DOI: 10.34641/ctestem.2022.465

Computational Thinking in Flanders' Compulsory Education

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ABSTRACT

To modernise education, the Flemish government defined new learning goals that take account of 21st-century competences, in particular on 'digital competence and media literacy', of which 'computational thinking and acting' is one of the building blocks. Since September 2019, 'computational thinking and acting' has been compulsory in secondary schools in Flanders. The basic concepts decomposition, abstraction, pattern recognition and generalisation, and algorithm have been pushed forward. A closer look at the newly defined learning goals clarified that 'acting' is about basic knowledge in computer science and computational thinking practices. The learning objectives show that 'computational thinking and acting' is best addressed interdisciplinary in a socially relevant context. Based on the abundant scientific literature on the subject, we found these goals to fit into an international perspective. To support teachers, we are adjusting the teaching materials we already developed on physical computing, programming, and AI.

KEYWORDS

Computational thinking, compulsory education, K-12, Flanders, Belgium

1. INTRODUCTION

Computational thinking (CT) is a way of understanding and acting upon that digital world. A basic skill in CT enhances one's ability to understand and interact with technological developments, which can counteract the fear of technology (Bocconi et al., 2016). It is therefore not surprising that there is a growing focus on it in compulsory education all over the world. The same is true in Flanders. Introducing CT into compulsory education does not aim to turn everyone into programmers or computer scientists, but to acquire the skills of CT and to explore what they mean for the various disciplines (Barr & Stephenson, 2011; Hemmendinger, 2010).

The term 'CT' first appeared in an educational context in 1980, in Papert's book 'Mindstorms' and became popular when Wing launched it in 2006 as "a skill set for everyone" (Papert, 1980; Wing 2006). As the term 'CT' is fairly new, CT is not always known to teachers (Sands et al., 2018; Yadav et al., 2017). It is often mistakenly thought that the term covers a whole new range of subject matter, when in fact the concepts of CT go way back, to a time when computers did not yet exist (Denning & Tedre, 2019).

According to Lowe & Brophy (2017), almost every digital system is part of a human-centred system. Wing (2006) argued that CT is about "understanding human behavior". After all, digital applications are made by and for people. So, CT is also about people (Curzon & McOwan, 2017; Denning & Tedre, 2019). Not everyone gives the same meaning to the term 'CT'. Also, the way in which someone applies CT differs according to what they want to use it for (Hemmendinger, 2010; Weintrop et al., 2016). Moreover, the content of the term is constantly changing along with developments in computer science (CS), i.e. with 'what modern computers can do' and the further digitalisation of society (Denning & Tedre, 2019). CT is mainly about the ability to "effectively use a computer to solve the complex problems that people face" (Lu & Fletcher, 2009). Although there is no consensus on a definition of CT, examining the scientific literature to see what the various descriptions of CT have in common led Selby and Woollard (2013) to the following definition: "CT is a focused approach to problem solving, incorporating thought processes that utilise abstraction, decomposition, algorithmic design, evaluation, and generalizations". Here, generalisation refers to pattern recognition. Although CT is required to perform activities, such as automation, and modelling, they are not included in the definition, to distinguish between CT concepts and CT practices. Over the years researchers formulated many definitions of CT. Concepts were added and others disappeared. Concepts of CT like 'decomposition', 'generalisation and pattern recognition', 'abstraction', and 'algorithm' appear to be broadly agreed upon (Bocconi, 2016; Grover & Pea, 2017; Lodi, 2020; Lowe & Brophy, 2017).

