization patterns recognition evaluation	problem composition analysis parallelization sorting reduction sequence selection repetition iteration transformation problem solving debugging simulation visualization modelling charting notation (non)computational artifact	

A, B: categories; a, b, c, d: themes

Lincoln and Guba (1986) propose trustworthiness criteria of credibility, transferability, dependability, and confirmability for demonstrating rigor at qualitative research. In the current study, credibility is ensured by persistent and systematic direct and non-participant observation for six weeks in almost all the academic subjects enabling in this way the detection of patterns across the three cases. The multiplication in perspectives ensures data consistency and thus, patterns identification. Transferability is ensured by the precise illustration of teaching practice which is supported by participantś verbatim accounts and is complemented with precise field notes. Additionally, the two different data sources and the multiple cases not only complement each other but also, verify their consistency, closely related to dependability and confirmability. Merriam (1998) further stated that as the number of cases increase, the more compelling the findings. The data were gathered and kept in both written and oral form, and their transcription were checked double meticulously.

Results

Within-case analysis

In this section, we present the results coming from field notes and interviews ´transcriptions. Main findings that were resulted from the analyses are: (1) almost all the CT skills were approached in all the academic disciplines across the cases; there are some CT concepts that are particularly used in specific academic subjects. For example, CT concepts such as problem compostion, problem solving, debugging, etc were encountered in mathematics across the cases whereas in academic subjects such as natural and social sciences we observed that computational artifacts were commonly used. These results are evident in Table 3 where we have categorized per school and per branch of academic disciplines the tasks we have documented and transcribed. (2) There are no important divergences among the three case studies. Almost all the CT skills and CT concepts were approached. (3) The divergences are more evident throughout the interviews´ transcriptions. Particularly, teachers per school focused on specific CT skills teaching. For example, teachers from school A stated explicitly that they develop abstraction and decomposition using examples from mathematics whereas generalization and patterns recognition skills were referred implicitly by explaining their existence in social sciences. Teacher from school B cited examples for every CT skill apart from algorithmic thinking. She clearly gave examples and explained one real-life situation involved all the CT skills (apart from algorithmic thinking). Teachers from school C focused on logical and algorithmic thinking by giving some examples from their practice. From the field notes analysis is resulted that all the CT skills are developed to some extent across the academic disciplines depending on the age and subject but from the interview analysis is resulted that teachers are unaware or even not fully aware of the CT skills development. This finding arises some other transformations that could be done and the need of professional development. We elaborate more on this last finding later on this study (see Discussion).

Table 3. Summary of CT tasks per case study and academic subjects

Branch of academic disciplines	Computational thinking tasks per unit of analysis and case study/school	CT skills	CT concepts per category
School A			
Natural Sciences	**Fieldnotes** Designing and manufactiring a rain gauge by following instructions; Recording the observations and measurements in a diary/calendar; Analyzing and comparing data, summarizing findings, charting data; Mapping out various routes using symbols folllowing specific steps and evaluation criteria based on reference maps; Distinguishing and analyzing data, dividing zones and analyzing features of civilizations; Juxtaposing countries according to specific features; Recognizing cultural elements; Summarizing the most important information in conceptual maps; Drawing and painting cultural elements; Revising information about anthropogeography; Analyzing information about a video and note taking; Creating, crafting and presenting a collage including maps, photos, text, etc, and note taking; Manufactiring a tower; **Interviews** Using the globe and observing the Ecuador, the meridian parallels and the little numbers related with mathematics; Creating things like the pyramid of Lubre	abstraction logical thinking algorithmic thinking decomposition evaluation generalization patterns recognition	**FORMULATING/problem recognition** problem composition **EXPLORING/solution exploration & transferability** analysis – parallelization – sorting – reduction – sequence – selection – repetition – iteration – debugging – transformation **REPRESENTING/solution representation** simulation – visualization – modelling – charting **COMMUNICATING/solution expression** (non)computational artifact
School B			
	Fieldnotes Analyzing information about a video and note taking; Summarizing its information in conceptual maps; Creating, crafting and presenting collages	abstraction logical thinking algorithmic thinking decomposition evaluation	**EXPLORING/solution exploration & transferability** analysis – sorting – reduction – transformation **REPRESENTING/solution representation**