Digital skills are seen as a way to acquire and evaluate the 21st-century skills. This is the main reason why countries are introducing CT into education. The 21st-century skills are general-purpose skills that should enable us to be resilient in a rapidly changing society. These skills are considered necessary to be able to function in and contribute to today's society: communication, cooperation, digital skills, social and cultural skills (including citizenship), creativity, critical thinking, problem solving, and productivity. Some include self-regulation in this list. Not all these competences are typical of our time, but due to the increasing presence of technology and digitalisation, 21st-century competences have gained in importance. Because of the rapid developments, digital skills should not only be limited to the use of applications but should also include, in addition to ICT skills, information and data literacy, CT, and media literacy (Bocconi et al., 2016; Denning & Tedre, 2019; Thijs et al., 2014; Voogt & Roblin, 2012; Voogt et al., 2013). The European Union emphasises that digital competences "involve the secure, collaborative and creative use of ICT, including coding" (European Union, 2015). "Skills, such as problem solving, critical thinking, ability to cooperate, creativity, computational thinking, self-regulation are more essential than ever before in our quickly changing society" (European Union, 2018).

Many researchers see CT as a skill that can be addressed in all subjects and provide numerous examples of this (Barr & Stephenson, 2011; Grover & Pea, 2017; Yadav et al. 2017). Hence, many voices are heard calling for CT to be offered cross-curricular, in relevant real-world contexts, especially given the link with 21st -century skills. But there appears to be a gap between the importance attached to the 21st-century competences and how they are dealt with in practice in the schools, f.i. little time is spent on them, the objectives are narrowed down to the use of software only, no real-life contexts are used or the opportunities that the digitalisation offers for learning differently remain unused. Examples of how 21st-century competences, especially digital competences, can be addressed within familiar lesson content can help (Voogt et al. 2013; Goldberg et al., 2013). And although one does not always need a computer to acquire certain skills of CT, the focus should ultimately be the computer (Barr & Stephenson, 2011). After all, digital skills, including CT, get so much attention because they are the means to make us function in today's (digitalised) society and understand the impact of digitalisation on society. The importance the European Union attaches to programming stands out. Many consider programming a crucial skill. Guzdial (2015) considers programming indispensable to be computationally literate: "Achieving computational literacy in society means that people can read and write with computation, which includes an ability to read and write computer programs". Some rightly warn against seeing CT as too separate from the computer (Denning & Tedre, 2019; Lodi, 2020). If CT is taught in non-computer science classes, or for example through unplugged activities, then the link to the computer should be made explicit to achieve the transfer of the activity to an understanding of CS. Bell and Vahrenhold (2018) argue that the popular 'CS Unplugged' is best linked to contemporary technology. 'Unplugged' often makes complex concepts more accessible, but they are not sufficient for learning to think computationally. To fully understand digital systems, programming, e.g., will have to be involved as well.

For several decades CS was almost absent in the curriculum of Flemish schools (wyffels et al., 2014). In 2014 the Royal Flemish Academy of Belgium for Science and the Arts brought out a report to call for action on CS in compulsory education. They link CT inextricably with CS as they describe CT as

the human ability to solve complex problems using computers as a tool … It is the process by which aspects of computer science are recognised in the surrounding world and applying computer science methods and techniques to understand and solve problems in the physical and virtual world (Samaey et al., 2014).

The Academy sees CT as a form of problem solving but with an interpretation that "computational thinking results in a computer program or a robot that really works". The report was one of the reference frameworks for the reform of Flemish secondary education concerning digital skills. The learning objectives of digital skills were expanded to include the concepts of CT and the basics of CS. Finally, Flanders follows the international trend of making CS education compulsory.

In the remainder of this paper we discuss the new learning goals in Flanders (section 2). We briefly mention how schools implement CT (section 3). We describe how CT is introduced (section 4), how CT goals are intertwined with other learning goals (section 5), and how this is related to our own work (section 6).

2. NEW LEARNING GOALS

In Flanders, the government recently formulated new learning goals for secondary education, with the aim of a future-oriented education that considers the challenges of the 21st-century. These learning goals list the minimum learning objectives schools must achieve with their pupils and explicitly mention the expected factual knowledge and the corresponding conceptual, procedural, and metacognitive knowledge. In addition, the proficiency level of the learning objectives is specified according to the revised Bloom taxonomy. The newly defined learning objectives are divided into 16 key competences, such as 'Competences in Dutch', 'Socio-relational competences' 'Civic competences', 'Digital competence and media literacy', 'Learning competences' and 'Competences in mathematics, science and technology'[1]. The starting point of the key competence 'Digital competence and media literacy' is "going into the digital developments and the importance of basic knowledge and good use of ICT to be able to participate in society". This key competence is composed of 3 building blocks: 1. 'Digital media and applications to create, participate and interact' around the use of information and communication technology. F.i., the use of online tools, creating digital content, and digital citizenship. This block is linked to learning objectives on acquiring and processing information from the key competence of learning. It addresses digital developments and the importance of basic knowledge and good use of ICT to participate in society. In the formulation of the learning goals in this block, there is an explicit reference to creation, sharing, and collaboration, a reference to the 21st-century competences. 2. 'Computational thinking and acting', which aims to provide "a basic knowledge and skill of computing", and to promote problem-solving thinking. 3. 'To deal responsibly, critically and ethically with digital and non-digital media and information', which is about media literacy. This block treats the impact of technological development on society and the ethical aspects associated with it. It also aims to reinforce critical thinking. F.i. the learning outcomes formulated for this building block pay attention to image literacy, which is important for dealing critically with various media. Given the interconnectedness of the digital world with all of our lives, there is no doubt that 'Digital competence and media literacy' cannot be separated from the other 15 key competences[2].

In short, since September 2019, the new learning goals were introduced in the first year of secondary school. They will be further implemented in the other years of schooling year by year. They represent a measurable standard as a

[1] https://onderwijsdoelen.be/uitgangspunten/4647

[2] https://onderwijsdoelen.be/uitgangspunten/4814

basis for curricula to be developed. The curricula and the evaluation of the learning progress of the pupils have to be adapted to this standard, but the government does not dictate how schools should achieve this. Most schools, however, receive guidelines from umbrella organisations that provide curricula and advice on pedagogical approaches.

3. TEACHING CT

Since September 2019, 'computational thinking and acting' has been part of the compulsory curriculum for all pupils in secondary education. For pupils in middle school (the first stage of secondary education), the subject has even been given the status of basic literacy. Each individual pupil must achieve this set of objectives. Although the government initially wanted to force CT to be taught in all subjects (sciences and non-sciences), this idea was abandoned[3]. This is a missed opportunity, f.i. to offer CT integrated with other 21st-century competences.

How 'CT and acting' is or will be dealt with in Flemish schools is still a big question mark. Schools can freely decide how they plan to achieve the learning goals of 'CT and acting', as long as the pupils meet the expected knowledge. Some school directors choose a project-based approach and want to see CT in integrated STEM lessons. In other schools, it is taught as a separate subject, which does not always benefit the interdisciplinary aspect and the link with society. Another approach is to offer it in project weeks. Some directors leave it to the teachers to find their own way. Schools do gratefully make use of initiatives related to CT that they can bring to school, such as the international Bebras competition, EU CodeWeek, the Belgian initiatives WeGoSTEM and AI Op School[4].

4. DEFINITION OF CT AND EXAMPLES

To make clear what is meant by 'computational thinking and acting' the minimal learning goals come with a definition given by the Flemish Government:

By computational thinking and acting we understand a process in which one arrives at output using the following techniques: recognising patterns (pattern recognition) and generalising (generalisation), dividing a problem into sub-problems (decomposition), abstracting the data or the problem itself (abstraction), shaping the solution method (modelling) and following a fixed step-by-step plan (algorithms)[2].

In addition, the Flemish Government clarifies:

These skills, found in computer science, help students to get a better overview of complex problems. Understanding these concepts helps to understand how a computer works and, at a later stage, to use the computer as a tool to solve a problem. Knowing the basic concepts and functions of computers and computer networks and being able to name, install and operate hardware and software are basic requirements for acquiring and processing information digitally, communicating and sharing and creating content.