			visualization – modelling – charting **COMMUNICATING/solution expression** (non)computational artifact
	School C		
	Fieldnotes Understanding and analyzing maps depicting services and searching/decoding the meaning of symbols in groups by following instructions; Note taking while watching a video about the history of the universe; Searching information, analyzing data in groups and exploring thoughts; Investigating the human body/anatomy/genitals by consulting various sources; Decomposing the topic by analyzing, drawing and charting information in conceptual maps; Exploring the electricity, observing, experimenting, hypothesing and charting data; **Interviews** Measuring decibels with the sound meter	abstraction logical thinking algorithmic thinking decomposition evaluation generalization patterns recognition	**FORMULATING/problem recognition** problem composition **EXPLORING/solution exploration & transferability** analysis – parallelization – sorting – reduction – sequence – selection – repetition – transformation – problem solving – debugging **REPRESENTING/solution representation** simulation – visualization – modelling – charting – notation **COMMUNICATING/solution expression** (non)computational artifact
	School A, B, C		
Maths	**Fieldnotes** Solving equations and fractions and greatest common divisor (GCD)/lowest common multiple (LCM) following specific steps; Analyzing the process, testing for errors and drawing similarities upon real-life examples; Representing/charting the share of the fraction in graphs/pies; Decomposing figures using compass, didactic games, etc; Measuring angles	abstraction decomposition algorithmic thinking logical thinking patterns recognition generalization evaluation	**FORMULATING/problem recognition** problem composition **EXPLORING/solution exploration & transferability** problem solving – analysis – parallelization – sorting – debugging – sequence – selection – repetition – iteration **REPRESENTING/solution representation** visualization – modelling – charting – simulation
	School A		
Arts	**Fieldnotes** Working various materials (soap, wood, stone, etc); Scraping, sculpting, cutting, doing carpentry, wood carving, forming shapes by following techniques/steps and measuring for accurately shape the materials; Following instructions to perform the choreography using materials and keeping the melody´s rhythm; Shaping variously a fluffy fabric; Playing instruments by following instructions for synchronization of voice and melody; Acting; Following instructions to perform the roles expressively with the voice & physically/kinesiologically with the correct posture **Interviews** Simulating conflicts and ways of their resolution; Improvising and dramatizing situations; Making a maquette or a song; Doing mockups; Inventing something	abstraction decomposition algorithmic thinking evaluation logical thinking	**EXPLORING/solution exploration & transferability** analysis – debugging – sequence – selection – repetition – iteration – transformation **REPRESENTING/solution representation** simulation **COMMUNICATING/solution expression** computational artifact
	School B		
	Fieldnotes Recognizing the instruments´ sounds at songs; Decomposing and charting information in conceptual maps; Decomposing and recognizing music genres; Singing with rhythm following instructions and notes; Searching, summarizing and charting information in conceptual maps	abstraction decomposition algorithmic thinking generalization patterns	**EXPLORING/solution exploration & transferability** analysis – parallelization – sorting – repetition – iteration – reduction **REPRESENTING/solution representation**

		recognition evaluation logical thinking	visualization – modelling – charting – notation
School C			
	Fieldnotes Decomposing the process of watch construction by charting it; Designing and manufactiring the watch by following instructions and analyzing its function; Decomposing, analyzing and drawing information upon videos/animation; Decomposing and charting information in conceptual maps; Decomposing and recognizing music genres; Singing with rhythm following instructions and notes; Searching, summarizing and charting information in conceptual maps; Acting; Following instructions to perform the roles expressively with the voice & physically/kinesiologically with the correct posture **Interviews** Solving conflicts and playing roles simulating various types of conflicts	abstraction decomposition algorithmic thinking generalization patterns recognition evaluation logical thinking	**FORMULATING/problem recognition** problem composition **EXPLORING/solution exploration & transferability** problem solving – analysis – parallelization – sorting – sequence – selection – repetition – reduction – transformation **REPRESENTING/solution representation** visualization – modelling – charting – simulation – notation **COMMUNICATING/solution expression** computational artifact
School A			
Social Sciences	**Fieldnotes** Narrating a story and analyzing/decomposing characters, dilemmas, issues, biographical and historical information and technical characteristics; Decomposing the skeleton of a poem´s by charting its essential elements in conceptual maps; Creating anagrams in groups; Selecting and decomposing characters; Recognizing specific elements, writing them down in a list and composing sentences; Improvising a game/mime representing words; Decomposing, charting and analyzing poem´s morphological & technical characteristics; Writing a poem by following instructions **Interviews** Writing novels, comics	logical thinking abstraction decomposition algorithmic thinking patterns recognition generalization evaluation	**FORMULATING/problem recognition** problem composition **EXPLORING/solution exploration & transferability** problem solving – analysis – parallelization – sorting – iteration - reduction **REPRESENTING/solution representation** visualization – modelling – charting – simulation **COMMUNICATING/solution expression** non-computational artifact
School B			
	Fieldnotes Testing for errors; Highlighting vocabulary, marking the punctuation marks and analyzing; Decomposing and analyzing argumentation in conceptual maps; Recognizing argumentation; Decomposing, analyzing and recognizing literary genres; Analyzing meaning of words, synonyms and significance; Analyzing various concepts in groups and charting them; Text analysis by decomposing and selecting elements and summarizing/ charting them in conceptual maps; Writing a story using these elements; Decomposing and analyzing the parts of an informal letter following specific instructions; Summarizing information in conceptual maps; Writing a sample letter **Interviews** Solving a problem with social implications by decomposing it; Transferring this situation to other circumstances; Reasoning & debating; Concluding in solutions and sumarizing conclusions	logical thinking abstraction decomposition algorithmic thinking patterns recognition generalization evaluation	**FORMULATING/problem recognition** problem composition **EXPLORING/solution exploration & transferability** analysis – parallelization – sorting – debugging – sequence – selection – repetition – iteration – reduction – transformation **REPRESENTING/solution representation** visualization – modelling – charting – simulation **COMMUNICATING/solution expression** non-computational artifact
School C			
	Fieldnotes Searching information in various sources in groups; Writing stories; Connecting and transfering the meaning with students´ personal experiences;	logical thinking abstraction decomposition algorithmic	**EXPLORING/solution exploration & transferability** analysis – parallelization **COMMUNICATING/solution**