By "not only teaching pupils to use digital technology, but also to understand how it works", the aim is to prepare them for life in a rapidly changing world and to equip them to think critically about the impact of technology on privacy, employment, and health. So, what was envisaged ties in with the need for digital literacy to acquire 21st-century competences.

To illustrate, some of the learning goals for secondary schools on 'computational thinking and acting':

For middle school: "The pupils distinguish building blocks of digital systems. (understanding)" and "Pupils apply a simple self-designed algorithm to solve a problem digitally and non-digitally. (analysing)". Depending on the field of study, followed by those in the second grade (level 9-10): "The pupils explain how building blocks of digital systems relate to and interact with each other. (understanding)". And "The pupils solve a defined problem digitally by adapting an algorithm provided. (creating)" or "The pupils design algorithms to solve problems digitally. (creating)". Depending on the field of study, in the third grade (level 11-12) followed by: "The pupils assess building blocks of digital systems in terms of their own use and their use in a social context. (evaluating)". And "The pupils solve a complex problem digitally by adapting an algorithm provided. (creating)" or "The pupils program solutions to problems using self-designed algorithms according to a certain system. (creating)".

The knowledge that pupils have to acquire with regard to 'CT and acting' includes: decomposition, pattern recognition, abstraction, algorithm, digital representation of information, testing and debugging, modelling and simulation, principles of programming languages (sequence, loops, selections, variables, data types, operators, functions), input-processing-output, binary representation, hardware, data format, applications such as word processing and games, operating system, communication between digital systems, properties of connections such as bandwidth, safety, reliability, connection between analogue and digital representation, internet, and impact of algorithms.

Hence, in Flemish education, the following concepts of CT have been pushed forward: decomposition, pattern recognition and generalisation, abstraction and algorithm. The new learning goals fit in nicely with the known consensus but go beyond the four basic concepts of CT. They also aim at basic knowledge of CS, since computational practices like modelling, testing and debugging, digital representation of information, and principles of programming are included.

In addition to the new term 'computational thinking', it is not always clear to teachers what is meant by 'decomposition', 'pattern recognition', 'abstraction' and 'algorithm'. For example, the term abstraction also occurs in mathematics. However in mathematics, abstraction does not exactly mean the same thing as in a computer-related context. In the aforementioned definition of the Flemish Government on CT, these new terms only briefly occur: decomposition is dividing a problem into sub-problems,

[3] https://etaamb.openjustice.be/nl/decreet-van-12-februari-2021_n2021031270.html

[4] https://www.aiopschool.be and https://www.dwengo.org

and algorithm is about following a fixed step-by-step plan. Abstraction, pattern recognition, and generalisation are not even explained. In the literature, researchers clarify each of these concepts separately and describe how one can work with them in a classroom (Bell & Vahrenhold, 2018; Dasgupta & Purzer, 2016; Grover & Pea, 2017; Rich et al., 2019; Statter & Armoni, 2016; Yadav et al., 2017).

An example of a 'basic literacy' goal (one that every pupil must achieve) in middle school: "The learner demonstrates in functional contexts basic skills to create and share digital content". The conceptual and procedural knowledge accompanying this goal is: "Digital media and applications to create and share digital content, such as online and offline word processing, calculator app, digital image processing, graphic programming language, browsers, electronic mail, common social media applications, cloud applications". This goal from the first building block of 'Digital competence and media literacy' is connected to 'CT and acting' and connects digital competences to creativity. The CT practice 'programming' is encouraged to be used to foster creativity. In any case, programming offers pupils an opportunity to express themselves in a creative and contemporary way, f.i. by implementing an original solution to a problem or by creatively creating a digital system. The computer also offers new possibilities for creative expression. For example, utilising digital tools or by coding, creative solutions can be realised which formerly were impossible. Mishra and Yadav (2013) argue that "human creativity can be augmented by CT, in particular with the use of automation and algorithmic thinking", and that CT can transform users into creators. Given the importance attached to creativity as a 21st-century competence, it is useful to consider how CT can best find its place in the curriculum in order to promote creativity in pupils (Voogt et al., 2015).

Grover and Pea (2017) note that certain aspects of CT overlap with the 21st-century competences of collaboration and creativity and believe that CT combined with "other modes of critical thinking" can serve to address the challenges of this century. Earlier, Papert (1980) linked CT to competences such as problem solving, collaboration, creativity, and communication. Gretter and Yadav (2016) state that, within the digital skills, media and information literacy are complementary to and partly overlap with CT. Both are about "the importance of being digitally literate as seen from the broader, social impact of the Internet". This brings an opportunity to teachers to offer these skills to pupils in an integrated way across different subjects. CT can reinforce other 21st-century competences, including media literacy, critical thinking, citizenship, and cultural awareness. One of the new goals on media literacy in the 2nd grade (level 9-10) is "The pupils explain the mutual influences between the individual on the one hand and media, digital infrastructure and digital applications on the other hand". This topic can be addressed via the impact of algorithms in daily life and illustrates the overlap between CT and media literacy. On the other hand, placing too much emphasis in lessons about CT on the acquisition of skills such as perseverance, the ability to work together and dealing with complexity and ambiguity, could lead to working on the skills of CT itself being lost (Voogt et al., 2015).

5. CT IN OTHER KEY COMPETENCES

Generally, as we live in a knowledge society, digital competences consist of basic ICT skills, information literacy, CT, and media literacy. In the new Flemish learning goals, CT, basic ICT skills and media literacy are part of the same key competence, reflecting this.

In addition to the learning outcomes in the key competence 'Digital competence and media literacy', there are other learning goals related to digital skills, and in particular to CT. In the format of the new Flemish learning goals, information literacy is not included in the key competence of digital competence; information literacy is included in the key competence of learning. The key competence of learning has four building blocks from which two include learning goals on CT, namely the blocks 'Use appropriate (learning) activities, strategies, and tools to acquire, manage and process information critically, digitally, and non-digitally, considering the intended learning outcome and process' and 'Recognising a (research) problem and finding an answer or solution using appropriate (learning) activities, strategies and tools'. An example of a learning goal from the former block is "The pupils process digital and non-digital information from various sources in a strategic manner into a coherent and usable whole". The latter tackles problem-solving thinking, to which CT is closely related. This block contains learning goals that require a digital skill, such as "The pupils carry out an investigation technique to acquire digital and non-digital data based on a research question". In the learning goals, overall, much attention is also paid to problem solving and communication. The knowledge that must accompany this includes decomposition, formulating problems and generating ideas, designing and programming algorithms, collecting data, making measurements, evaluating and adjusting, applying an iterative process, and applying computational skills.

Kafai and Proctor (2022) frame CT within "computational literacies in the 21st-century". They emphasise that it is not just about technical skills, processing algorithms and information, and being able to program, but also about the social and cultural dimensions that go with it. It is also about citizenship, critical use, personal expression, and connecting with others. Working with computers is also a social activity where one has to take into account its role in society; an example of this is dealing with cultural bias in computer systems. They also caution to carefully choose contexts wherein CT is offered (one does not want to inherit the leaky pipeline from STEM), ensuring that the target group for whom teaching materials are being created is engaged.

Moreover, some of the learning goals within the key competence 'Competences in mathematics, science and technology', especially the ones relating to mathematical skills and integrated STEM, lend themselves well to the acquisition of digital and computational skills and build-up from the first to the sixth year of secondary education. These goals range from honing the use of ICT tools to

maintaining a computer. Table 1 shows some of the contexts these learning goals are situated in.