		thinking patterns recognition generalization	**expression** non-computational artifact

Case study A/School A

School A follows a pedagogical approach based on Steiner´s educational theory and practice proposing a holistic view at children development with equal attention to intellectual, emotional and physical needs of the child (Steiner 1996). Subjects like horticulture, eurythmy, theatre, calligraphy, crafts are specialized academic disciplines that are not encountered at the other two case studies as standalone subjects. More specifically, the teachers verified during the interviews that they develop almost all the CT skills. Particularly, abstraction and decomposition are developed at mathematics and more intellectual academic subjects. The teacher A stated, ´abstraction is used in mathematics, for example, in equations. This skill is developing because there is transversality in their thinking abilities´ and she continued supporting that, 'we decompose (i.e. the problem) it in variables and understand their operation'. Regarding generalization and patterns recognition skills, she described some examples from her teaching practice concerning mostly social issues, 'we put children in polar situations/positions … if a child has a conflict with another and it does not say the truth and say stories but not exactly what happened this indicate that specific patterns exist behind this behaviour rooted in other school environment or family environment, etc .... They are produced some patterns that they do not allow them to do appropriate generalizations and ample vision'. With regard to programming, teacher B stated that students start learning programming at the ages between 14 and 15 aiming at using the computers, not as users but as creators.

Case study B/School B

School B follows a conventional approach including subjects like mathematics, languages, arts, natural sciences, etc. adding a subject called 'emotions' towards a social-emotional development of students. The teacher C stated that decomposition is mostly cultivated at mathematics and abstraction skill is developed across several academic disciplines. She stated that algorithmic thinking is not yet developed, whereas generalization and patterns recognition skills are developed, ´we try to explain personal and social situations in the classroom to solve conflicts not only within the classroom, but also outside through generalization´. The skill of evaluation is developed as well since they try to reach at solutions, ´... reaching at possible solutions by resolving with the best possible solution, in the most appropriate way and transfer this resolution in another situations´. Lastly, she explained that logical thinking is also used in all the academic subjects. She stated a paradigm from her teaching practice concerning a real-life issue which develops all the CT skills, ´... Maybe we work a bit more on abstract thinking. It's also used for social skills. For example, a girl's fanny pack dissappeared and we tried to solve this problem. Everyone gave their opinion without blaming anyone and then, we transfer this case to other out-of-classroom situations, as for example, walking down the street and suddenly your cell phone is stolen. It's someway of breaking down a social problem and through reasoning and debating, they exercise the skills of abstraction and decomposition and helps them to solve the problems more effectively. Through abstraction and decomposition, they arrive at specific conclusions and solutions because of following this path´.

Case study C/School C

School C follows more innovative approaches, like project-based learning, use of technology, social-emotional learning, etc. whereas the academic subjects are similar to school B. This school develops almost all the CT skills and concepts. However, teacher D focused on algorithmic thinking and logical thinking skills during the interview. She stated that students implement the skill of algorithmic thinking in situations when a set of orders is required. She continued by elaborating towards this direction arguing that physical materials help this thought by connecting in this way the unplugged approach with the physical materials. She proceeded with the skill of logical thinking by stating that when students follow a specific order of actions, a logical thinking is required, ′... They play games … which help them to think and sharpen. One group can play manipulative games, another group can use books or create a story. The law is a story that asks you for a series of things. It's logical′.

Constructing the taxomony

We identified the most characteristic and concrete tasks that develop CT skills and involve CT concepts across various non-computing academic disciplines. We drew on three resources/units for the creation of our taxonomy: (1) educational tasks coming from the field notes across the three cases involving computational thinking skills and concepts in all the academic disciplines, (2) existing frameworks (3) interviews with teachers. We elaborate on the four steps that we followed to construct the taxonomy:

Step 1. The first step was the creation of a predefined framework of codes (computational thinking skills and concepts). We reviewed existing unplugged computational thinking studies and frameworks for K-6 education to identify which CT skills and concepts are repeatedly used and cited as core elements in unplugged CT education for primary schoolchildren. We concluded in three works: (1) six computational thinking skills that the ′Computer Science Unplugged′ project based at the University of Canterbury proposed for the unplugged approach (algorithmic thinking, abstraction, decomposition, generalization and patterns, evaluation, logical thinking) (Bell, Witten, and Fellows 2015); (2) we made use of the learning context of CT incorporation at K-6 education that Kakavas and Ugolini (2019) summarized in their systematic literature review; (3) we utlized the CT concepts that used by Kordaki and Kakavas (2017). During the review of these works, our goal was to map out what the existing literature identified as core and common in unplugged settings to develop computational thinking at K-6 education. This review produced a set of 25 codes (Table 2, first and second columns) which were used as core elements for our taxonomy.

Step 2. The second step in constructing the taxonomy was to collect, document and categorize per school a variety of tasks and discern unconsciously and unintentionally computational thinking skills and concepts that were used by the teachers in their daily practice across various academic disciplines. The primary corpus of the CT tasks was documented as field notes and the secondary corpus stemmed from the transcribed semi-structured interviews with the teachers to supplement the primary one. In total, 94 lesson plans composed our primary corpus which was coded for elements of computational thinking skills (7) and concepts (18) deductively and theory-driven and five semi-structured interviews were analyzed inductively and data-driven to detect any further practices, to ensure the existing ones and understand whether, which and how the each case study/school approached the CT skills development (9 codes).

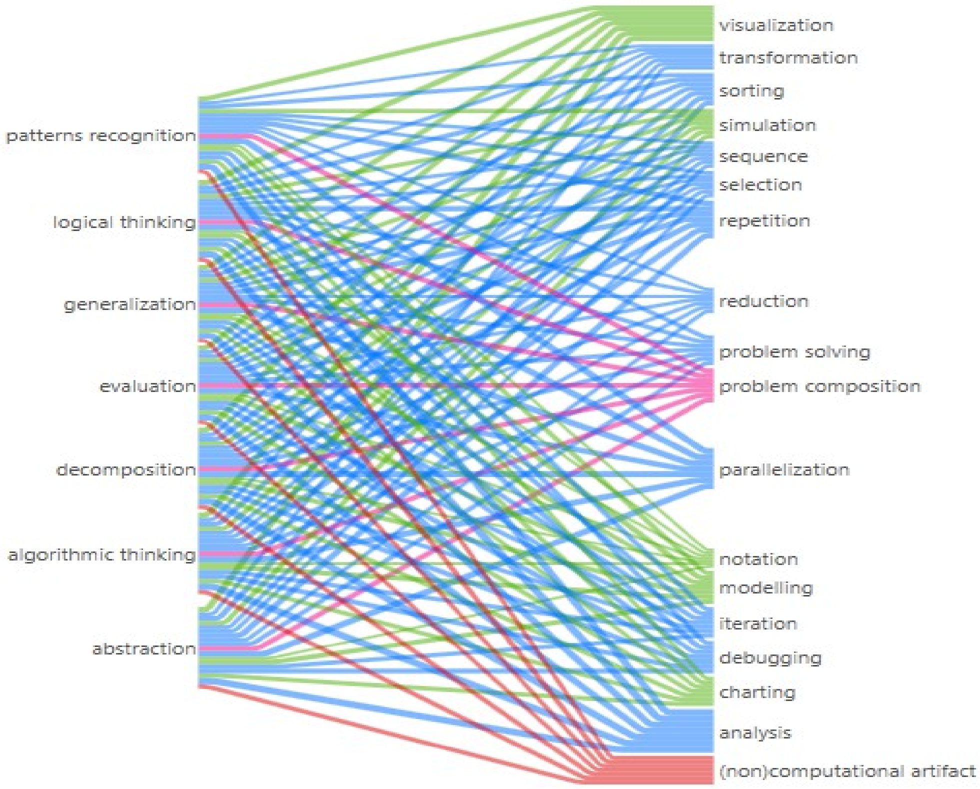
Step 3. Upon completion of the initial coding, the codes revised iteratively and the categories were refined afterwards. We end up in the first full version of the taxonomy consisting of 79 unplugged computational thinking tasks (63 tasks came from the primary and 16 from the secondary corpus) (see Table 3). The review of the 94 lessons plans was performed with the intention to detect tasks including CT skills and concepts based on the step 1. Due to the different pedagogical approaches that each school/case follows, we summarized the academic subjects by their nature, i.e. arts, natural sciences, mathematics and social sciences to ease the convergences´ and divergences´ detection across the cases.