Table 1. Learning Goals from other Key Competences.

Digital applications	- creating, sharing, collaborating, communicating, participating and interacting with digital applications - ICT in certain school subjects
(Digital) systems	
Information literacy	- acquiring/processing information - data literacy - modelling and simulation
Media literacy	
Algorithms	
Logic	

In the key competence 'Competences in mathematics, science and technology' one of the goals in the 1st grade is: "The pupils investigate the principles of construction and operation of technical systems, their subsystems and components as well as their mutual interrelationships in the context of a technical process", which tackles system thinking. The knowledge accompanying this goal includes the function of sensors and actuators, logic, and input-processing-output. An example on integrated STEM in the 2nd grade: "Using concrete social challenges, the pupils explain the interaction between the individual STEM disciplines and between STEM disciplines and society", of which the knowledge includes system thinking. Two examples of modelling and simulating in some fields of study in 3rd grade are "The pupils use models for exponential growth" and "The pupils work out models and simulations using simulation software". Weintrop et al. (2016) developed a framework useful for teachers to work with CT in mathematics and science.

CT and 21st-century skills are interwoven in the new learning goals. The 3rd grade goal "The pupils critically process digital and non-digital information from various sources into a coherent and usable whole, taking into account possibly contradictory information", links digital competence, to critical thinking and information literacy. A goal for 1st grade shows the link between ICT skills and communicating and cooperating skills: "The pupils demonstrate basic skills for working together communicate and participate in initiatives in a digital way".

6. WORK IN PROGRESS

In Flanders, there is a lack of adequately trained teachers (Bocconi et al., 2022). Since they are crucial to making the integration of CT successful, teachers need help to develop curricula and to bring CT in their familiar lesson content. Examples can familiarise teachers with the new concepts (Grover & Pea, 2017; Voogt et al 2015; Yadav et al., 2017). Based on the knowledge that the literature brings and our own experiences, we want to address the needs of teachers and teacher trainers in Flanders regarding CT. We want to give teachers insights into what CT is, what the basic concepts entail, and teach them to recognise when it is opportune to introduce basic concepts of CT in their lessons. Therefore, we are adjusting the teaching materials we already developed on physical computing, programming, and AI: we add concrete examples of how to integrate 'computational thinking and acting' in interdisciplinary and school subject-related contexts and clarify the terminology used. These open-source, online materials will be available to professionalise Flemish teachers in CT. We want to provide both unplugged and plugged activities, starting from day-to-day examples to solving complex problems. We will try to elucidate the different levels of abstraction, the different ways of decomposition and pattern recognition, and how to address algorithms in an unplugged and plugged way. We are developing a frame for evaluation, considering the Bloom taxonomy. For this, we can rely on the work of Selby (2015) or Bell and Vahrenhold (2018). Within the framework of an ongoing project, we test our material in schools and adjust it based on the feedback from teachers.

7. CONCLUSION

Taking into account the 21st-century competences, the Flemish government imposed new learning goals, CT included. The reason for the new learning goals is to be found in the need for 21st-century competences to be able to function in our digitalised society, which is in line with how CT is viewed internationally. Teachers must not lose sight of this higher goal of the new learning objectives. In compulsory education, in Europe and elsewhere in the world, there are still plenty of questions on how the 21st-century competences can be integrated into the existing curriculum or how they can be developed cross-curricular. The same question is posed considering CT. In this paper we demonstrated how, within the frame of the Flemish government, the CT learning goals are connected to the ones about developing the 21st-century competences. We also discussed some noticed connections between CT and STEM. These links show Flemish teachers the way how to address these new learning goals in an integrated manner, such as in an interdisciplinary and socially relevant context. For the time being, in Flanders the way teachers deal with 'CT and acting' varies from school to school.

8. ACKNOWLEDGEMENTS

The work in this paper has been funded by a grant from the Flemish Government for the implementation of a pilot project to strengthen teacher education.

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