Step 4. The resulting set of tasks was revised again and was categorized into four distinct categories. We collapsed similar tasks into unified categories per school and per academic discipline (for example in Mathematics). Particularly, the within-case analyses led to the identification of four computational thinking categories that were salient in the data units. The resulting taxonomy was a revised list of 79 tasks grouped into four-level categories (see Table 4). We have visualized through the Sankey diagram the flow between CT skills and CT concepts during the computer-aided analysis with ATLAS.ti software (see Figure 1).

Table 4. Four-category taxonomy of CT tasks

<table>
<tr><th>CT skills</th><th>CT concepts</th><th>CT categories</th><th>CT taxonomy</th></tr>
<tr><td rowspan="4">abstraction
logical thinking
algorithmic thinking
decomposition
generalization
patterns recognition
evaluation</td><td>problem composition</td><td>problem recognition</td><td>FORMULATING</td></tr>
<tr><td>analysis
parallelization
sorting
reduction
sequence
selection
repetition
iteration
transformation
problem solving
debugging</td><td>solution exploration & transferability</td><td>EXPLORING</td></tr>
<tr><td>simulation
visualization
modelling
charting
notation</td><td>solution representation</td><td>REPRESENTING</td></tr>
<tr><td>(non)computational artifact</td><td>solution expression</td><td>COMMUNICATING</td></tr>
</table>

Figure 1



Cross-case analysis

From the observation field notes we conclude that all the computational thinking skills were developed and approached to some extent even though teachers were not fully aware of their teaching. This finding about misconception, misunderstanding and unawareness is obvious through the interviews and is a common barrier found across the cases. Teacher from school B seems more aware of these skills since she cited examples from her teaching practice and also discerned them. Teachers from school A focused on abstraction and decomposition skills as the mostly used skills although one teacher gave example that implicitly touched generalization and patterns recognition skills. For these two skills, teachers from schools A and B stated real-life situations covering in this way not only the intellectual skills but also the social ones. Abstraction and decomposition seem as skills attached to mathematics and intellectual skills for teachers from school A, whereas teacher from school B extends its implementation to social ones. Logical thinking and algorithmic thinking skills were developed by school C. Various materials were used and diverse sources where used to develop them. This finding is verified by the both field notes and transcripts. However, teacher seems that is not fully aware of the remaining skills. Algorithmic thinking was the only skill that teacher from school B stated that students are not yet ready. In relation to our theoretical propositions that school A follows a more stuctured format for CT skills development due to the diversity existing in the academic subjects is ensured since we have found that this diversity in subjects allows students to cultivate the CT skills and concepts from different point of views. For example, the skill of algorithmic thinking is developed differently in horticulture, in mathematics, in arts. This distinction coming from the nature of the subjects which is intense because of the various tasks performed each time. The second proposition about the school B that follows a more narrow format for developing CT skills is partially verified. Although all the skills were developed, the ways and the means did not present variety that could result in various perceptions and manners that a child can cultivate these skills and concepts. Namely, each subject is approached in a predictable way, for example abstraction in mathematics. The last proposition about the school C is that approaches the CT skills with more flexibility. This assumption is fully verified from the evidence, since this school used a variety of sources, materials and means facilitating the CT skills and concepts development.

Discussion

In this section, we discuss our findings in relation to two similar empirical studies employing the unplugged methododology in primary education without coding/programming. Sabitzer, Antonitsch, and Pasterk (2014) conclude that most teachers are unaware they already teach informatics and discusses hidden issues of informatics within the Austrian primary school curriculum. This finding is aligned with our conclusion that CT skills and concepts are already introduced even unconsciously by the teachers in the daily teaching practice. Brackmann et al. (2017) describe activities introducing CT concepts at students aged 10 to 12 years old, like decomposition activity (by breaking down tasks into steps), map activitiy (using four-directional arrow keys to move objects from one point to another on a map), song activity (converting a song into an algorithm to detect variables, repetition and conditionals) and so forth. They resulted in the conclusion that the unplugged approach is effective to develop CT skills. They also ensured that CT as a cognitive variable involved in problem-solving and its development can be decoupled from computer programming. This findings are in line with our proposition and approach, that CT can be cultivated in conditions that do not require coding or computers and that simple instructional tasks can affect the CT skills development at students.

The transformations that could be followed by the schools to meet the unplugged approach are summarized in two levels, at teaching practice level and at teacher training level. At teaching practice level, the natural language could be used precisely to cultivate these skills in terms of vocabulary and semiotic language (i.e. notation). Pane and Myers (2001) studied how natural language can facilitate the computational competence by writing algorithms at fifth graders. Towards this direction, Barr and Stephenson (2011) argued that a crucial factor in successful incorporation of CT skills into school curricula is the use of specific vocabulary that both students and teachers will utilize. A common computational thinking language (CTL), not a programming one, includes vocabularies and symbols to annotate and describe various tasks and processes (Cohen and Haberman 2007). The introduction and use of vocabularies can create and reinforce awareness of computational processes (Lu and Fletcher 2009). This last statement is directly connected with the transformations we have set at teacher training level. The formal vocational training can increase the teachers' awareness over CT practices since it would be unreasonable to expect teachers to incorporate computational thinking concepts into their practice without supporting them (Yadav et al. 2013).

Conclusions, limitations and implications for future research

Children should be taught the CT along with the 3Rs (reading, writing and arithmetic) (Wing 2006). CT helps students to develop a thinking mode similar to that of a computer scientist in tackling problems and the impression that is required only by computer engineers is just stereotypical (Grover and Pea 2013). Our work aims at documenting educational tasks that involve unplugged computational thinking skills and concepts in non-STEM disciplines and non-programming environments at K-6 schooling. Within this context, students are introduced unconsciously to CT avoiding in this way the drop-out attitudes if programming/coding would be involved. Through three cases/school settings we uncovered tasks deployed in regular teaching practice. Since similar studies were not encountered in primary education, the added value of this study is the proposition of a framework upon which activities, tasks and practices could be developed by functioning as a starting point.

This study encompasses several limitations. First, the findings from the current study may not generalize to other classrooms. This is the reason why we do not refer to the teaching practice in terms of practices but that of tasks. Consequently, future research should replicate the study across different school settings and grades to ensure which findings are consistent and which are inconsistent. Additionally, it would be purposeful to examine how different pedagogical approaches followed by the shools affect the findings. In the current study we attempted to shed light towards that direction but more diversity at pedagogical approaches is welcome to gain a more in-depth understanding. Second, this study based on interviews and observations. Future research could include focus groups with both students and teachers or even directors. Third, multiple coders could check the reliabiltiy and validity of the analytic process. Lastly, this study focused on a small sample of teachers and the observation took place within a limited period of time. Further study is needed with more participants and with higher diversity across school settings for an extended period of time. Future research agenda could also involve the use of the emerging taxonomy in designing activities and teachers´ feedback could in turn lead to another round of revisions to consolidate a more solid taxonomy of CT tasks. Additionally, interviews with professionals whose work relies heavily on computational thinking is necessary to validate the taxonomy and to provide supplemental data coming from authentic scientific settings. Although the findings are promising, more research is needed to validate them. It is noteworthy to stress that, all the data and tasks are representative of the participant schools, contextualized in the restricted time that this study was carried out. More rigorous and longitudinal studies are needed to conclude with the same findings or/and generalize them. Last but not least, how CT is connected with other powerful ideas and skills such as imagination, creativity, new media skills, and collaboration could be further explored (Tsortanidou, Daradoumis, and Barberá 2019 ; Tsortanidou, Daradoumis, and Barberá 2021).

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